Stimulating waste separation in the Intensive Care Unit

Exploring opportunities for Circular waste streams

Master Thesis

Integrated Product Design
by Júlia Pongrátz

Colofon

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Executive Summary

This design thesis explored the possibilities of recycling medical waste from the Intensive Care Unit of the Erasmus MC Hospital in the transition towards Circular ICUs. Through a combination of qualitative research methods, such as observations, interviews and waste audit, the medical context and the waste composition were explored. By selecting the most promising waste types for recycling, proposals for their collection and following parts of the waste journey were prepared.

In close collaboration with the main stakeholders and several sessions with the nurses, two directions for the final design were defined. Both solutions bring part of the waste stream upwards in the hospital waste hierarchy, ensuring better environmental scenarios in the short term. The first part of the design provides a process for separately collecting the packaging of special infusions bags used for dialysis. This process is aided by several physical and graphical tools which help the waste generating group, the nurses, to integrate the separation into their practices easily and correctly.
The second part of the design promotes the correct usage of existing waste shredders through simplified rules and aided decision making.

By implementing the proposed solutions, nearly 10.000 kg of plastic waste can be derailed from incineration towards mechanical recycling, and 2000 kg of infectious waste can be saved from high intensity hazardous waste incineration. The overall environmental impact of the design is calculated to reach a reduction of 26.000 kg CO_2 yearly and more importantly, poses an example to other hospitals, that recycling of their waste is a possible scenario.

Table of contents

List of abbreviations

SZA	Specific Hospital waste
ICU	Intensive care unit
EMC or Erasmus MC	Erasmus University Medical Center
UMC Utrecht	University Medical Center Utrecht
EPS	Expanded polystyrene foam or Styrofoam
PPE	Personal protective equipment
PMD or PBD	Waste stream of plastic, metal cans and drinking carton
PB	Waste stream of plastic and drinking cartons
LDPE	Low-density polyethylene
HDPE	High-density polyethylene
PP	Polypropylene
PET	Polyethylene terephthalate
PVC	Polyvinyl chloride
PS	Polystyrene
EU	European Union
MFA	Material Flow analysis
LCA	Life cycle assessment
WHO	World Health Organization
EOL	End of life
GHG	Greenhouse gases
EPR	Extended Producer Responsibility
TRL	Technology readiness level
UV	Ultraviolet radiation
MSW	Municipal Solid Waste
LAP3	National waste management plan 3
Eural guide	European waste framework directive

Glossary

Healthcare waste refers to waste generated in hospitals and other healthcare facilities (Rutala & Weber, 2015).

Medical waste is part of the hospital waste, which is generated during patient diagnosis, treatment, and immunization (Rutala & Weber, 2015).

Infectious waste refers to that part of the waste that have potential risk to transmit diseases (Rutala & Weber, 2015).

Specific Hospital waste The official name for the infectious waste category in the Netherlands

Life cycle assessment is a method used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle, from raw material extraction to disposal.

Incineration with energy recovery is a waste management process that involves burning solid waste at high temperatures in a specially designed facility. The heat generated by the combustion of waste is then used to produce electricity or heat.

Decontamination is the process of removing or neutralizing contaminants or hazardous materials from a surface, object, or environment in order to make it safe for use or disposal. The goal of decontamination is to reduce or eliminate the potential health and environmental risks associated with the presence of contaminants.

Sterilization is the process of eliminating all forms of microbial life, including bacteria, viruses, fungi, and spores, from an object or surface. The goal of sterilization is to achieve a level of cleanliness that is free from any viable microorganisms.

A circular economy is an economic system in which resources are used for as long as possible, waste is minimized, and products and materials are reused, recycled, or regenerated at the end of their life. The goal of a circular economy is to create a closed-loop system where materials and resources are kept in use rather than being disposed of as waste (Bakker et al, 201)

Extended Producer Responsibility (EPR) is a policy approach that holds manufacturers responsible for the environmental impact of their products throughout the entire lifecycle, including after the products have been used and disposed of.

Material Flow Analysis (MFA) is a methodology used to quantify the flows of materials within a system. It is a systematic approach to track the movement of materials from their extraction or production to their consumption or disposal. MFA allows for the identification of material inflows, outflows, and the transformation of materials within a system.

Reading guide

This report describes the whole process of my Master graduation project. The process consisted of a research phase, followed by the proposal development and a concept development phase, which resulted in a final design. Compared to a regular design graduation project, the research phase became a more substantial part of the thesis, therefore extensive in length. In order to make it easier for the reader to focus on the outcomes of the project, the report is built up with a specific structure shown in Figure 1.

The document is divided to four main sections. The first section, Summary of Final design concludes the final design solution in a concise manner, highlighting what is achieved with the design and how is it done.
The second section gives and introduction to the project which is necessary for the understanding of design space. The third part describes the second and third phase of the process, the development of the solutions in detail. It starts with the most important conclusions of the research phase and builds the direction for the outcomes from there. The conclusion and further recommendations are also given at the end of this section. The last section describes the extensive research in detail, where more in-depth information can be gained about the starting point of the project, the research activities performed and the outcomes of the research.

The sections are cross referenced, therefore more details can be read about factors influencing the design process in the referenced chapters of the research. The reader can decide the order in which the sections are read, and the level of detail they wish to know. However, for a complete understanding of the process and factors influencing the design, it is recommended to start with the research phase and move on to the design phase.

Enjoy reading my master thesis!

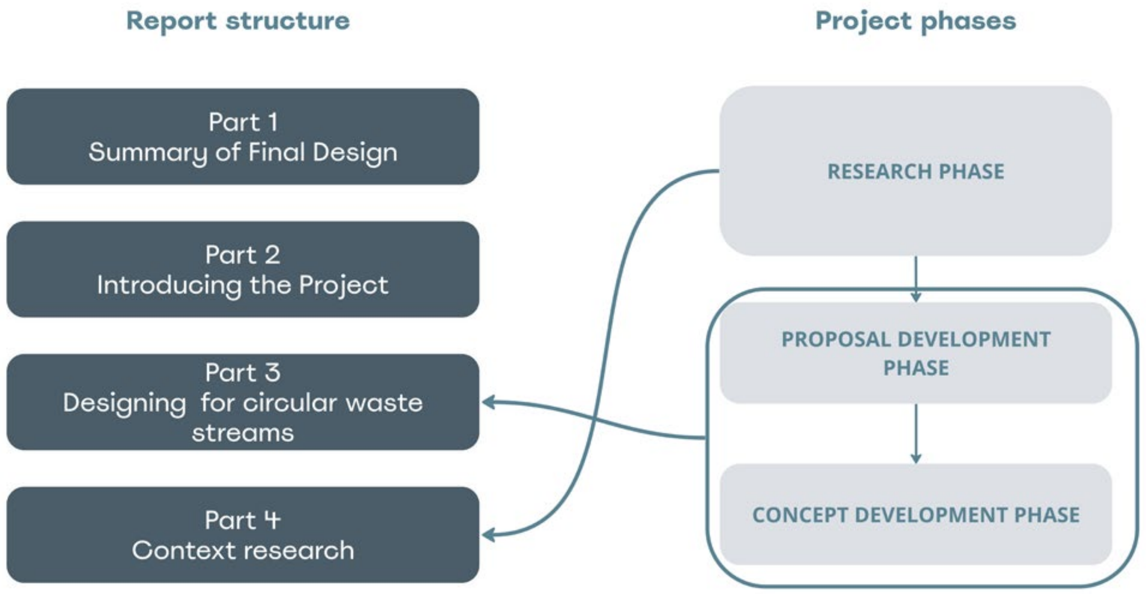


Figure 1. Structure of the report connected to the project phases

Part 1

Summary of final solutions

Summary of final solutions

In this section a brief summary of the final solutions is given. The outcome of the project gives solutions for bringing waste upwards in the hospital waste hierarchy, resulting in decreasing the environmental impact of the waste disposal and creating circular waste streams. From Specific Hospital waste, 2000 kg is brought to residual waste, while from the residual waste, 10.000 kg can be transferred to recycling. Both of this result can be achieved by the proposed design interventions.

First, an improvement in the waste shredder disposal process is proposed to help nurses in quick and informed decision making and disposal procedure, resulting in more infectious waste disposed through the waste shredder. This waste is sterilized and can be treated as residual waste to dispose in a safe and more environmentally positive way.

Secondly, a new procedure is proposed for the separate collection of dialysis bag packaging to produce a clean and high-value recyclable stream. The proposal gives recommendations to the entire journey of the waste, but provides detailed design solutions to the nurses on the ward to ensure proper and effortless collection. Both solution is aided with a set of facilitators and signals that support behaviour change.

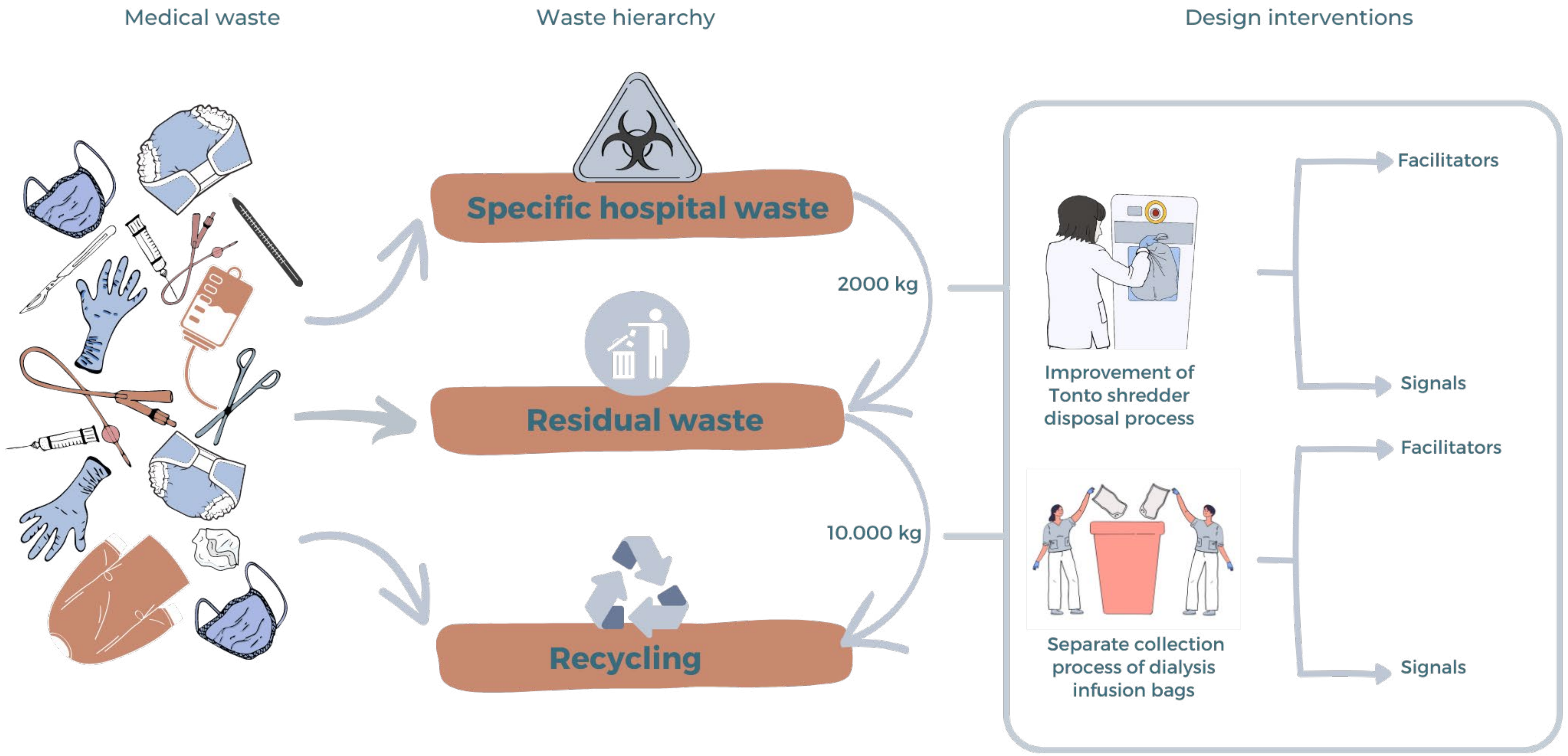


Figure 2. Summary of the final solutions

Part 2

Introducing the project

Chapter 1

Project Setup

This chapter introduces the project, the problem scope and involved stakeholders. Furthermore, the aim and the approach used to guide the project is explained.

1.1. Introduction

Currently, the healthcare sector is one the most polluting areas, contributing to 4.8% of global net greenhouse gas emissions and toxic air pollutants, which nevertheless negatively affects public health. In the Netherlands, this number is even more excessive, the country's high-quality healthcare results in 5.9% of its carbon footprint (Karliner et al., 2020). Modern healthcare practices require a large amount of material, more than two third of the emissions are from the production, transportation, and disposal of medical goods.
Patients with critical illnesses are treated in the Intensive care units (ICU) of hospitals, which use the largest amount of resources due to the required constant assistance. The majority of the used products are fossil-based, single-use equipment with very short life cycle that usually ends in incineration (Metabolic, 2021).
Since the start of the pandemic in 2020, the use of infection-preventing equipment has increased as well, which contributes to an even more significant impact on the environment.

The current medical industry places great emphasis on the convenience and safety achieved by disposable materials. There has been a shift from reusable items, towards disposable alternatives in recent years, mainly due to the associated benefit in their contamination risk and the economic and regulatory reasons for manufacturers. It is easier to label the product disposable and it ensures continuous purchasing (Gamba et al., 2021). It used to be different before disposables, clothing was washed and instruments were sterilized. Hospitals got rid of reusable products, the on-site cleaning and sterilization equipment also closed. Many cases, there is no more room or investment available to reinstall these and. not enough space to store reusables. (Gamba et al., 2021)
However, there is a lack of evidence proving the decreased infections are the result of disposable materials (Gamba et al., 2021). In some cases, for example with surgical gowns, a recent study showed better protection with reusable alternative (McQuerry et al., 2020).
The current waste management method, incineration, takes a lot of energy and the burning of materials also releases a lot of CO_2 and toxic substances. Furthermore, the materials that were once made with a lot of energy, effort and cost get lost. Although incineration is considered a better option than landfill and is becoming a standard in many Western European countries, we should not continue to waste and burn the materials that all require resources to be produced. Establishing a circular economy and reduction of waste are also top priorities for the European Union.

Circular ICU

The awareness of these negative effects is growing in the healthcare community and some institutions take the initiative to address them. A green movement has started among Operating Rooms in the Netherlands to transition from a linear to a circular approach (Metabolic, 2021). As such, the Erasmus Medical Center (MC) in Rotterdam has begun to work towards a future with sustainable medical practices by aiming to organize the highly complex ICU department in a more circular way. As a first step, a Material Flow analysis and impact assessment was conducted by Metabolic in 2019 to identify the highest impact material flows in the system. This provided a base for a series of graduation projects in collaboration with TU Delft to design sustainable solutions particularly for the ICU, of which this project is also a part.

Erasmus MC

TU Delft

Scope and impact

The project is focusing specifically to Erasmus MC and solution suitable for them. However, the outcomes of the research and the solutions can be potentially used more generally for other Intensive Cares as well.
Erasmus MC is the largest academic hospital in the Netherlands and is recognised as a leading innovator in healthcare. They provide high-quality patient care by exceptional healthcare professionals. The hospital is specialized in complicated and rare health problems and acute treatments (Erasmus MC, n.d.)). Being a medical, research and educational institution, they are in a great position to show example and be pioneers in making changes towards a more sustainable healthcare.

1.2 Problem Definition

Although Erasmus MC also stands behind the line “prevention is better than cure” and taking several measures to reduce the amount of waste generated, it is still unavoidable to produce waste. Due to the kind of waste produced, it is very important to handle waste carefully, therefore the separation needs to be accurate and safe. Clearly sustainability should not be at the expense of quality of care and patient safety, but with a good separation system, the burden on the environment can be decreased and unnecessary cost of waste collection can be saved, while the employees and patients remain healthy, and the regulation and legislations are met.

In the ICU the amount of products used and disposed per patient each day fills six garbage bags (Figure 3). Sadly, the majority of this waste is not separated and due to safety mechanisms for hazardous material or hospital specific waste, is incinerated (Figure 4). According to the World Health Organization about 85% of the total waste generated by healthcare related is general, non-hazardous waste similar to household waste. The remaining 15% is considered hazardous material which may be infectious, chemical, or radioactive (World Health Organization: WHO, 2018).
More specifically on the ICU, according to research from McGain et al., a large amount (approx. 44%) of this waste is non-infectious and could be potentially recycled with proper logistics, safety measure and training of staff. This shows prospects for Erasmus MC as well and this project focuses on stimulating waste separation to enable the recycling medical waste from the ICU.

Figure 3. Amount of waste produced at the ICU each day per patient

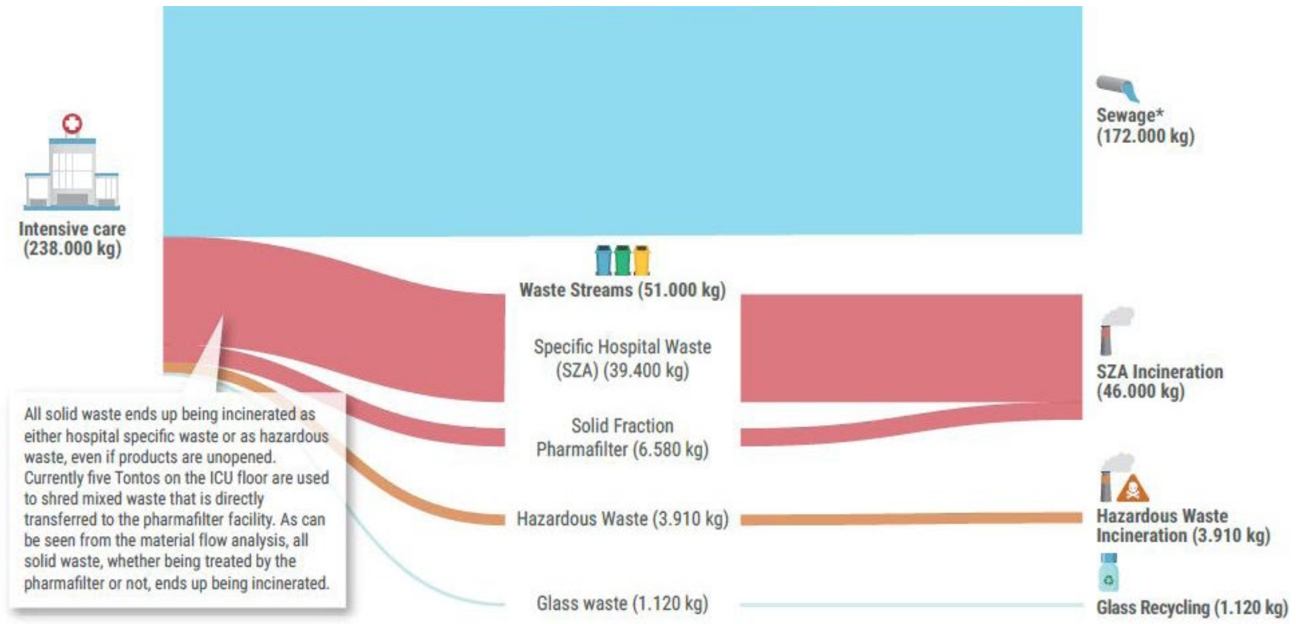


Figure 4. Waste management of the ICU waste (Browne-Wilkinson et al., 2021).

1.3 Project Focus

A linear economy is the current economic model that follows the traditional „take-make-dispose” approach to production and consumption. It is a linear process that involves extracting raw materials from the earth, manufacturing products, using them, and ultimately disposing of them as waste. In a linear economy, resources are seen as abundant, and waste is not adequately managed, leading to environmental degradation and depletion of resources. It has been the dominant economic model for many decades, but it is becoming increasingly unsustainable due to the growing population, resource depletion, and climate change. To address these challenges, there has been a shift towards a more circular economy, which focuses on reducing waste and optimizing resource use through recycling, reuse, and regeneration (The Circular Economy Glossary, n.d.).

Circular economy

In contrast to the linear approach, the circular economy model aims to close the loop of production and consumption by designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.
The Value Hill model (Figure 5) is a tool used in the circular economy to understand the different levels of value creation in a product or service. The model is based on the idea that there is value to be found at every stage of the product life cycle, from the extraction of raw materials to the end of the product’s life (Circularity, n.d.). On the left side of the model, the value of a product is built up from raw materials through manufacturing, assembly, retail until it gets to the use phase. At the top of the hill, the product has reached the end of its life. In a circular economy, this stage represents an opportunity to regenerate

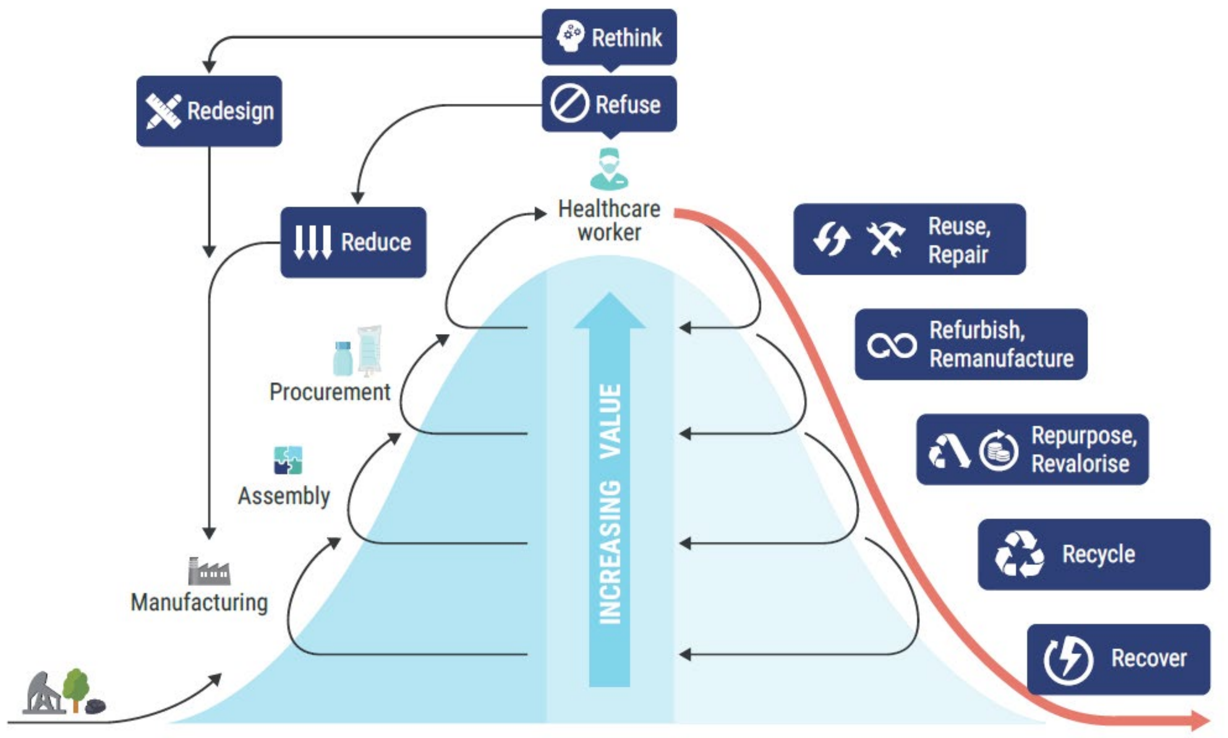


Figure 5. Adapted Value Hill model (Circularity, n.d.)

materials and create new products. Different R-strategies can be used to maximize the value of the product and keep the materials in use.

The project focuses on the recycling of materials, which is among the lower R strategies in the Value Hill. The lower R strategies are considered less effective in the preservation of value, since these give a solution for reintegrating materials only at the end of its life, instead of prolonging the lifetime.
Although other circular strategies, such as reduce, reuse and repair are more effective, in the specific case of healthcare products, many times there can be difficulties in applying these steps of the waste hierarchy and even reusable items ultimately have a finite lifecycle, in which case recycling can effectively provide a solution to put materials back to use.

A large part of the waste is low value disposables, which would not be suitable for reuse, but are used frequently, therefore a large amount is created. The 7 bags of waste per patient per day directly going to incineration requires urgent solutions which can be implemented.

The assignment does not include the redesign of product for better recyclability or material changes, because a large part of the manufacturing of these medical equipments is centralized Asian countries (Joseph et al, 2021) and the Netherlands is only a small customer. Therefore, implementing redesign strategies would require effort, which cannot be achieved in the scope if this project for multiple products. These can be explored in further project focusing on specific products. Nevertheless, recommendations for product procurement can be made to increase the recycling rate by purchasing products with more recyclable material types and easier separation and to replace certain products with reusable ones.
Furthermore, redesign is more important with complex products such as devices with electronic equipment and these should be addressed in separate projects as require different approaches.

It is essential to have a solid understanding of the healthcare system and processes in the ICU to create solutions that fit the context and the users. Multiple perspectives need to be taken into account, such as the healthcare staff and patient needs, habits and behaviour, the logistics inside and outside of Erasmus MC, the recycling possibilities, the environmental impacts, the regulations and protocols, costs and procurement. Therefore, the research will get a large focus in the project.
A good understanding of the context of the stakeholders is needed. The project investigates opportunities and roadblocks determined by the different factors mentioned and based on the research outcomes, proposes directions with a comprehensive approach for steps towards circular waste management. The possibilities are translated to action plan and detailed design solutions proposed for the implementation.

Problem complexity

Regulations and emphasis on patient safety
The medical environment is highly regulated, which affects possible opportunities for change. Starting from the requirements of products and their packaging, through protocols in the hospital itself, by the handling of medical waste, the regulations are focusing on maximizing safety, sometimes for the price of neglecting other areas. (Browne-Wilkinson et al., 2021).

High workload on ICU staff
Working on the ICU is an intensive job, mentally, emotionally, and even physically. The staff, especially the nurses need to deal with patients in serious conditions, trying to save lives and deal with loss as well (Gamba et al, 2021). The patients require extensive daily care on top of emergency situations. The priority of nurses is providing the best care for the patients. When new waste management procedures are introduced, the nurse's workload should not be increased considerably, and their focus should stay on the patient. The solutions need to fit into existing ICU practices.

Healthcare waste perceived as dangerous.
Waste processors typically find accepting or sorting waste from hospitals risky and refuse to do so because they are afraid of infections or other hazardous materials (McGain et al. 2009) The standard procedure is incinerating all hospital waste, which is usually also supported by the hospitals themselves for simplicity and safety reasons.

Product complexity
There are thousands of products used at the ICU supplied from hundreds of Manufacturers. Each product has its own role, and each manufacturer is working with different materials, packaging, sizes and types of products. This makes the range of products disposed wide and the recycling possibilities complicated to be assessed.

Hospital logistics
Running a large hospital such as Erasmus MC requires a delicate and complex logistic system. The flow of incoming and outgoing products is carefully planned and executed by the logistic department. The waste management system of the hospital is part of that. Changes in waste flows needs to fit into the existing system.

1.4 Approach

The approach to the project was based on the principles of the Double Diamond methodology (Design Council, 2019), but modified for the needs of the topic. The basis of the method is a flexible and iterative approach, that encourages creativity, collaboration, and a deep understanding of the problem space The project is divided to threw main phases (Figure 6), research phase, a proposal development phase, and a concept development phase.

In the first phase, research is conducted for a comprehensive understanding of the subject. This stage was focused on divergent thinking, where a wide range of perspectives were explored. Literature review was conducted for the understanding of medical waste context and recycling opportunities. while semi-structured interviews, observations, questionnaire, and a waste audit was performed to find opportunities and related challenges in the ICU context. Based on the collected information, criterias were formulated to use for the next phase.

In the Proposal development phase, first, six directions were chosen based on most relevant criterias. Each direction focused on a specific waste category and developing an intervention for their separate collection. The detailed proposals were evaluated with the relevant stakeholders and three direction was chosen for development. The focus of the design directions were chosen Two of the proposals were merged into one.

At the end of the phase, design goals were formulated for the interventions to guide the ideation and conceptualisation.

The third phase involves ideation and prototyping, where a range of potential solutions are generated, iterated through prototype and the best solutions are selected with the user group. The final process and concept were developed and evaluated in a user evaluation and a short-term pilot was performed to test the solutions in real working environments. Based on these, evaluations are given for the implementation on the ICU.

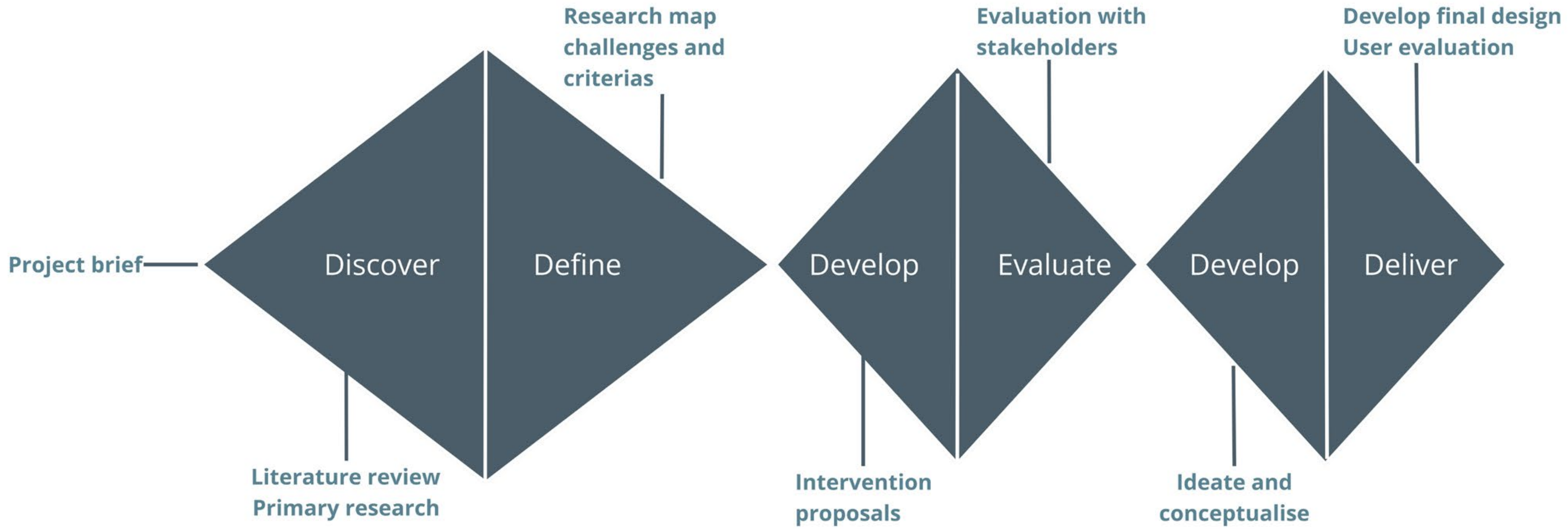


Figure 6. Overview of the approach adapted from the Double Diamond method

1.5 Research aims

Research scope

The scope of the conducted research in this project is to investigate the system surrounding the waste in the ICU. Starting from technicalities such as waste regulations and safety and health protocols the research aims to find what are the possibilities withing the complex regulatory environment. Furthermore, the research is focusing on exploring possible recycling technologies for material types and their implementation possibilities on the hospital. Examples for recycling medical waste is searched in literature for inspiration and conclusions from that. Next to these areas, a main part of the research is focusing on the waste composition of the ICU and its recyclability. Furthermore, the waste disposal system is mapped throughout the hospital with a focus on the point of waste generation and logistic challenges. The nurses' practices need to be understood in order to find for opportunities of waste separation. Lastly, the waste disposal strategies of other Dutch ICUs are researched with the possibility to adapt strategies from them. The research outcomes will be used to define possible strategies for waste separation and criterias for choosing possible directions for waste areas.

Overall questions

The project aims to answer the following main research questions, through the research phase and through research by design. The answers to the questions are given at the relevant chapters. The research questions are further detailed at each part of the research area.

Q1. What are the challenges and opportunities of the complex environment surrounding the medical waste protocols?

- Chapter 7, 8 ,9 , 10 and 11

Q2. What are technological barriers in the recycling of the waste specifically produced at the ICU?

- Chapter 9

Q3. What are the potential waste types that could be separated for recycling and what procedure it would require?

- Chapter 2

Q4. What are the design opportunities that enable the separation of the selected waste streams?

- Chapter 4

Method

The research on the context was done mainly by reviewing literature, and some information was already transferred from the client at the beginning of the project. The primary research was gathered by observations, interviews, and questionnaires.

The research activities were performed simultaneously, not specifically in order, therefore information from one research were not always acquired when a connecting information was gathered in the other are. this can result in answering questions inf multiple research areas or building on the knowledge of one area to formulate questions in the other one. For better understanding, sometimes they are cross referenced.

Part 3

Designing for Circular waste streams

This part of the report describes the design activities performed after the research phase. For reading the research phase firts, see part 4.

Chapter 2

Intervention proposals

This chapter starts with a summary of the research conclusions. The detailed research activities and results are in Part 4 of the report. After the research is concluded, the selection of the proposal directions are given, then the seelcted proposals are detailed. The chapter finished with a selection from the proposals for further development and design solutions.

2.1 Conclusions from the research

In this section, the most important research conclusions are presented from the research phase (Chapter 7-11)

2.1.1 Conclusions on Literature

It was seen from the litarure review (Chapter 7) that items from the general waste stream can be recycled without barriers in regulations and even the infectious waste is recyclable if it is sterilized first. However, it needs to remain separate and recognisable during collection, transportation and disposal.

Later it was concluded that a sterilization device would not bring any more value than the existing system, the Pharmafilter. However, the shredded waste from there is not suitable for recycling anymre. Therefore the recycling on infectious was concluded as not an option for now.

Furthermore, it was found that mechanical recycling is still the best option for short term solution. In the long term, chemical recycling is a promising option.

2.1.2 Conclusions on Research on hospital waste management system

The most relevant opportunities and challenges found in Chapter 8, the research related to the hospital's waste management system are shown below.

CHALLENGES

Waste type need to be large or combined with other streams from hospital

Waste type need to be large enough to fill a truck every couple of months. Since it is quite difficult to achieve only by ICU waste, the waste streams needs to be combined with already existing or future waste streams from the hospital. This means it needs to be the same material type.

Cardiac ICU waste storage room is together with operation wards

Since the two department uses the same waste storage rooms, collaborations is neede to create a new waste stream collection. Space and rules needs to be agreed on.

Waiting times at elevators can increase

With new waste streams the waiting times can increase at elevators, which can slow down to process of the logistics deparment

Pharmafilter system cannot be used for biogas or recycling

Although the Pharmafilter was designed for making biogas and recycle the remainng solid waste, this is not feasible to do. Therefore the positve aspects are limited to infectious waste sterilization

OPPORTUNITIES

Significant costs can be saved

There are large differences in waste disposal costs, which can be greatly reduced for recycling waste streams or by reducing Specific Hospital waste. This gives good convincing power for the hospitalmanagement to invest in the new sterams (if investment is needed)

Separation units are implemented for plastic and food

From 2023, the new waste streams of plastic and food are going to be started and separation units will be implemented in common areas. This will reduce the food related waste and creates possiblities for combining waste with the plastic stream.

Tonto reduces waiting time at elevators and transportation time

Tonto has the potential to reduce waiting times at elevators when more waste is disposed in it

Tonto can be scaled up

The pharmafilter system has the potential to scale up tonto use now that initial flaws has been fixed

2.1.3 Conclusions on Research on ICU practices

The most relevant opportunities and challenges found in the user research (Chapter 10) are shown below.

CHALLENGES

Separation of materials with many item type not realistic

It needs to be easy to decide for the nurses what goes to which category. With the rising number of accepted product types, the complexity increases and mistakes are made

Tonto is not used to its potential

View on Tonto is not clear, too many rules around it, and tricks need to be done to avoid breakdowns. these are not written anywhere. Many products disposed in SZA kegs instead because that is easier

Peak in waste

There is a moment when lot of waste is produced in a short time, the patient admission. However, many types of waste is generated and it is a busy moment

Crowded rooms

Many different types of waste is produced during patient care and the room is already full with the waste and textle bins. When more nurses is in the room, it becomes too busy.

OPPORTUNITIES

Nurses are open to recycling

Nurses attitude towards recycling is positive and even with some extra effort they would be willing to take steps in separation. They are especially annoyed by plastic.

Clean packaging waste

During stocking up storage spaces, there are small amounts of packaging waste generated at many location. It is a sclean packaging waste which were not in contact with patients. The amounts for this waste in each location is still quite small.

With stable patients, time is not of the essence

Patient care moments are usually not very busy unless there is an emergency. the nurses are not in a rush, some time can be spared for separating waste

Dialysis infusion bags

Dialysis requires 4 infusion bags per set per patient, which is a lot of amount during 24 hour. these are also quite large and easy to differentiate from the rest

2.1.3 Conclusions on waste composition - recyclability

Barriers

From chapter 9, the main barriers found in the recyclability of the ICU waste can be grouped into these six categories.

Product is built up from multilayer materials (different plastic types or paper-plastic combination) woven or fused together. The layers are hard to separate to monomaterials.

Liquid medicine is trapped inside the product. Due to the medicine, it is not accepted by waste handling company.

The products consist of different parts made of different materials connected together which need to be separated by hand or by other means, before the recycler can accept.

Danger signs on products cause fear for employees working in recycling chain. Even if material is recyclable, not accepted.

Dry blood stains on products causes fear for employees working in recycling chain. Even if material is recyclable, not accepted. Note: Dry blood stains are not dangerous and not considered infectious.

Product is made from a material, which is not recyclable economically with current technologies.

Already recyclable waste types

Product types identified which are already recyclable. The amount per weight is generally low in most of these types.

Aluminium packaging
Tissues without visible contamination
Wipes without visible contamination
paper which could be discarded in paper - collection bins.
plastic foil packaging
plastic bottles (without danger sign)
diapers (downcycled)
plastic secondary packaging of dialysis

Possibilities

It was seen that waste separation simply by material type (plastic, paper, glass) is not possible in case of the ICU waste. The products are too complex to be simply categorized into these categories.

Such complex separation system cannot be fit into the routine of ICU staff. Therefore, choices need to be made for focusing on part of the waste and overcoming the difficulties in their recyclability. A compromise needs to be found between effort required to overcome the barriers and waste quantity.

2.1.4 Conclusions on waste disposal in Dutch ICUs

From Chapter 11 the most important findings are that from the examples of successfully implemented waste streams in other ICUs, plastic collection and diaper collection can be promising directions for the ICU in Erasmus MC Furthermore, in the future collaborations should be made for plastic recycling with other ICUs as more than two third of them has the aim for this separation. This way they have more convincing power to negotiate with waste collectors.

2.2 Proposals for separate waste collection

Six interventions are proposed based on the challenges and opportunities derived from the research.
The aim of the interventions is to provide a plan for the process of collecting a new waste type separately, which is suitable for recycling. The information used in the proposals is based on all areas of the research phase. Six interventions were chosen to work out, from which, some will be selected for further development. In the next chapter, the selection of the six intervention is explained.

2.2.1 Selection of directions

Method

The waste types for the proposal were selected from the categories made from the waste audit of the general waste stream. For the selection method, a modified version of the Harris profile was used to allow for easier comparison of the types. The Harris profile is a method for comparing ideas, concepts, or alternatives in different stages of the design process. It uses a four point scale to assess to what extent an alternative is fulfilling the given criteria. Based on the criteria, '++', '+' , '-' and '- -' scores were given to each waste stream. The scores were sum up numerically, resulting in positive or negative total scores. The five highest positive scores were chosen. Figure 7 shows a comparison between the waste types. The criterias used for the selection are the most important ones from the research conclusion for recycling that can be implemented in a short term. These include topics about the technical recyclability, the waste sizes, environmental effect, and the collection possibilities. It needs to be mentioned that a limitation of such selection methods is that the results are subjective, as the designer is providing the alternatives, the criterias and gives the scores. However, the methods are effective in quick decision making which is necessary to move on with the project.

Results

The criterias used for the selection were suitable for comparing waste types for recycling purpose but did not allow for including other type of interventions. Based on the research and discussions with the client, a different type of intervention was added as sixth, which is focusing on reducing the infectious waste stream. Therefore, the final list of proposed waste streams is the following:

Ci-Ca dialysate infusion bag
Ci-Ca dialysate secondary packaging
Soft plastic packaging
Plastic bottles
Absorbent hygiene products (diapers and bedpads)
SZA waste reduction through Tonto disposal

Criteria/waste types	Apron	Gown	Paper packaging	Ci-Ca infusion bags	Absorbent hygiene product	Tubes	Syringes	Plastic packaging	Tissues	Gloves	Face masks	Paper cups	Protective glass	Ci-Ca pouch	Wipes	Infusion bags	plastic bottles	Paper-Plastic sterile packaging	Medicine vials	Bandages
Waste is made of monomaterial or can be easily separated into monomaterial	- -	-	++	+	-	- -	- -	++	++	++	- -	- -	-	++	++	+	++	-	-	-
Waste is recyclable with current technology	- -	-	++	++	+	+	-	++	+	- -	- -	-	+	++	+	+	++	-	-	-
Waste does not get in contact with patient fluids	-	-	++	++	- -	- -	- -	++	-	-	+	+	-	++	-	+	+ +	+ +	+ +	-
Waste poses no risk to staff working in recycling process	+	+	++	+	+	- -	- -	++	+	-	+	+ +	-	+ +	+	-	+ +	+ +	- -	+
The amount of the waste stream is large enough(fills a truck) or can be intergated into other waste streams from the hospital	-	+	+	+	++	+	-	+ +	+ +	-	-	-	-	+ +	+ +	-	+ +	+	-	- -
Waste requires minimal extra effort from nurses to collect separately on the ward	+	+	+	-	+	-	-	+	-	-	+	+	+ +	+	+	-	-	- -	++	-
Considerable environmental impact can be acieved through recycling	-	+ +	- -	+	++	+	+	-	-	+	-	-	+	+ +	- -	+	-	-	++	- -
Costs are saved for management	-	+	-	+ +	++	+ +	+ +	-	- -	+	-	-	-	+	-	+	-	-	+	- -
Waste is going to still occur two years from now	- -	- -	- -	+ +	++	++	++	++	++	++	+	- -	+	++	++	++	++	++	++	++
Score	-8	1	5	10	8	0	4	11	3	0	-2	-4	0	16	5	4	9	1	4	-7

Figure 6. The comparison of the waste types through the modified Harris profile

2.2.3 Development of proposals

The six proposals were prepared about the separate collection of waste types and procedural changes that can be implemented in the short term. Five proposals are focusing on recyclable waste categories, while one is focusing on more efficient Tonto disposal.
The chosen waste streams/interventions were detailed, and their exact amount and impact was calculated. Details for each part of the system are proposed. The final proposals are a result of an iterative process, including new insights.

Calculations

The amount calculations are based on the 2019 yearly procurement from Metabolic report (chapter 9), the own waste audit (Chapter 9) and the weighting of individual products, the daily number of products needed (from nurse interviews) and the number of patient days per year. The financial consequences were calculated in consultation with the Waste Disposal cost list (Appendix M) of the hospital as well as the waste management company, Prezero. The calculations can be found in Appendix L. All calculations are limited to the 40 bed General ICU and the 18 bed Cardiologic ICU is excluded.
The environmental impact is expressed in CO2 emissions and was sourced from already calculated LCA results comparing end of life scenarios. It was chosen instead of own Fast-Track LCA calculations after consultation with an LCA expert. It was learned, that the available and widely used program in the master education, IDEMAT is not the most suitable for comparing end-of life scenarios. It does not take into account the different factors influencing positive and negative aspects of incinerating plastics and the quality of the material aimed to be recycled. Instead, there is already extensive scientific research done on the impact of plastic recycling with more accurate data and more detailed calculations. Such research was done by Schwarz et al., 2021, which was used for calculating emission reduction. The CO2 emissions compare the emissions of current and proposed Life cycle scenarios, namely incineration with energy recovery and mechanical recycling of materials.

When such data was not suitable (in case of the Tonto solution) a Fast Track LCA was performed with IDEMAT, which can be found in Appendix L. It compares the disposal of infectious waste by SZA kegs to the disposal through Tonto. The calculated results reliability is limited and for exact amounts, further calculations should be performed.

The proposals were prepared for communicating them to the most important stakeholders, Prezero Zero Waste Project leader, Erasmus MC ICU Sustainability Project leader and the nurses.

2.2.4 Description of proposals

In this chapter, the different aspects of the proposed interventions are detailed, including the waste type, the financial and environmental aspects and the collection and disposal procedure. A more detailed one-page summary of each proposal can be seen in Appendix N.

1.Recycling of plastic packaging

Waste type

The proposal aims to collect for recycling the dry soft plastic packaging which occur at almost any product used at the ICU.
It is mixed plastic waste stream, which mainly consists of LDPE (low density polyethylene), but due to the large number of packaging types, it is likely that other type of plastics are involved.

It is a relatively clean waste stream which is produced constantly at the ICU with all patients, since almost every (non-sterile) medical product is packaged in this.

Size and saved emissions

Although the amount by weight is relatively low due to the lightweight and small items (around 1500 kg per year, 3.8 % of general waste), the waste can be integrated into the PMD plastic stream which is going to be set up from 2023 (see chapter 7). This means, that it would go through plastic sorting together with all other type of plastic collected in the hospital. The CO2 saved by recycling is calculated as 3750 kg per year (Schwarz et al., 2021b)

Collection

The material is not getting in contact with the patients but are produced mainly in the rooms during patient care. In this case, the nurses are the main generators of the waste. The waste type is constantly being generated during the day with a peak at admission of new patients, when the room is set up and all the equipment is opened. Apart from the room, the waste also occurs in the storage areas 2-3 times a day when the care assistance fills the shelves.
Separate collection bins are necessary in each patient room (40 in total in general adult ICU) for instant disposal of the frequently produced waste type.
It requires low-middle effort from the nurses to differentiate and separate from other waste.

The waste stream can tolerate some contamination (as long as not infectious) as the plastic packaging recycling needs to be 85% effective by the Prezero standard (F. Ottens, Personal communication, Jan.12,2023).

Hospital waste stream

The waste can be integrated into the PMD waste stream, no new waste type or agreement is required.

Financial aspects

Financially, the hospital needs to invest in several bins, which are not covered by the reduction in waste disposal costs within a year. The investment would return after two years. However, the hospital can dispose of the waste for free of charge due to the new law from 2023 (see chapter 7).

Risks

Because the bin is in the room, it can be mistaken by family visitors or doctors visiting. Clear signs are needed.
It occurs when a large number of waste items are generated. There is a high risk that other waste will be disposed in the bin by accident.

2.Recycling of plastic bottles

plastic bottle

Waste type
Similarly to the plastic packaging, the plastic bottles are also a clean waste type with no patient contact. There are less types of plastic bottle products, mainly nutrition bottles, IV bottles and ethanol bottles. The plastic types are PET, HDPE, and PP, which are all recyclable and processed through Prezero.

Size and saved emissions
The amount is very similar to the plastic packagings, (1500 kg per year, 3.8 % of general waste). The CO_2 saved by recycling is calculated as 3150 kg per year (Schwarz et al., 2021b).

Collection
The nutrition bottles are produced 3-4 times a day, other IV bottles depending on patients and the ethanol bottles once every couple of day.

The collection can be together with the plastic packaging waste stream, when both is set up, otherwise similarly a bin would be required in every room.

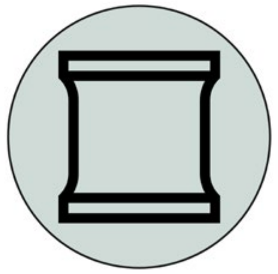
It requires and extra step in the collection because the bottles need to be emptied before the separation (some drops can stay). From ethanol bottles, the hazardous label needs to be removed. This makes the effort for the nurses middle-high. Medicine bottles are not allowed or would need to be rinsed before collecting them.

The waste stream can bear some contamination (as long as not infectious) as the plastic packaging recycling needs to be 85% effective by the Prezero standard. (F. Ottens, Personal communication, Jan.12,2023).

Hospital waste stream
The waste can be integrated into the PMD waste stream. A similar pilot is already set up in the Children's hospital, and in the operation rooms, which can make the implementation of this one quicker.

Financial aspects
An investment of around 500 € is needed for the bin in the room, but it only needs to be made once (in case the plastic packaging is also set up). However, waste disposal costs can decrease even more, because currently the liquids are disposed together with the bottles, causing extra weight

3.Recycling of dialysate solution secondary packaging



Ci-Ca dialyse secondary packaging

Waste type
The proposal aims to collet separately and recycle the outer packaging of the dialysate fluids. The material is Polypropylene, which makes it a higher value material as it does not require further sorting. It can be sent directly to the recycler without the extra steps in between. This, however, makes it more sensitive for contamination. The material needs to stay purely PP for the recycling company with minimal contamination.

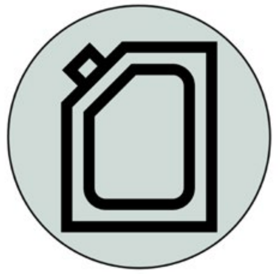
Size and saved emissions
It makes up a large proportion of the general waste streams around 7% with 5000 kg per year. One individual bag is relatively heavy, around 65 grams. The CO_2 saved yearly by this waste stream is 11500 kg compared to incineration. (Schwarz et al., 2021b)

Collection
It is produced several times a day for dialysis patients (40% of all patients), every 4-5 hours, when the new fluid bags are replaced. The nurses open the bags at the dialysis storage space (next to the ward) or on the ward corridor. The waste bins would need to be placed on these locations. The waste type is an easily recognizable and produced on specific moments, therefore easy to differentiate it.

On the whole hospital, the waste can be collected together with the PP blue wraps from the OR (see chapter 8). It does not require a new waste stream and agreement for the hospital. The amount is comparable to the blue wraps which are 8000 kg per ton (F. Ottens, Personal communication, Jan.12,2023).

Financial aspects
The disposal of the waste stream is free, and due to the high purity of the materials, the hospital even receives incentive, around 200 Euro/ton (F. Ottens, Personal communication, Jan.12,2023). This would mean 1800 € savings per year.

4.Recycling of dialysate solution infusion bags



Ci-Ca dialyse
infusion bag

Waste type
The fourth intervention is proposing the separate collection of the dialysate fluid bags. These 5-liter infusion bags are made of the same material as their packaging, polypropylene. Furthermore, the weight of each bag is almost equivalent to the outer packaging.

Size and saved emissions
Thus, the proportion from the general waste stream is also around 7% with 5000 kg per year. Similarly to the secondary packaging, it can be transferred directly to the recycler, increasing its value. The calculated C02 emission reduction is 11 500 kg (Schwarz et al., 2021b).

Collection
The waste is produced in the patient room, when the empty bags are replaced, but it does not come into contact with patients. It can be collected together with the outer packaging; however, some extra step is required. The infusion bags have connectors on the top for the draining of the fluid through the tubes. These connectors are made of different type of plastics, therefore need to be removed. The easiest way to do it is cutting off the top part of the bags. Furthermore, the remaining liquid in the bags needs to be drained in the sink. These extra steps make it high effort to perform the separation.

Hospital waste stream
No new waste stream is required in the hospital, because it can be integrated into the blue wrap stream.

Financial aspects
The hospital would receive 200 € / ton for this waste stream too on top of free disposal. The costs which can be saved are even more than with the outer packaging, because with the traditional disposal, the liquids are trapped within the bags and contribute to the wight related cost of disposal. The savings are estimated for 2000 € per year in total.

5. Recycling of absorbent hygiene products

absorbent
hygiene product

Waste type
The so-called absorbent hygiene products, namely diapers and bedpads are a special waste stream which is actually recyclable through specialized companies. There is a company in the Netherlands, called ARN which actively recycles diapers through Thermal Pressure Hydrolysis (TDH) (Thermische Drukhydrolise (TDH), n.d.). The recycling is already running successfully in UMC Utrecht (read more in chapter 11).

Size and saved emissions
The diapers make up the largest section of the general waste streams from all the proposals with 6000 kg per year, making up 10 % of all the general waste. Since not all parts of the diaper can be recovered to the same value material, it is currently downcycled. However, this already avoids the emission of 964 kg CO2 per ton compared to incineration (Recycling Diapers, n.d.) For the yearly 6 tons of waste, it means 5784 kg CO2 saved.

Collection
The diapers are produced usually 3 times a day, at the beginning of the shifts in the patient room by the nurses. An important consideration from the nurses is that the wipes are usually disposed together with the diapers, therefore they would find it too difficult if they wipes were not accepted together with the diapers. It has been confirmed that the wipes used during changing diapers are also accepted in the waste stream (F. Ottens, Personal communication, Jan.20,2023). In that case, it could be low or middle effort for the nurses to collect this stream separately.
The waste should not stay in the patient room for a long time due to the smells associated with it or a special sealed container needs to be used. A temporary collection solution can help to store the diapers until the nurses finish the care and can disposed in the waste storage room.

Hospital waste stream
From the hospital it would require new agreements because it would be an entirely new type of waste stream. This usually takes some time, but Prezero's contact with the recycling company (through UMC Utrecht) can help to simplify the process.

Financial aspects
Financially the hospital would not be in a better position, because the cost of the diaper waste stream is comparable to the general waste. Some investment would need to be made for the bins. When it is only in the waste storage room, the price is neglectable, but if each room needs to be equipped with a special diaper bin, the costs can reach 1500 euro for the investment.

6.Assistive Tonto disposal

Assistive Tonto disposal

Waste type
The last proposal differs from the rest as it is targeting the reduction of the hazardous waste stream. During the research phase, it was found, that the infectious waste shredder, the Tonto (see chapter 10 for more information) is not used up to its potential. Part of the infectious waste is still disposed in the SZA kegs, which has higher environmental impact. Therefore, the intervention would simplify the Tonto disposal process with the aim to dispose more infectious waste in there.

Size and environmental impact
Currently the waste disposed in the Tonto is estimated around 6500 kg per year, while 3900 kg is still discarded through the Specific Hospital Waste kegs.

Based on the items seen in the kegs and the items disposable in the Tonto, the waste is the kegs could be reduced by half. This would result in lower environmental impact because of the normal incineration instead of the high temperature incineration. Furthermore, the emissions from transportation cost are lower because less liquid is transported. Lastly, with every 10 kg of waste, the production and incineration of 1 kg PP (one certified bin) is saved. These three aspects together reduce the CO2 emissions by 3000 kg per year (see fast track LCA in appendix L.

Collection
The collection process would remain similar but needs to be simplified. Easier access needs to be provided to the Tontos and to the Tonto bags, and the decision making should be faster through clearer rules. It would hopefully also make the nurses job easier because the process would be simpler and less issues would be presented by the machine.

Hospital waste stream
The same hospital waste streams would be used as before. It is confirmed that the Tonto usage can be scaled up from the ICU, the sewage system is able to handle that now. (W. Broer, Personal communication, Sept. 30, 2022)

Financial aspects
The hospital would gain considerable assets when the hazardous waste stream is reduced by half. The hazardous waste disposal is almost 4 times more expensive than general waste (Appendix M). On top of that, each certified bin costs 7€, which is burned with the waste afterwards. The costs saved by waste disposal prices is estimated to 900 €, while the avoided purchase of the bins is 1400€ yearly, together 2300 €.

2.2.5 Overall impact

When all the proposed interventions are implemented, overall, it would mean that one third of the general waste stream is moved to recycling waste streams and around half of the hazardous waste can be turned into general waste. This would result in the overall reduction of 37.680 kg of CO2 every year compared to current emissions.

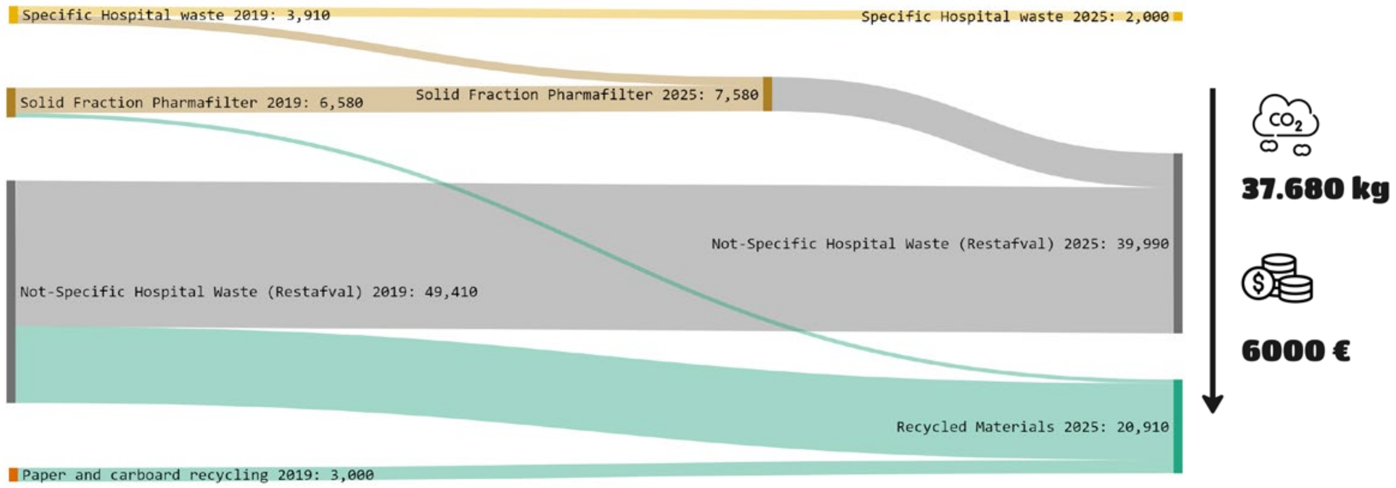


Figure 7: Impact of the proposed interventions

2.2.6 Selection for further development

Aim

Six proposals for different waste types that would allow the ICU to start recycling were presented in this chapter. Since the proposals are not alternatives to the same problem, they could all be further developed. Nevertheless, the time constraints of the project require a selection from them. It was decided with the supervisors and client that three proposals are selected out of the six, and one of them is developed in more detail, while the remaining two is delivered on a brief concept level. The aim of the selection is to choose the three proposals to move forwards with.

Method

The six proposals were evaluated with the help of the most relevant stakeholders. With each stakeholders, the focus was on parts of the process which is relevant to them. The rest of the process was not discussed in detail. With the Prezero Project leader and the ICU Sustainability Project leader, the proposals were discussed during one-on-one meetings, while the nurses evaluated them in a focus group session. Seven nurses from the C-D units participated in the session. The goal of the sessions was to find out which proposals they prefer and why, and to find what barriers they see in their implementation.

There were many competing interests, mainly between Prezero and the nurses. When a material is easily accepted by Prezero, it usually runs into resistance with the nurses and the other way around. These can be balanced at later stages of the development.
Based on the insights of the stakeholders and the most important criterias, such as environmental impact, management acceptance and logistics acceptance, an order of the proposals were made by Weighted Objectives method (Figure 8). The method helps comparing a selected number of alternatives through a set of criteria, which differ in importance (Van Boeijen et al., 2020). The weights assigned to the criterias were reviewed with the supervisors and the client.

The evaluation resulted in the following order of the proposals (Figure 9). Based on this, the Dialysis secondary packaging, the dialysis infusion bags, and the Assistive Tonto disposal is chosen for development.
It is important to mention that the client's interest was taken into account with a larger weight, even if it meant that something is not entirely approved by the nurses or Prezero. For instance, Prezero is concerned about the safety of the content of the dialysis infusion bags. Some drops of the fluid would be remaining in the bag, which needs to be ensured that does not cause any harm, since it is a pharmaceutical product. This needs to be confirmed later on the project.

Criteria	Weight	Dialysis pouch		plastic packaging		diapers and bedliners		Nutrition bottles		Assistive Tonto disposal protocol		Dialysis infusion bag	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Accepted by recycler (Prezero)	20	10	200	9	180	10	200	9	180	10	200	5	100
Logistics acceptance	5	9	45	7	35	8	40	7	35	10	50	9	45
Can be fit into nurses process (Nurses)	20	9	180	3	60	4	80	9	180	7	140	5	100
Favoured by client (Nicole)	20	10	200	9	180	5	100	9	180	10	200	10	200
Environmental impact (kg CO2)	25	9	225	3	75	10	250	3	75	2	50	9	225
Management acceptance (cost, contract)	10	8	80	4	40	2	20	5	50	10	100	8	80
Total	100		**930**		**570**		**690**		**700**		**740**		**750**
Order		1		6		5		4		3		2	

Figure 8: Selection by Weighted objectives method

Figure 9: Order of the proposal based on the evaluation

2.2.7 Conclusions

Six interventions were prepared for separate waste collection types. They were elaborated and evaluated with key stakeholders. The evaluation resulted in an order of preference taking into account the opinions of the stakeholders and other essential criterias. The final order of proposals determined that further solutions will be prepared for the first three intervention, one of them focusing on practical solutions, while the other two suggesting procedural changes and providing information for nurses.
The Focus group results showed that the nurses experience the largest barriers, and the solutions should focus on providing them with aids to overcome them.
Since no barriers were found during the evaluation with the stakeholders, which could not be overcome, the last three proposals are still possible options for the ICU to realize in the short-term. Suggestions are made for how to implement them in the Recommendations chapter.

Chapter 3

Ideation and development

This chapter starts with the formulation of design goals for the selected proposals. Afterwards, it describes the process of creating ideas for the chosen interventions and evaluating them. The chapter described two rounds of ideation and shows the selected ideas at the end. The selected ideas are developed into final concepts through testing and iterating.

3.1 Design goal

The proposals aim to consider the viability, feasibility and the desirability by different stakeholders throughout the whole process from the generation of the waste until the final waste treatment. However, some parts of the process need further detailing before it is ready to be implemented. During the evaluations with the stakeholders, it was seen that the part where design solutions are needed the most is the collection by the nurses on the ward.

This conclusion aligns with the initial brief of the project. Since the nurses need to change their behavior on a certain level compared to the procedure they are used to, designing for behavior change can help to make it happen. Based on the previous research and the evaluation session with the nurses, the following design goals were formulated.

Reduce the amount of infectious waste disposed in SZA kegs by making the aim of the Tonto clearer, the disposal process smoother and the decision making easier.

AND

Provide the nurses with tools to make the separate collection of dialysis fluid bags and their secondary packaging low effort, easy to follow and correctly performed.

3.2 Idea generation and selection

3.2.1 Method

With the selected intervention proposals in mind, ideas were generated for each intervention. For the idea generations, How-To questions were used. How-Tos are open-ended questions, which help formulating the design problem in various ways to stimulate coming up with ideas (Van Boeijen et al., 2020). It is even more effective in a group brainstorm session, but also requires in-depth insights in the problems from the participants. Due to this limitation, it was decided to ideate alone, and think along with stakeholders based on the ideas later.

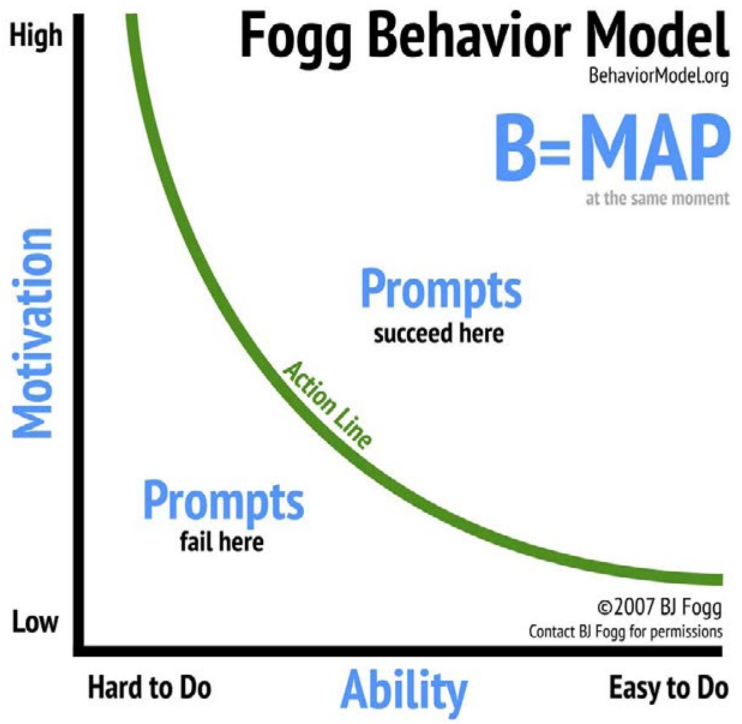


Figure 10: Fogg behavior model (Behavior Model, 2023)

The How-to questions were guided by the design goals for each intervention and the elements of the Fogg Behavior model. Fogg Behavior Model helps design for behavior change. According to the Fogg behavior model, a person needs three elements in order to perform a certain behavior: Motivation, Ability and a Prompt (Figure 10) (Behavior Model, 2023). The figure shows that either the motivation needs to be very high, or the task needs to be very easy to do or both above a certain level to make the behavior occur. The individuals can be prompted to perform an action or behavior, which effectiveness depends on their ability and motivation.

The motivation part is influenced by factors such as anticipation, the feeling of belonging. The model also breaks down the ability to physical effort, e.g cutting off the connectors or walking to the other room, and mental effort, such as thinking, which items should go into which waste stream. The time needed for the task is also influencing the perceived effort.
The prompts can help in both in increasing the motivation and the abilities of a person. When someone has high level of motivation but lower levels of ability, facilitators can help to make the action easier. When the opposite is true and the motivation is low, sparks provide a boost of motivation to trigger the behavior. Signals can initiate action as well when both motivation and ability exist (Behavior Model, 2023).

Based on earlier sessions, there is a large variety in the nurses ability and motivation level. A considerable part of the nurses currently finds the task of separating the proposed waste streams demanding and although some nurses are concerned about the environment, not all of them are motivated enough, especially for the long term.
The mentioned prompt categories can help in all cases and can result in fulfilled conditions for the behavior to happen.

3.2.2 Requirements

Requirements for the collection of the waste streams were formulated based on the information gathered mainly from the stakeholder evaluation sessions. The requirements help to keep the ideas in line with the conditions needed.

Ci-Ca pouch

1. Minimal mistake is allowed, the waste stream needs to stay clean, otherwise it can risk a whole container of waste incinerating instead of recycling.
2. Needs to be adapted to the location of opening the bags, which can differ per unit and per nurse.
3. The unit container needs to be large enough for ~ 180 bags per day for the size of 57x42 cm.
4. The content should be visible to spot mistakes easily.
5. Should not be easily accessible to visitors and doctors from outside.
6. The container in the waste storage room should not be mixed with the foil waste stream.

Ci-Ca infusion bag

1. Minimal mistake is allowed, the waste stream needs to stay clean, otherwise it can risk a whole container of waste incinerating instead of recycling.
2. The content should be visible to spot mistakes easily.
3. Only some drops of liquid are allowed.
4. The connectors are not allowed in the waste stream.
5. Another type of infusion bags is not allowed in the waste stream.
6. The unit container needs to be large enough for ~ 180 bags per day for the size of 44x30 cm.
7. The bags should be thick enough to withstand the sharp edges of the bags.
8. Should not be easily accessible to visitors and doctors from outside.

Tonto

1. Tonto needs to be easily accessible.
2. Tonto bag needs to be ready to use when an infectious waste in produced with loose parts or tubes.
3. The number of products on the Tonto list should be lowered.
4. Nurses need to be clearly informed about what is preferred and what is the purpose of the Tonto.
5. Visual cues need to be added to aid quick decision making.
6. SZA kegs accessibility should be limited or discouraged.

3.2.3 How Tos

The following How-To questions were used in idea generation.

For dialysis bags and pouch (separately):
How to reduce the effort required by the nurses? Physically and mentally?
How to reduce the time required for the task?
How to motivate the nurses to perform the separation?
How to avoid mistake?

For the Tonto:
How to make Tontos more desirable?
How to make the WIVA kegs less desirable?
How to provide space for Tonto bags in the patient room?
How to make the nurses aware of items that should be disposed in the Tonto?

An example of the How-to questions is shown in Figure 11. The results of ideation for each How-to question can be seen in Appendix H.

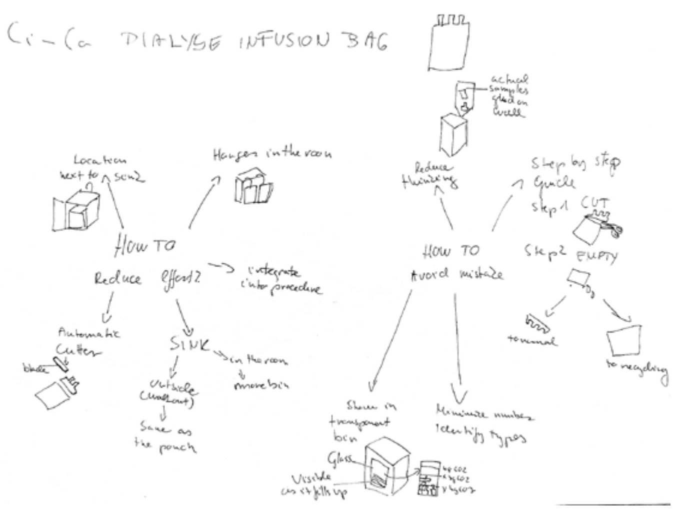


Figure 11. Example of generated ideas by How-to method

3.2.4 Idea Selection

In the first ideation session, a wide range of ideas were created. The purpose of this session was to see what kind of solutions would help the nurses, not going into details. The ideas were presented to the nurses from A-B units in a focus group session with around 11 participants. The session was an informal discussion about the proposed ideas, where the nurses expressed their opinions about them.

From this session, it turned out that main part of the design development should focus on developing solutions for lowering the physical effort for the process of dialysis bag collection, especially on the steps of cutting and storing the bags, as these are the most demanding parts.

The ideas for motivation and correct separation were also discussed with the nurses and the most preferred ones are incorporated during the concept development phase. In the dialysis pouch collection, it was concluded that the best solution is to keep the waste bin in the waste storage room, thus the nurses do not need any design solution for the physical collection, as they find it easy to just dispose directly in the waste storage room. However, information materials are needed to introduce the new procedure. For the Tonto disposal, the main focus points were decided as the signs on the Tonto machine and over the SZA kegs as well as storing the bags in the room on the wall.

3.2.5 Focused ideas

In the next step, further ideation was made focusing on facilitators for the cutting and collecting part of the process. For this, two possible scenarios were considered:

Scenario 1: The nurses cut off the connectors instantly and collect the bags separately.

Scenario 2: The nurses collect the bags as they are, and the cutting and emptying is done later collectively. This can be done daily as an activity during the night shift for example.

For these two scenarios, more detailed ideas were created organized into these four categories:

Holders for the dialysis bag while cutting is performed with scissor.

Cutting solutions

Collectors for the separation of dialysis bags

Collective cutters and collectors

In order to better communicate them visually, a selection of promising ideas was drawn more detailed. The whole list of these idea drawings can be seen in Appendix I.

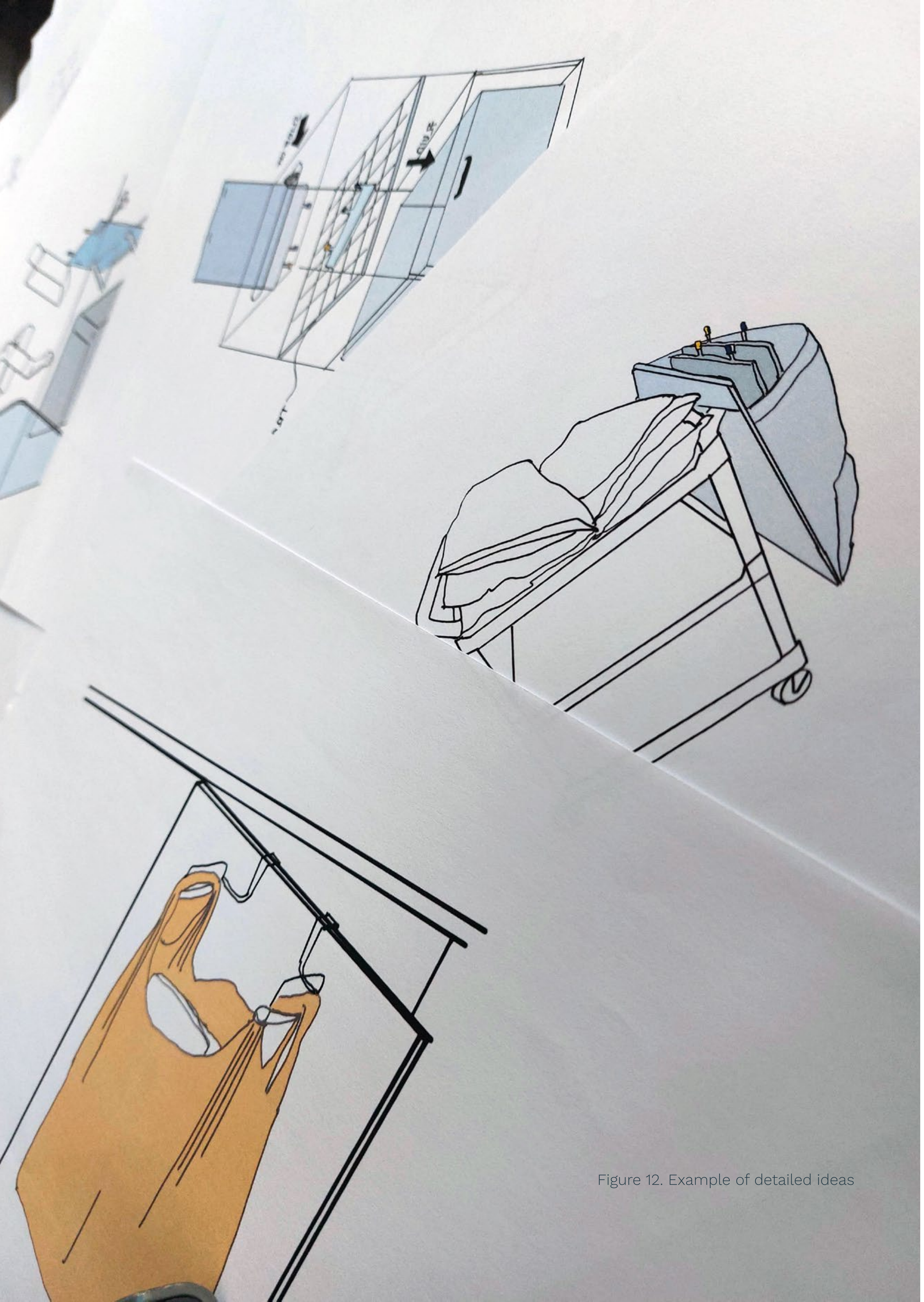


Figure 12. Example of detailed ideas

3.2.6 Idea validation

Method
The ideas were selected through another creative session with some nurses. The session was held in the ICU and three nurses participated in it. The scenarios were explained to the nurses and the ideas were presented and discussed one by one together. The nurses played an active role in coming up with new ideas as well.

Results
By the end of the session, it was concluded that scenario 2, the option of collecting the bags in whole and later on cutting them collectively was not favored. They believed it is much more effort and nobody will do it, while doing it right at the moment is much easier.
It also became clear that the holder solutions don't bring them further value compared to holding the bags in their hand, while cutting, therefore an actual cutter is needed to improve the situation. From the cutter ideas, the sliding hand cutter and the paper cutter inspired blade were found the best options. For the second one, serious safety concerns are

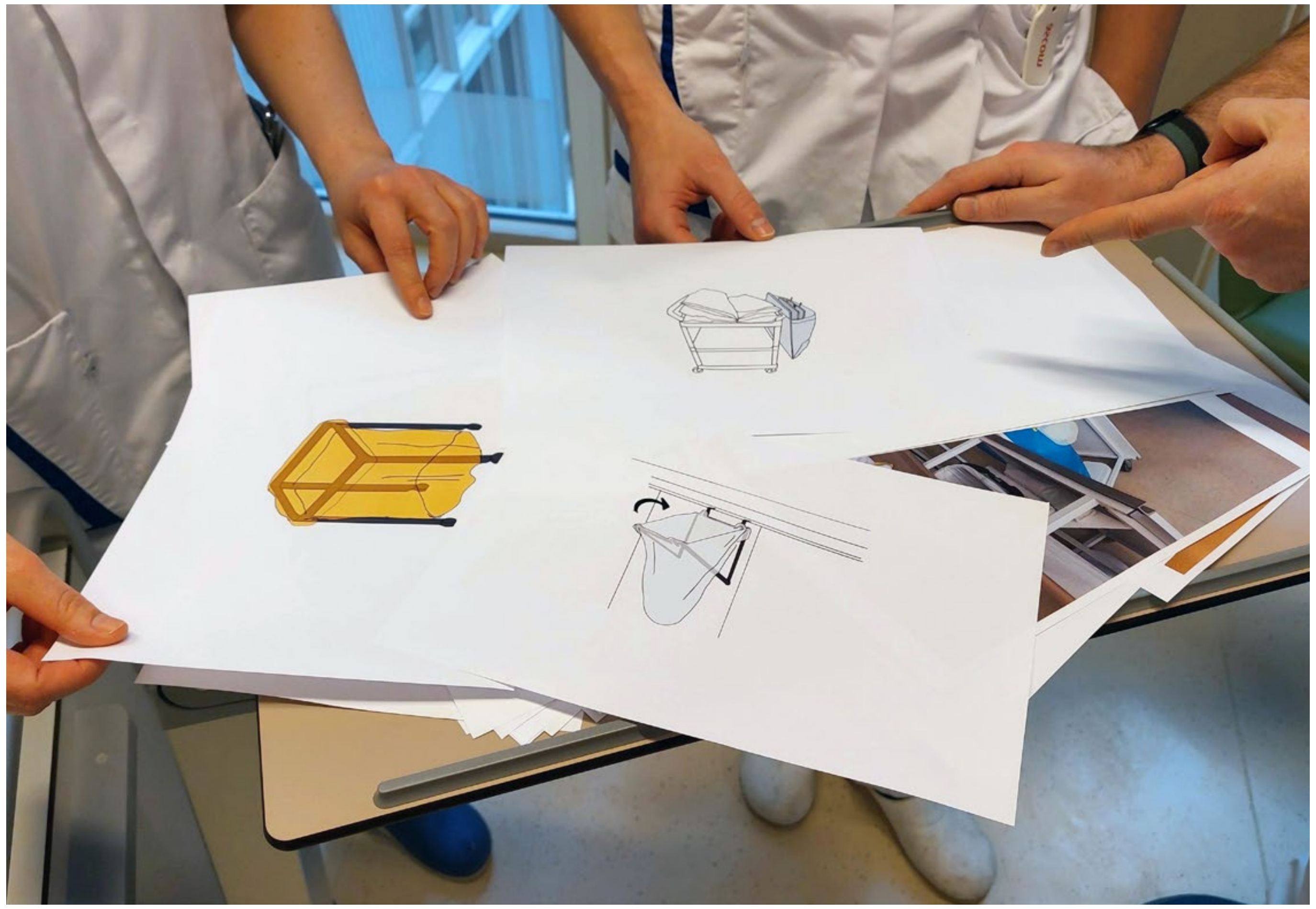


Figure 13: Nurses discussing ideas

raised due to the large size of the open blade, and it would take up too much space on the already limited counter area, therefore it was not selected. From the storage solutions, an unambiguous opinion from all nurses was that the storage on the dialysis cart would make a great addition to the process and could provide a good location for storing the bags. The carts are used for each dialysis patients, when the dialysate bags are brought from the storage area. This way, the nurses can collect the bags at the patient room (outside at the door) and can transfer them directly to the waste storage room, which is next to the storage area for the new bags.

The selected ideas for the facilitators of cutting and storing the dialysis bags are shown in Figure 14 and 15. These are merged into the process with ideas for motivation and informing and were further developed in the next steps of the process.

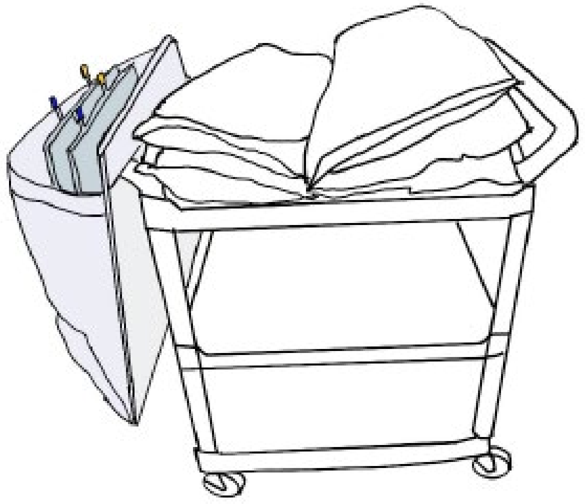


Figure 15: The selected storage idea

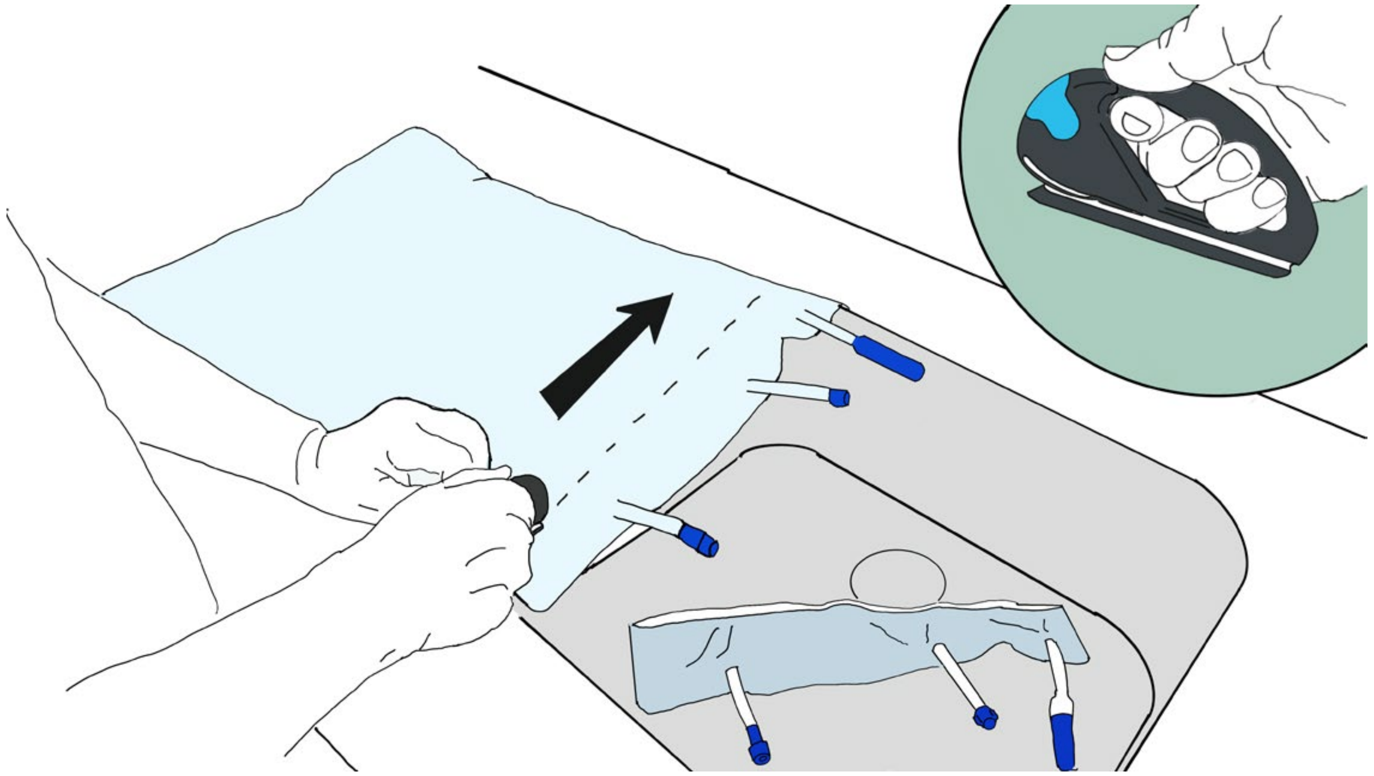


Figure 14: The selected cutter type idea

3.3 Concept Development

This chapter provides information about the development process of the final solutions.

3.3.1 Assistive Tonto disposal

The information materials for the Tonto were developed in consultation with the waste guide, a Pharmafilter employee, the results from the observation days and the close examination of current rules.
The waste in both the Tonto bin (Figure 16) and the SZA kegs (Figure 17) were monitored and documented every time the ICU was visited. It was seen that the waste in the Tonto bin is mainly gloves, masks, tubes, suction bags and tissues, which are all allowed materials. Some smaller carboard pieces were also included sometimes, which can clog the pipes.

In the development of the Information materials, all materials in the infectious bins were identified and matched with the Tonto list of allowed materials. Several items were identified which are accepted by the Tonto. This was also confirmed by a Pharmafilter specialist. So how can we achieve that these items end up in the Tonto instead of the SZA bins? What kind of information or tools the nurses need to only dispose the necessary materials in the SZA bins. Based on the user - centered research (Chapter 10), and discussion with the nurses, the following aims were

Figure 16: Waste in Tonto bin

Figure 17: Waste in SZA kegs

identified:
Make the nurses think about whether an item really can only go in the infectious bins or also in the Tonto.

Make the nurses aware that it is favored and better for the environment when an item is disposed in the Tonto instead of the SZA kegs.

Make the nurses aware that for non-infectious items, the Tonto is only better if the item has a lot of liquid inside, because the solid waste of Pharmafilter ends up at the same waste processing scenario as the residual waste (incineration)

Provide clarity about the purpose of the Tonto bin in the Tonto room.
Help the nurses place the items in a Tonto bag before they dispose it in the Tonto.

In order to fulfill these aims, it was decided that informing and nudging should be used on strategic locations. From the five behavior change strategies (Bakker et al, 2022), informing is the least strict agent, leaving the power of decision making to the nurses, while nudging places more power into cues which subconsciously steers the behavior to the desired direction.

These information and nudging cues can be implemented on the sticker applied to the Tonto and by applying other posters around elements which are part of the process.

For the sticker redesign, the current list of materials shown on the sticker were closely studied and the following conclusions were made:

The list contains 27 items for the "yes" and 13 items for the "not" list. Of course, there are still items which are not listed in either category, as there are more than 40 types of items in the ICU. The lists are too long to read through.

Many items listed in the "yes" list are considered general waste when it does not come from an infectious patient.

There is no indication of which items needs to be placed in a bag and which do not.

Part of the forbidden items are repeated (not the whole list).
The maximum allowed amounts are mentioned separately from the products list. This can result in mistakes when someone does not check both locations.

These insights guided the redesign for the sticker. First of all, the lists were shortened in a way that for the "yes" part, only the infectious items are highlighted, taking in focus those items that were typically found in the infectious bin. This list was put together based on information from the nurses. Furthermore, the "yes" was rephrased to "what should go in the Tonto?", to help shift the focus to those items which has the added advantage when disposed through the shredders. The items are visualized to represent the actual look and make them easily recognizable (Figure X). The maximum numbers as well as the need for a bag are also incorporated into the visuals.
The list of the materials that should be disposed in the Tonto:

Urinals. max 3
Bedpan max 1
Measuring jar max 2
Blood and blood bags
Filtrate bags 10 L
Catheters and ostomy bags
Cytostatics
Artificial kidneys
Suction bags
Redon drain and Thoracic drain max 1 40 L full bag

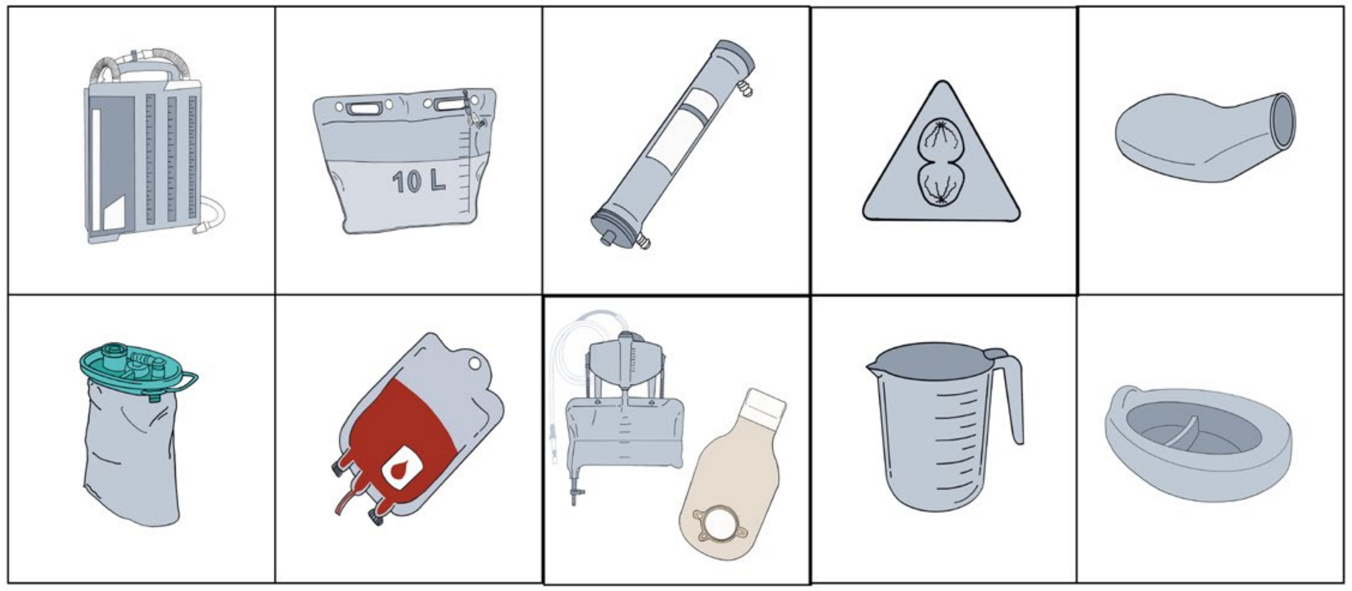


Figure 18: visual representation of items

The forbidden list was also reduced to 9 items by grouping instruments together and visualized similarly to the other list. Drawings were used as visuals instead of pictures to abstract the item categories instead of showing individual items which may differ in appearance. The most important tips were about dealing with parts that stick out and cause problems. The two most important tricks for this were incorporated, namely placing items in a bag first or taping the connector to the item.

The final redesign of the sticker can be seen in the next chapter.

However, when people come into the Tonto room, they might already just walk with the item directly to the infectious bin (which is in the same room) without looking at the Tonto sticker. In this case, a reminder can be used next to that bin which can warn the nurses before they throw something in the kegs. For this reminder a poster with a message was prepared. A nudging strategy was showing the most commonly misplaced items on the poster next to the message.

In order to make everyone aware of the purpose of the bin with the Tonto bag inside (which is a reused SZA keg, therefore can be confusing), another poster is developed for the wall above the bin. This informs the nurses about the role of that bag and shows the steps to use it.

The last piece of this solution remained at an idea / early concept level in order to focus on other solutions. This idea can be easily implemented by the hospital without a detailed design. It focuses on providing the nurses with accessible Tonto bags. From the observation, it was a clear reason why someone used the SZA keg instead of the Tonto, because they could not possibly open a bag and place the given item in it, because their hands were occupied with the item. To avoid this, a bag roll holder can be installed in the rooms, providing the opportunity to take and open a bag at the location of the waste generation. This way, the nurses can prepare the bag before the infectious item is produced and directly place it in it. A visual and further information is provided in the next chapter.

3.3.2 Separate collection of dialysis bags and secondary packaging

At the end of the selection for further development, 3 interventions were chosen, 2 of them were proposing the collection of dialysis bags and their packaging. During the development, these 2 interventions were merged into one. This allowed for a clearer communication and the development of an integrated solution which works for both.

The Concept Development for the dialysis bags focused on creating physical prototypes and digital graphical solutions as well with the following aims:

Help the nurses reduce the effort of cutting off the connectors.

Help the nurses reduce the effort of collecting the bags.

Aid the nurses in decision-making about what belongs to the new waste stream.

Reduce the need for keeping the separation in their mind.

Increase the long-term engagement to the task.

At the end of the ideation phase, the idea of a collection bag for dialysis bags was chosen together with a sliding cutting solution. This way, the nurses can directly dispose of the bags at the point of generation, without interrupting their task. They only need to go to the waste storage room, when they would do it anyway, at the pickup of new dialysis fluids. Since the collection box on the cart requires a more custom-made solution, it was decided that the physical development is going to be focused on that. The idea was further developed to prototypes and iterated before the final design was reached.

Figure 19: Cutting solutions tested (from left to right number 1, 2, 3, 4,5)

The cutting solution

Due to the time constrains of the project and the type of cutting direction that was chosen, it was decided that already existing safety cutters should be chosen and tested to find one which makes the process easier.

For this, four cutter type (Figure 19) was chosen from the producer Martor and evaluated with the nurses in the ICU. All of them are specialized safety cutters mainly designed for opening boxes and packagings.

Three nurses tested the cutters by laying the bags on the counter with the connectors above the sink and pushing it down with their left hand while cutting off the connectors from one bag with each of the safety cutter and with a scissor. This was to ensure the liquid is not spilled while also keeping the bag in place during the cut. They were compared to each other and with the baseline solution, the scissor.

It became clear through the test that a special device for cutting does help them in making the process easier compared to cutting with a scissor, because they reduce the number of cuts and the time needed. However, not all of them had a good grip or large enough blades to make the cutting smooth. It was obvious by the end of the test, that cutter number 5 (Figure 21) was the best for the task and the participants clearly expressed that it is prioritized over scissors. The chosen cutter was accepted as it is, but it can be further redesigned to better fit the hand ergonomically and to take into account the hospital environment with better hygiene properties. The cutter is described in detail in the Final Design chapter and a redesign is suggested.

Figure 20: nurses testing the cutters on the dialysate bags.

Figure 21: The chosen cutter

The collection box on the carts

A custom made collection box was developed to fit the carts used specifically for dialysis patients at the ICU.

For this, the measurements of these carts (Figure 22) had to be analyzed. There are two types of carts used, a two-shelves and a three-shelves version. The bag needs to fit both.
The box is fixed up on the front of the cart, while it is being pushed from the back by the user. The fluid bags are stored on the top, while another type of infusion bags on the middle and the empty filtrate bags on the bottom.

Figure 22:Cart types used for dialysis patients

Figure 23: Placement of the equipment needed for dialysis

The development focused mainly on the size of the collection bin and the attachment method to the cart. The size of the box was determined based on the number and size of the dialysis bags that needs to fit in it. Ideas were generated for the attachment method, which can be seen in Appendix H.

To help the development process, a list of requirements was generated for the box:

Size of the basket:

1. The basket needs to fit at least 8 dialysis bags (two rounds of dialysis)
2. The basket needs to fit dialysis bags with the size of 35x41 cm.
3. The empty bags need to be easily removable from the basket.
4. The basket needs to be open from the top
5. The basket needs to be closed from the bottom and the slides to keep liquid drops inside

Attachment:
1. The basket needs to be easily removable from the cart to clean it.
2. The attachment needs to be stable during the movement of the cart.
3. The bags need to be stable in the box during the movement of the cart.
4. The box should not disturb the storage of the fluid bags on the cart.
5. The basket needs to be both attachable to the version with the middle shelf and without the middle shelf.

The material:
1. The materials should be easy to clean for high hygiene standards.
2. The materials should be lightweight enough to easily lift the box.
3. The material of the basket should be waterproof.

Two concepts were further developed into simple mock-up prototypes from carboard to explore the usability and operation of the baskets together with correct dimensions (Figure 24 and 25).

Figure 24: Concept hanger

Figure 25: Concept ring

The main difference between the concept were the attachment methods and the dimensions of the baskets. The first concept was attached to the edge of the top shelf with a hanging solution, while the other concept used the posts of the cart to secure itself.

The concepts were tested with two nurses by interacting with the boxes. The stability and usability of the attachments were tested, as well as the convenient size of the basket.

The chosen attachment method was the ring type due to its stability and sturdiness. For the size, the larger box was chosen to conveniently place all the eight bags in it, but the cutout from the other box should be integrated in it.
In the next step, the final size of the basket was determined, and further iterations were made for the connection part through 3D printing. The reason for the iterations was to make it easily producible for the hospital and to fit the carts post better. In the earlier prototype, a part of a bicycle equipment is used, which is not a realistic scenario for the hospital. The iterations for the connection method are not detailed here, but shown in Appendix O. The final attachment can be seen in the Final Design chapter.

The graphical solutions

In order to help with the behavior patterns, such as correct collection and engagement part, different signs are developed which help the nurses to go through the process. An important part is to clearly show only which type of bags (only the 5-liter dialysis bags and their plastic packaging) are separated and in what condition (empty and without the connectors). These need to be showed visually and named to ensure they are identified correctly. The locations for these signs include the front of the collection basket and the waste storage room, the two place where the disposal happens.

It is also crucial to differentiate the new waste stream from the already existing waste stream of foils. This is important in the waste storage room, where the foils are collected in the same type of bins which can be used for the new waste stream. The same bin type is used for logistic and space limitations. To easily separate the two waste streams from each other, color codes are given to these waste streams. The colors were chosen based on analyzing the colors of existing waste streams and future waste streams which will (or might) be implemented soon. Most of the main colors are already occupied, therefore the remaining options are limited. The existing and new waste stream colors can be seen in Figure 26. The colours can be uniformly used through all steps of the process to strongly associate with the waste type.

The posters are developed for the wall in the waste storage room, but a sign fixed on the waste bag itself is needed as well, because from previous experience, the bins are moved within the waste storage area.

It is especially important with a setup of a new waste type that the previous behaviors are broken, therefore the nurses need to be reminded at the old disposal location, the general bin in the patient room,that the dialysis bags no longer belong there. Therefore sticker are created to serve this purpose.
Lastly, a reminder is developed for the dialysis machine, on eye-level, to remind the nurses when the bags are removed. An important consideration was that most part of the dialysis machine is equipped with a weight sensor, which can be disturbed even by a sticker, so the location had to be carefully chosen.
In order to avoid repetition, the actual signs and stickers are shown in the next chapter.

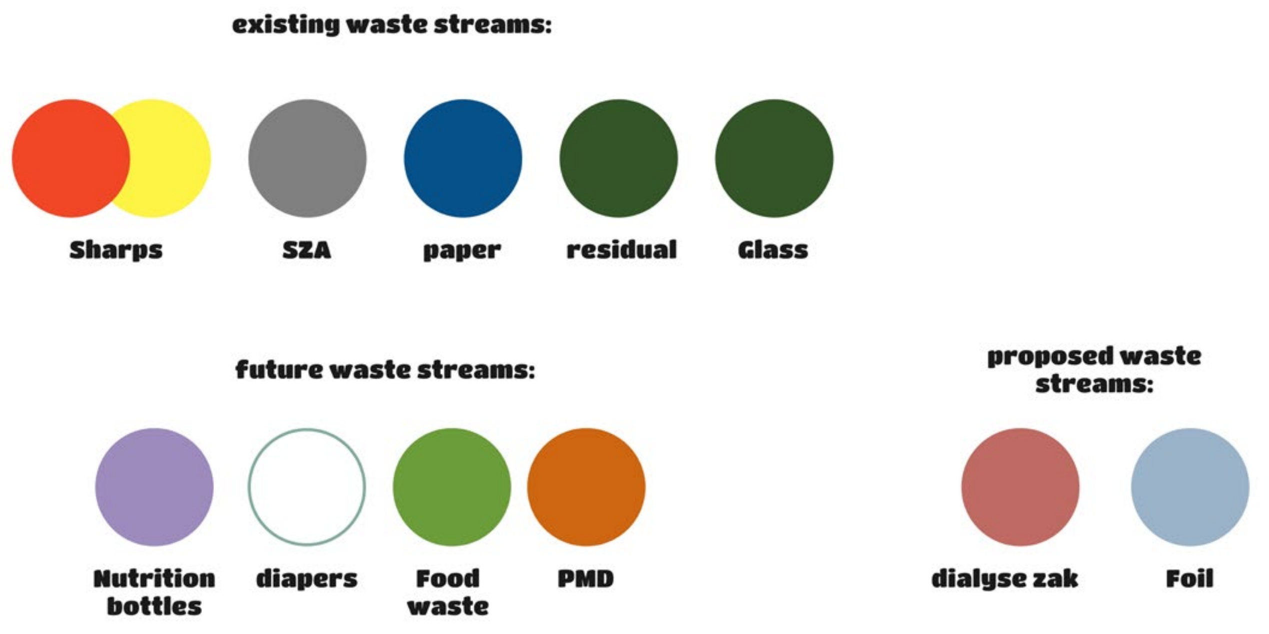


Figure 26: Colours associated with exisitng and future waste streams and chosen colours

Safety of the dialysis Fluid

As mentioned at the end of chapter 3.3.2, the waste management company was hesitant about the safety of the dialysis solution, therefore an important part of the development was to find reliable information about that. The elements of the solution were discussed with the nurses, and they said the fluid is basically a salt solution with electrolytes. The pharmaceutical company was contacted and they ensured that since in the treatment several liters of these fluid goes through the human body per hour, they cannot put any harmful material in it. They also sent the list of components and confirmed that the components and their combination are totally harmless.

Chapter 4

Final Design

This chapter presents the final design outcome of the project. First, an overview is given, then a detailed presentation is provided about each part of the solutions.

4.1 Overview of design

The final design is focusing on two separate parts connected to waste disposal on the ICU. The first solution provides a procedure for introducing a new recycling waste stream on the ICU, together with a set of physical and graphical aids which help the user group, the ICU nurses in the process of separate collection. The design consists of a special collection bin, a safety cutter and signs to guide the correct disposal and engage the nurses. The second solution redesigns the rules for a waste shredder machine, the Tonto on the ICU ward. Part of the design is a new information sticker on the machine and posters that aim to influence the behaviour of the nurses. Lastly, a bag holder is proposed for the easier accessibility of special waste bags required in the process.

The impact of the design

The Material Flow analysis shows the transformation of the waste streams as the effect of the proposed solutions. It can be seen that half of the infectious waste stream (around 2000 kg yearly) can be converted into general waste and around 8000 kg, 14% of the general waste can be transferred to the recycling waste stream. The C02 emissions associated with these reductions can reach 26.000 kg yearly.

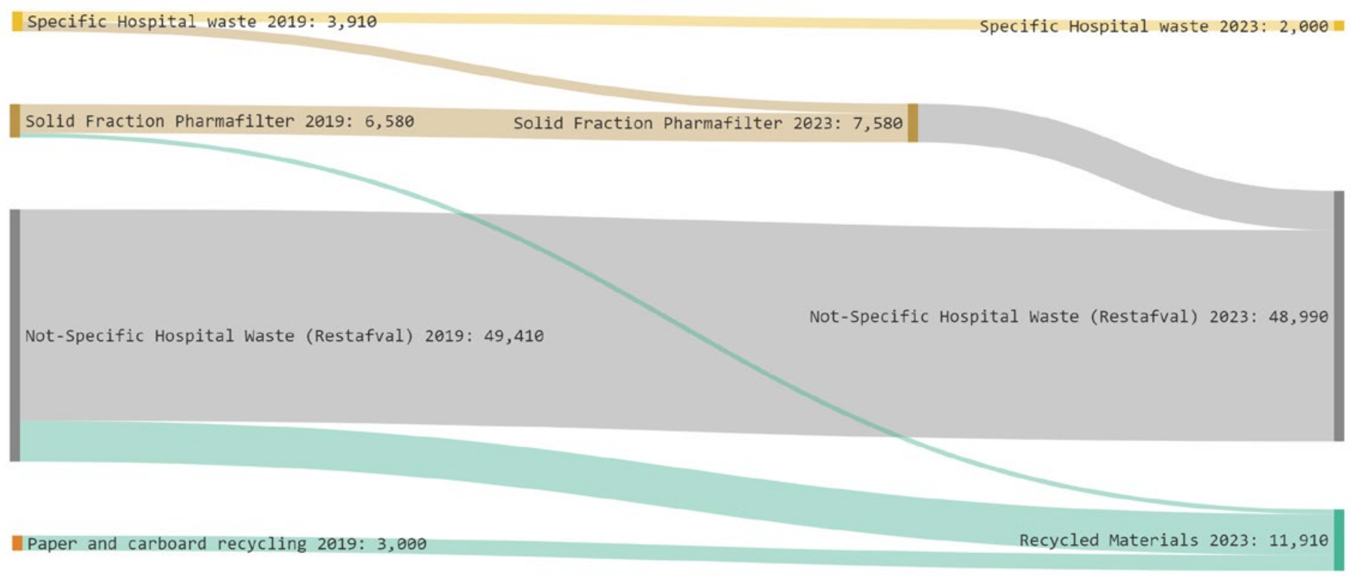


Figure 27: MFA of the waste flow change

4.2 Design Details

This part explains the designs in detail, highlighting important features and the impact of the design.

4.2.1 Dialysate fluid bags

Process

In the final solution, the dialysis fluid bags, and their outer packaging is separated from the rest of the general waste stream. Together they create a new, purely Polypropylene plastic waste stream. The hospital can collect this waste stream together with the blue wraps from the OR, which is an already existing stream. The blue wraps and the dialysis packaging fill a truck, they are transported to a recycler, where they are turned into valuable material resources for future products. The solutions focus on the collection in the ICU ward. The process of collecting the dialysis bags can be seen in Figure 28. This process is supported by several facilitators and signals, which reduce the physical and mental effort required by the nurses, engage them in the process and help them to separate correctly.

Facilitators

Safety Cutter

Through the test of several cutting solutions, a commercially available safety cutter was chosen to make the procedure of separating the connectors quicker and less effort.

To cut off the connectors, the empty dialysate bag needs to be laid on the counter, with the top part hanging over the sink. One hand can hold the bags in place, while the other hand will cut through the materials with a sliding motion. The handle provides a comfortable and stable grip for the hand.

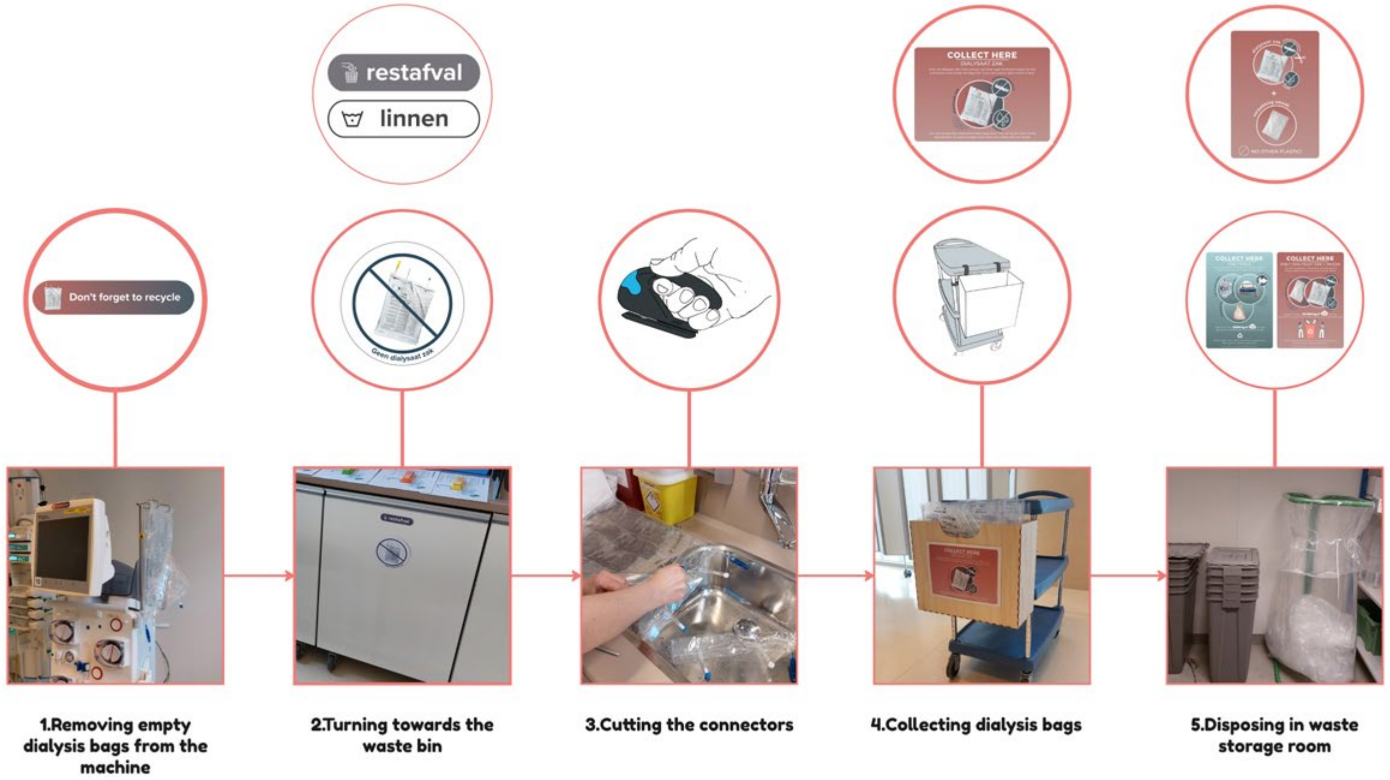


Figure 28: the process of collecting the bags with realated solutions

Figure 29: The process of cutting off the connectors

The cutting can be performed in one or two motions compared to doing it with scissor, in which case, several cuts are required. The remaining fluid in the bags can drain in the sink. Moreover, the cutter has a safety feature, making it impossible to make harm in oneself. The blade can be easily replaced to a new one, when the sharpness has deteriorated.
It can be used both by right- and left-handed people which was and important criteria (Fgiure 30). When it is not in use, it can be easily hung on the hanger above the sink, where the scissors are also stored. This way, no extra space is used on the counter, which has already limited free surface area.
The choice was made to use an already existing cutter instead of designing one,

Figure 29: The cutter solution, highlighting the safety feature (Safety Knife SECUMAX SNITTY NO. 43037 | MARTOR, 2021).

Figure 30: The cutter does not differentiate between left- and right-hand grip.

Figure 31: It can be stored on the hanger above the sink.

because the product fit the purpose well already and can be more realistically implemented in the hospital within a short time frame than a newly designed and manufactured one. Besides, developing a similar quality cutter would have taken more time than what the timeframe of this project allowed. Nevertheless, based on insights from nurses and initial requirements, a possible redesign is suggested illustrated in Figure 32. The redesign includes increasing the cleanability of the parts by removing unnecessary hollow parts, which can collect dirt. This is important for hygienic standards. Moreover, the back of the grip is opened up to make it suitable for larger hand sizes as well (which is common for male nurses at the ICU).

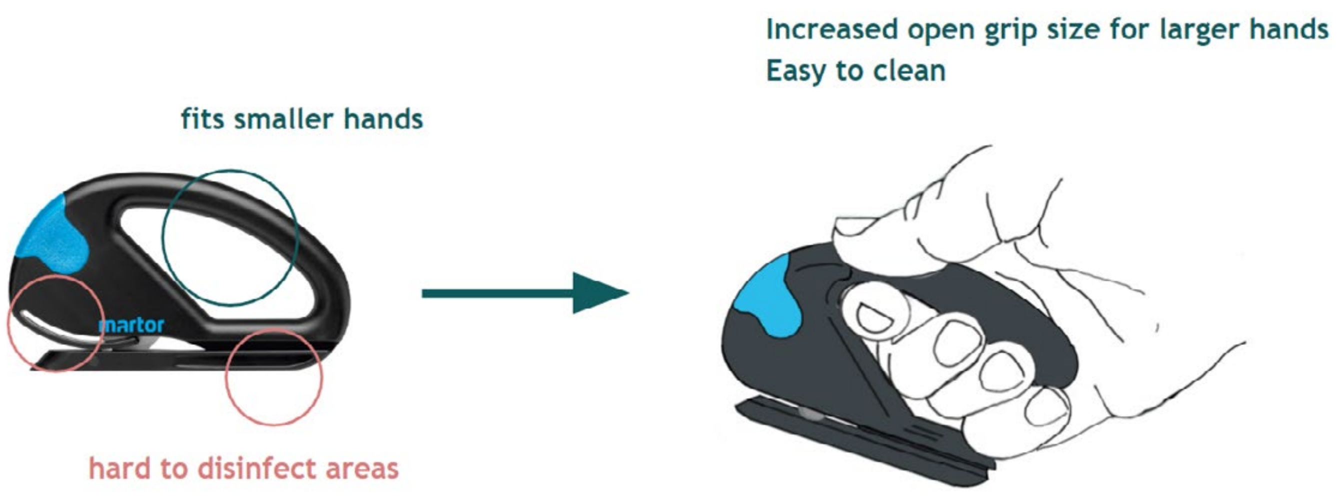


Figure 32: Redesign of the cutter to fit the ICU context.

The Collection basket

The empty dialysate bags, with the connectors removed, need to be collected together in the waste storage room. In one set of dialysis, 4 bags are used. A set needs to be replaced to full bags every 3-4 hours, depending on the patient. To avoid going to the waste storage room every time, a special basket is designed for the temporary collection of the bags.

Carts are used for dialysis patients to bring and store the needed dialysis fluids. Each dialysis patient has one

Figure 33: the collection basket attached to the cart.

cart standing in front of their room. The basket is designed to fit these carts so the bags can be thrown away right at the source.

The size of the basket

The size of the basket is determined to fit at least eight dialysate bags, equivalent to two rounds of treatments. This is usually done in one shift of the nurses. The dimensions also allow for convenient placement of the bags into the collection bin as well as easy removal. The reduced height in the middle also helps easy grabbing of the bags inside.

The connection of the basket

The basket is connected to the carts through the metal posts of the cart. They are attached to the two posts on the front to not extend the dimension of the cart on the sides. The attachments allow for easy removal of the baskets when it is needed for cleaning or other reasons. In the meantime, it also ensures secure connection. It consists of one part wrapped around the posts, and one attached to the back of the basket. They are secured with bolts and nuts.

For the removal of the basket, it needs to be lifted up until the connectors are disconnected. For reattachment, the positive part on the basket needs to be placed on top of the hollow part on both sides and pushed inside. The bins can be used for both the 2 shelves and 3 shelves version of the cart. Both of these are used at the ICU.

The proposed material of the basket is recycled Polypropylene, as it is easy to clean and sturdy enough to withstands occasional bumps. It is also waterproof (drops of liquid could leak from the bags) For the attachment, 3D printing can be used to create the plastic parts, while for the bolts and nuts commercially available items can be used.
The list of parts can be found in Appendix S.

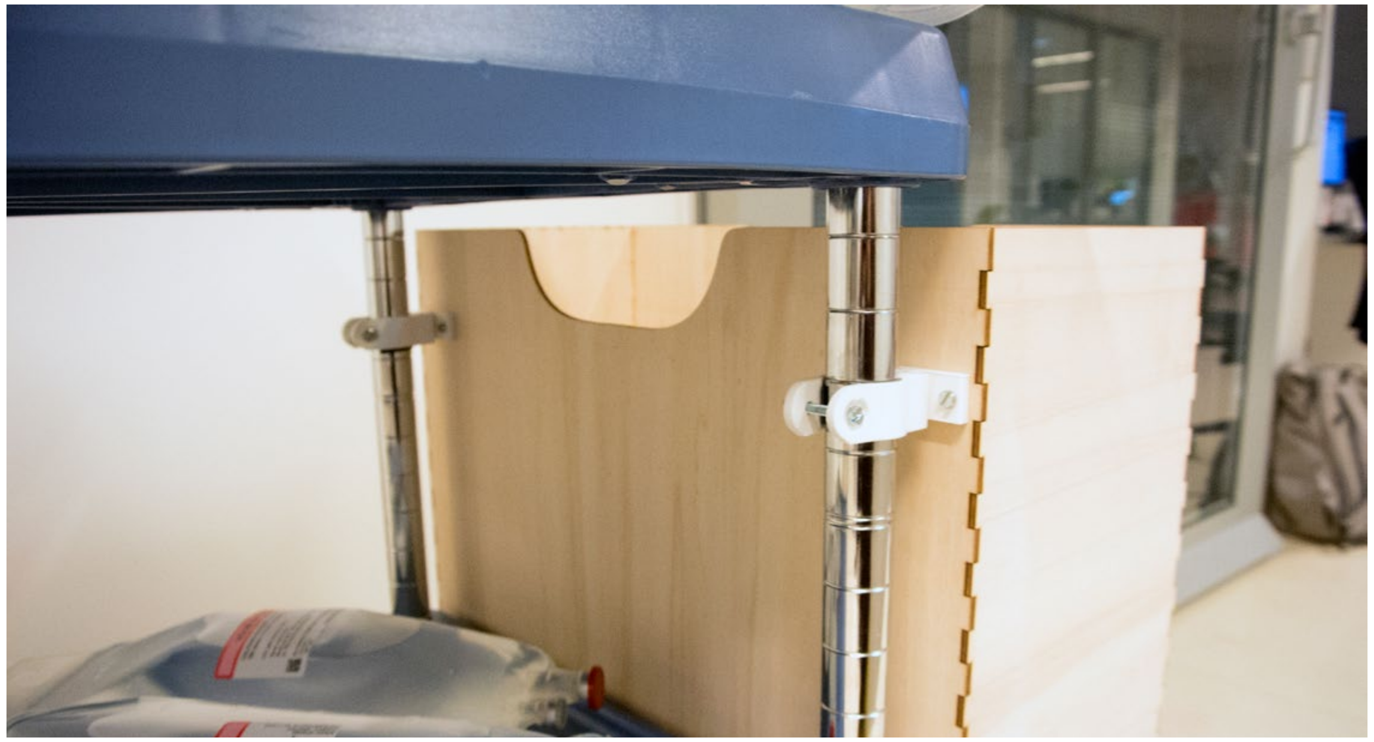


Figure 34: the attachment of the basket.

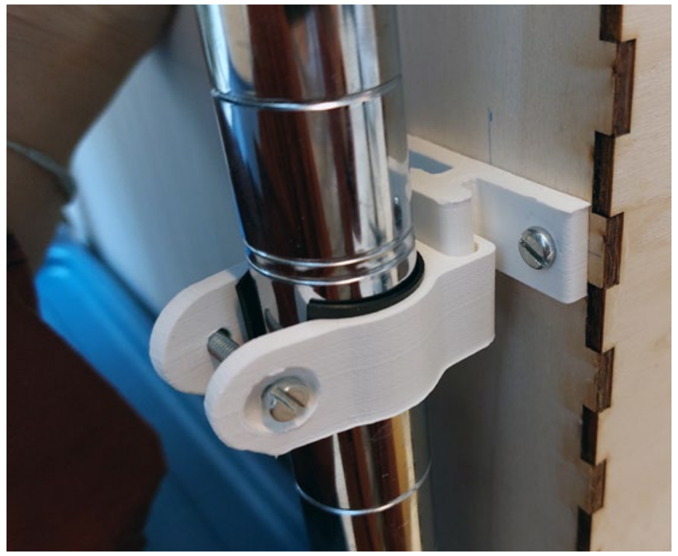


Figure 35: : The attachment during removal (sliding upwards)

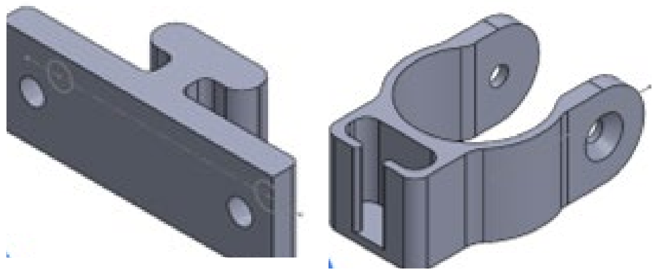


Figure 36: The two parts of the attachement

For the 3D printing, ABS filament is recommended for increased flexibility and durability.

The bin also avoids previous problems with the disposal of these specific dialysis bags. Currently, the nurses disposed it either in the general waste bag in the room, which caused the bag to tear apart due to the sharp edges of the stiff plastic, or in the Tonto, where the connectors sticking out can potentially cause the breakdown of the Tonto. By placing them in the bin, both of these scenarios can be avoided.

Sparks and Signals

The previous part of the design showed how the nurses can be equipped with tools, which enable them to perform the separate collection more hassle-free. However, especially in the beginning of the process, they also need to be adjusted to the new protocol and need to remember how to collect it. Although many are eager to help the environment, all of them need to be engaged for a successful introduction. Moreover, they need to do it correctly, avoiding placing other type of materials in the waste stream. A range of graphical solutions, such as signs and sticker help them along the way.

Sign on the collection basket

A poster was created to be placed on the front of the collection baskets. It aims to act both as a reminder and a graphical aid for correct collection. The poster shows both visually and through text which item and in what condition need to be placed here (without connectors and empty).
A colour was chosen to be associated with this specific waste stream and all signs follow the same colour scheme. The choice was based on analysing the colours used for existing and future waste streams and looking for an unused, easy to distinguish colour.

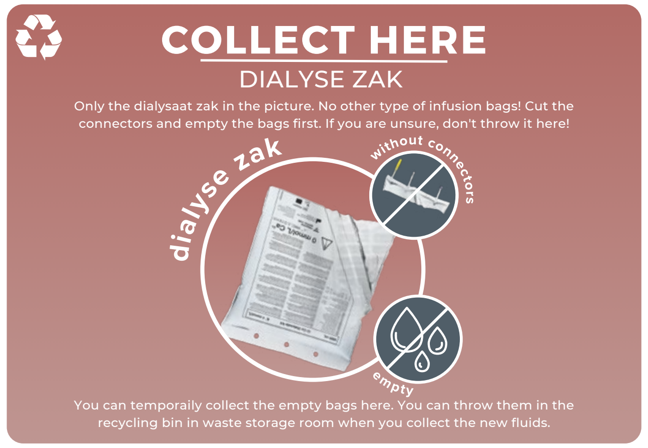


Figure 37: Sign on the collection basket

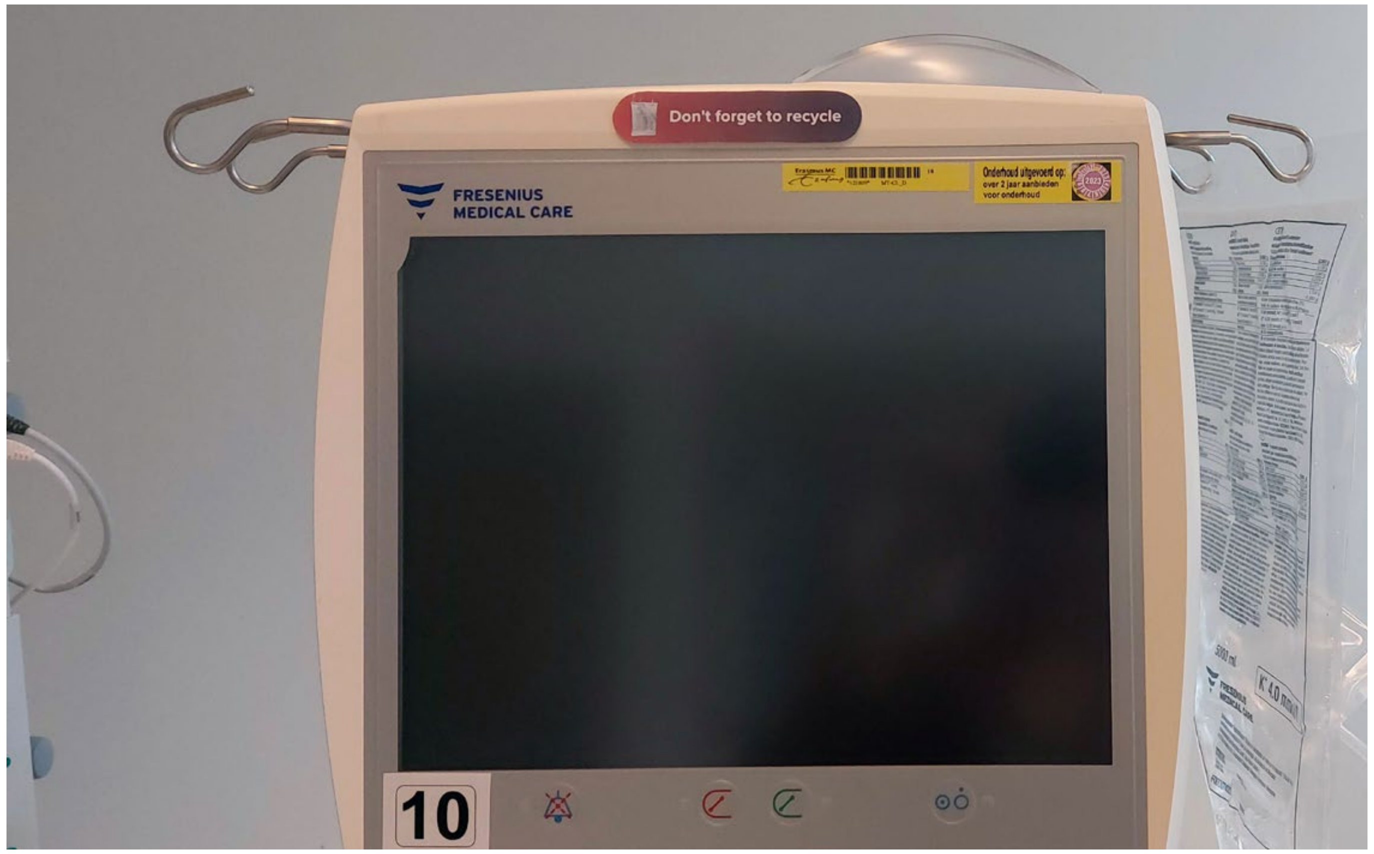
Stickers on the waste bin

Another signs can be found in the patient room, on the front of the waste bin used for general waste.

The signs replace the original afval name to restafval, to help the users reframe the purpose of that waste bag. With more and more recycling sceme being setup in the future, the less waste they should throw in there. The sign is also larger than the orginal sticker and a similar has been made for the washable textile, to match the style.

Additionally, a “no dialysate bag”; “geen dialysaat zak” in dutch; sign is placed on the bag to ensure it is not collected in there anymore. It is especially important in the transition period, before it becomes a habit.

Figure 38: stickers on the waste bin



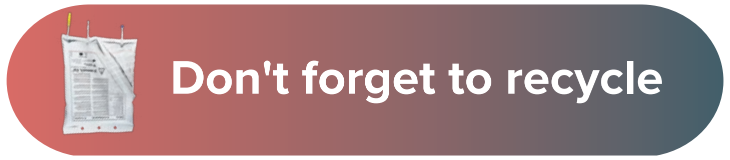


Figure 39: Sticker on the dialysis machine

Sticker on the dialysis machine

Another small sticker is placed on the dialysis machine, above the screen, so when the nurses remove the bags hanging from the machine, they are looking at the sticker.

The nurses need to pay attention to many things during their work and these signs help them to adjust to the new process without having one more thing they need to remember.

Figure 40: Poster for dialysis bags and overpouch (left) and for foils (right)

Poster in waste storage room

In the final step, when the collection basket is full with the bags, the nurses come to the waste storage room to dispose it in the large collection bag. Since these bags look exactly the same as the ones used for an already existing waste stream (the foils), they need to be properly differentiated.
This is done with a poster on the wall above the bin showing a visual about the disposable items and highlighting the environmental impact that can be achieved by recycling. It also reminds the nurses that by doing it, they are contributing to the health of people (and concequently their patient's help). The different colours also help in the instant recognition.
In contrary to many recycling streams, the collected material goes directly to the recycling company. As it is a clean stream and one type of plastic, it does not require extensive cleaning or further sorting. The direct collection does increase the value of the material, but also makes it more sensitive to contaminants. If the stream is contaminated with other materials, it is likely that the whole batch is going to be treated as residual waste and incinerated.

Figure 40: Poster for dialysis bags and overpouch (left) and for foils (right)

Figure 40b: Signs on the waste bin frames

Recommendation
When the hospital does not want to manufacture the baskets, they can replace it with other boxes on the market. In this case, the size should be comparable to the custom-made version to function properly (see size in Appendix S). The holes can be drilled in the box and the 3D printed parts can be attached.

4.2.2. Assistive Tonto disposal

The other part of the final solution is focusing on the Tonto waste shredders installed on the ICU. It aims to improve the nurses experiences with the Tonto, reduce the number of breakdowns and make the decision making of Tonto disposal easier. The true purpose of Tonto can be better utilized by disposing more infectious products in there instead of in the SZA bins. Reducing the number of used SZA kegs results in less plastic produced and burned, burning the waste in a lower temperature and without fluids and lastly less transportation emission.

Process
The proposed process of tonto disposal starts with the production of the infectious waste. When it is produced on the room, the nurses can take a Tonto bag from the dispenser and place the item in it. They don't need to interrupt their process by going to the tonto right away. They can then go to the Tonto room and look at the visual signs on the Tonto to quickly make a decision about disposing in there or not. When a nurse is producing an item and does not place it in a bag, they can still do it the prepared Tonto bin in the infectious waste room. Lastly, when a person goes into the room with an item and walks to the infectious bin to dispose it they get a reminder do think again if the item can be disposed in the Tonto. Then they can check the signs on the Tonto.

Signals

A set of signals is used on different locatiosn related to the Tonto process to help the decision making and inform the nurses.

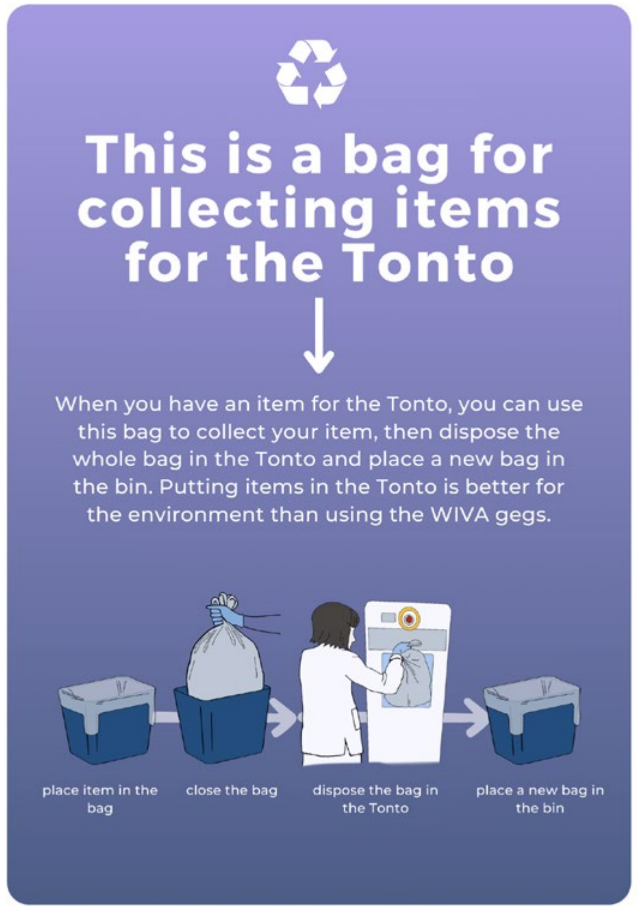
Figure 41: Process of diposing waste in the Tonto

Information sticker on the machine
The most important part is a proposal for the information sticker on the Tonto. The role of this sticker is to show the rules associated with the disposed products. Instead of listing all the products that can and cannot be disposed in the Tonto, the new design is focusing on the products that should be disposed in the Tonto. This results in a limited number of products to scan through, and the visual aids also help to identify the products and maximum allowed amounts. It also highlights more to nurses that waste from isolation patients can and should be just as well disposed in it. Similarly, materials that could damage the Tonto, therefore should not be placed in it are also summarized in less items and visualized. In the beginning it explains the purpose of the Tonto and shows what happens to the infectious waste thrown in there.
Lastly, it gives tips about how to place the products in it, for example placing it in a bag often helps to avoid parts getting stuck between the blades of the shredder. These were not written before anywhere and not all nurses were aware.

Figure 42: New sticker on the Tonto

Sign above Tonto bin
In the room where the Tonto shredder stands, there is a WIVA keg prepared for products belonging to the Tonto. It contains a special Tonto bag which is disposed in the Tonto when full. Since the WIVA keg is originally used for infectious waste and closed once full, it can be confusing what is it for with the bag inside it. To make the purpose clear a poster is hung on the wall above it, providing a clear explanation (Figure 43).

Figure 43: poster placed above the Tonto bin



Sign above SZA keg
The actual infectious bin, the SZA keg, stands next to the Tonto (Figure 44). When a person would approach it with a waste, which could potentially also be placed in the Tonto, the sign shown in figure 44 acts as a trigger for thinking it over before they dispose in there. The sign also contains the most commonly found items in the bin which should be directed towards the Tonto.

Facilitator

Tonto bag dispenser in patient the room
Lastly, a dispenser is proposed on the wall of each patient room, which can contain the special bags for the Tonto. This way, when an item belonging to the Tonto, such as a urine bag is produced in the room during patient care, the nurse can directly place it in a Tonto bag and walk to the Tonto machine. Even if the bags have connectors and loose parts, the Tonto will be able to handle it easily.

This part of the concept is not worked out in detail, but validated with the nurses that it would make their job easier. There are several solutions on the market for storing waste bags and other items on a roll, so it is recommended to purchase an available item that fits the size of the Tonto bag and equip the rooms with it.

Figure 44: Sign placed above SZA keg

Figure 45: visual of the Tonto dispenser concept

Chapter 5

Final Evaluation

This chapter describes the final research study of the project, the user evaluation of the final design solutions. Based on the results, it gives recommendations for further developments.

5.1 User Evaluation

5.1.1 Approach

The final design package is evaluated through the Product Usability Evaluation method described in the Delft Design Guide. In this method, the product's usability can be validated in actual use conditions through almost fully functioning prototypes. The assumptions used during development are validated by the participants and it helps to determine whether the initial requirements are met. The outcomes can be used to further improve the design.

The graphical parts of the final solution do not require usability in the traditional way, but user perception and cognition can still be evaluated similar to the physical parts.

Test environment

The final design solutions were evaluated on the ICU Unit C. An empty room was chosen and prepared for the test. Prior to the evaluations, the stickers were printed and applied to the correct surfaces, the bin was assembled and connected to the cart. Eight empty dialysis fluid bags were brought (the connectors already removed) to represent the content of the bin. A dialysis machine was brought into the room and empty dialysis fluid bags were attached to the hangers. The overall setup represented all the necessary equipment the nurses would use during real patientcare.

Participants

Due to the specific nature of the processes and used products, it was important to have the final design evaluated by the user group, because they can compare it to the current protocol and see the added advantages or difficulties. The participants were chosen from the available nurses at the time of the evaluation. The setup was prepared for five participants, but due to the number of occupied nurses, the final evaluation was carried out with three participants. All 3 participants were nurses working at the ICU, two female and one male, age between 25 and 45. Two participants were involved in previous sessions; hence, they were familiar with the context.

Procedure

The evaluation was chosen to be in the form of a discussion group together with an evaluation form (Appendix P). Because of the time limitations of the ICU staff, it was chosen not to do an individual interview with each of them separately, but collectively perform the tasks and discuss their opinion. To have more quantitative results as well, an evaluation form was filled out individually by each of them. The session was voice-recorded for the purpose of analyzing the results with the participants consent.

At the beginning of the session, the participants were briefly introduced to the topic and to the conclusion of the research that influenced the final design direction. The purpose and the elements of the final design were introduced.
The evaluation form was handed to the participants for reading the introduction and giving consent.

The test was divided to two main parts, the first one focusing on the design related to the separate collection of the dialysis bags and the second part on the solution for using the Tonto. The participants were asked to think out loud and also reminded that they are not tested, and that they should express their opinion freely.

In the first part, the participants were asked to go through the process of collection from the point of taking empty dialysis fluid bags hanging from the dialysis machine until going to the waste storage room with the cart. They were sharing their experience while doing it and a set of open-ended questions were asked resulting in a discussion afterwards. The participant filled the related part of the evaluation form before moving on to the second part. The evaluation contained closed-ended questions with a rating scale.

In the second part, the signs helping the Tonto disposal process were introduced and explained to the nurses. They had time to read and examine them and each of them were discussed. The idea about the Tonto bag holder in the room was showed as well. Lastly, the nurses were asked to fill the evaluation questions about this solution.

At the end, the participants were thanked for their contribution and some sweet treats were handed to them to express gratitude.

Figure 46: Test setup in a patient room

Discussion questions

1. How did you experience cutting the connectors?
2. What do you think about the size of the bin?
3. How do you experience walking with the cart with the attached bin?
4. How easily can you place and remove the bags in the collection bin?
5. What do you think about the attachment to the cart?
6. What is your opinion about the posters?
7. What is your overall opinion about the proposed set of solutions?

8. To what extent do you think the new sticker makes it easier to decide which items should be disposed in Tonto?
9. How clear do you find the information presented on the sticker?
10. What is your opinion about the sign over the WIVA kegs?
11. What is your opinion about the sign over the Tonto bin?
12. What do you think about having the Tonto bag holder in the patient room?

The list of questions from the evaluation form can be found in Appendix P.

5.1.2 Evaluation results

The data was analyzed both qualitatively from the discussion questions and quantitatively from the evaluation form. The results are clustered by sub-solutions and the important results are quoted.

Dialysis bag collection

The cutter

The participants expressed that they find the cutter useful and speeds up the process. An interesting finding was that the room was mirrored compared to the room the previous tests with the cutters were done. Therefore, the sink was accessible only from the right side (there is a glass panel on the left side). This resulted in a less comfortable position to cut with your right hand. With some more trial, it was figured out, that in this case, the bag can be hold from the front of the sink and the body can be slightly tilted towards the bag while cutting. For left-handed nurses, the same can be recommended in the other type of rooms. The location of the cutter when it is not in use was found convenient.

The box

The size of the box felt easy to use, all participants found it easy to place the bags inside and remove them.
The connection of the box with the cart was found stable and easy to use when the box was removed and attached to the cart.
One participant mentioned that the hollow part of the connection can possibly collect dusts. However, it was discussed later that since these carts are used for the dialysis patients mainly, the box can stay on the holder, eliminating the open surface of the hollow part. This would also help in the boxes not getting lost.

Otherwise, it was considered hygienic to clean the surface of the box when it is made of plastic.
Moving around with the box attached to the cart provided the same experience, it did not influence the maneuvering of the cart or the feeling of weight. The box felt stable on the cart.

“There is no difference, with or without the box attached.”

“We can be rough sometimes, but it feels sturdy.”

One participant expressed that looking at the prototype, it might be fragile and breakable if they bump into some object. It is true to the current prototype, but in the final design, the plastic material would be less fragile and more flexible as well.

Sign on waste bins

All three nurses said that the signs help them to reframe the waste category as “not all waste” and to not dispose the dialysate fluid bags in the main waste stream.

Sticker on dialysis machine

Two participants agreed that reminder would help to dispose the fluid bags correctly, while one nurse remained neutral in the question.
Waste room signs

Waste room signs

The graphic in the waste storage room was found useful and engaging, but all participants expressed that for the waste storage room, it contains too much information, because nobody spends there more than five seconds. It was expressed that the information it shows is great and they would like to see it, but it could be better used as a poster on the screens or on the information board. In the waste storage room, they prefer signs with only the information about what can or cannot go in there.

“This is too much information; we only need to know what can be put in there and what is prohibited.”

“The message is great, but not the location of the message.”

When the participants were presented with the additional signs that can be attached to the frame, they were very enthusiastic and said this is exactly what they would need.

“It is the perfect solution.”

The nurses admitted that due to the similarities in the waste stream and the collection bins, it would be easy to mix them up. The additional sign for the foils was found useful in helping to not confuse the two waste streams with each other. The colors were found easy to distinguish.

In the end, the nurses were asked about what they think overall, two nurses expressed that it is great start and if they can contribute with helping the environment with this just a little bit, they are happy to do it. When they were asked what they think about the effort of the whole process, they found it not difficult to do, and did not feel like extra steps. One nurse said that with the box it is even more easy to put the bags in there than in the original waste bin in the room.

"In my opinion, it is not difficult this way."

"I think this is very smart that you put an extra box on the cart we use already to transport fluids, it will not make us lazy."

Overall, all participants expressed, that the solution package together makes the process easier, and they would like to see it implemented.

The Tonto procedure

When the solutions for the Tonto were presented, it confirmed previous findings, that they were not very familiar with the purpose of the Tonto and what happens to waste they throw in there.

One nurse explained that she does not put a certain item in the Tonto, because in her experience, it even breaks down from the small connectors, while this item has many tubes and connectors with massive parts.
óAnother nurse explained that for him, the same item can be seamlessly put into the Tonto if he places it in a bag first. This is because it helps for the problematic parts to not get stuck when the platform in the Tonto is tilting.

This shows another confirmation that the nurses need to be informed officially about what they need to place in a bag and how the breakdowns can be avoided.

Sticker on the Tonto
All nurses expressed that it would make it much easier to have the proposed sticker on the Tonto. They liked the visuals and found them easy to recognize.

"This really works. Right now, it is just a lot of texts. You start reading and halfway you stop caring. "

The visual about isolation patient waste was also clear and did not require listing of all the items. The tips provided helps to be confident in placing an item in the Tonto without worrying about problems it could cause. It was pointed out that it is unlikely that the nurses will read all the text.

Sign over WIVA kegs
The purpose of the sign was found clear, and participants expressed that they think it will work. The items presented were found recognizable and easy to scan through.

"The main message is easy to read and if you have more time, you can read more below."

Sign over Tonto bin
The participants stated that it is indeed good to use this sign and can help in clear communication.
It was added that the sign should also express that the items placed in there should not contain anything from the forbidden list.

Tonto bag dispenser in the room
All nurses confirmed that they would find it useful and would help in the disposal process to have the Tonto bags in the room. It was mentioned that sometimes they use the small white bags for this purpose, but many of the infectious items are larger than the opening of such bag, making it unsuitable for a major part of the cases.

"I was thinking, would there be an easier way to use the bags, and this is better!"

'Well thought of."

One participant said that it is not absolutely necessary to have a dispenser, just a place to store it in the room. But he also agreed that it is easier to have it on an easily accessible place such as on the wall than in the cupboard.
Another participant mentioned that it would be needed to have a sign on the bag holder stating what is it for and what you can put in it.

5.1.3 Limitations

The bin was tested through a prototype, which represents the size and connection type of the final design, but the material is wood instead of plastic which can influence the weight and the surface quality experienced by the participants.

Since all nurses were present during the evaluation together (for most of the time), they were able to hear each other's reaction, which could also influence their answers. However, all of them were very active during the test, showing individual thinking and sometimes opposite opinions were discussed.

The actual effect of the reminder signs and the signs on the bin cannot be correctly evaluated based on first impressions, it would require testing for a longer period, when nurses are focusing on their daily tasks and not thinking about the collection of the bags.
One nurse had to leave during the evaluation due to urgent care for her patient and could not come back for an hour. The test was finished with her separately after she cared for the patient. The break within the two parts of the evaluations could have caused some loss of focus for the participant and could have potentially influenced her results.

5.1.4 Suggestions to improve the design

Include the image of the secondary packaging of the dialysate bags on the collection basket
Some nurses expressed that they usually still bring the dialysis fluids to the ward wrapped in their secondary packaging. For these nurses, it would make sense to collect the secondary packaging in the collection basket as well. In this case, the sign on the bin needs to include the image of the secondary packaging as well. It would also result in more material, so the bin might fill up more quickly.

However, other nurses explained that they already remove both the carboard layer and the secondary packaging in the storage space and dispose it in the waste storage room next to it. After this, they only place the fluid infusion bags on the cart and go inside to the ward with them. This order avoids unnecessary steps, so it is more effective in the process.

It is recommended to considered whether all nurses could follow this process or if some still continue to bring the secondary packaging to the ward, the sing on the basket could be extended accordingly.

Use the poster for advertisement
The poster initially made for the waste storage room can be used for advertisement material in the common room or on the screens. It proved to be too much information for the waste storage room, nevertheless interesting to know and the nurses would like to see it.

Shorten the text on the Tonto sticker
It was revealed in the User Evaluation that although it is good to have

background information on the Tonto, the nurses found the text too extensive. The texts can be shortened or visualised more.

Add prohibited materials to the sign above the Tonto bin

Since the nurses might not look at the sticker on Tonto when they are placing an item in the prepared bag in the bin, there is a risk of placing an item in there that could cause problem. The sign above the Tonto bin should be complemented with the prohibited list of materials or should warm the nurses about them to avoid any problem.

Add information label to Tonto bag dispenser

The opinion of one of the nurses was considered, namely that the Tonto bag might need only an assigned place in the room. However, when it does not have a dedicated location which needs to be refilled regularly, it is more likely that the bag will be displaced and lost or that it won't be replaced when one roll is used up. Also considering the low price of such bag roll holder, the investment from the hospital could remain low, while providing a more reliable solution.
A sign for the bag dispenser is indeed necessary to help the communication, therefore it will be added to the final design package.

Testing for a longer time

To effectively measure how much effort they consider the process of dialysate bag collection; it would need to be used for a longer time. To measure the effect of the Tonto stickers and signs, again, a test period is needed when the SZA kegs are monitored, and the nurses' experiences is studied.
For both solutions, a pilot study is recommended in a unit pair (since both the Tonto and waste storage room is used together) to test how easily the nurses can use the solutions during their actual work and see the effect on the collected waste streams. It is important to do the pilots separately to keep the focus on one solution at a time.

5.1. 5 Conclusions

The user evaluation revealed that the final solutions can help the nurses setting up the separate collection of dialysis bags and more effective Tonto usage.

In the process of dialysis bag collection, the physical facilitators reduce the time and the physical effort required to perform the activity, while the signals help in creating awareness and coherent instructions.

The nurses collectively expressed that they would like to see the solutions implemented and communicated that they are ready to start the collection.
In the case of the Tonto Communication solution, it provides value for the nurses by making the use of decision making for Tonto faster and less effort and shows prospect for increasing mindful thinking while disposing infectious waste. It also physically makes their job easier by providing easier accessibility for the Tonto bags at the location where the waste is generated.

The evaluation also revealed some required modifications mainly in the graphical parts of the solutions. Some of these are be implemented in the final design package.

5.2 Pilot day at the ICU

After the final evaluation, a pilot was held in the ICU to evaluate the process of the dialysis bag collection during actual working conditions. For logistic reasons, it was decided to only do it for the duration of one shift in one unit.

5.2.1 Aim

The aim of a pilot project is to prove the viability of a project idea or concept and identify deficiencies before further resources are spent on implementation. It is done through a small scale and short-term experiment. In this case, further pilots are going to be needed lasting for a longer time, but within one day valuable information can be gathered. First of all, the nurses experience in actual working conditions can be seen, which might differ from the testing environment. They carry out multiples tasks and focus on their work, while the separate collection is only a small part of it. They might be in a hurry or stressful situation. These can all influence how demanding they feel the task. Furthermore, the assumptions made during development can be confirmed or disproved. Lastly, potential flaws during actual use can be identified and improved in the future.

5.2.2 The Pilot setup

The pilot was performed during a dayshift in Unit D of the General adult ICU. Before the dayshift (7:30-15:30), the preparations

Figure 47: Two dialysis carts with all equipment needed for dialysis and the baskets installed

were made to install all parts of the solution.
There were two dialysis patients in the chosen unit on the given day, therefore two sets were prepared from everything. The stickers and cutters were installed in the rooms, the signs in the waste storage room, information slide on the screen and the collection baskets attached to the carts.

The nurses received a short introduction before their shift started and the steps of the process were explained. Although only two nurses had dialysis patients, all nurses in that unit were involved, so they would be aware when help is needed. The nurses were not monitored during their work but were asked about their experience at the end of their shift.

5.2.3 Results

Nurses experience

The two nurses were interviewed in a semi structured interview after their shift ended. The questions were based on the final evaluation questions (Appendix P), but they were adapted to the situation and their number was reduced. Both nurses have changed the dialysis bags once during their shift. There were three changes in total, but only two were performed by the nurses (see in limitations section)

Both nurses went through the whole process that was introduced in the morning. A difference was found, mainly that they were already bringing the fluid to the ward with the outer packaging on it, and they also collected the outer packaging in the collection basket. This has come up as an option on the final evaluation as well. They also already disposed the bags in the waste storage room after one set of bags. The reason for this was that they preferred to do it as soon as they had the time, to be done with the task and bring new fluid bags as well. Although it was not mentioned, but the baskets were filling up more quickly with the outer packaging.

It was interesting to observe, that one nurse brought the cart inside with her into the room, while the other one kept it in front of the room. This was only for personal preference, but the carts are suitable for both scenarios even with the baskets on them.

The nurses found the location of the cutter convenient, as it is close to the scissors which they are used to. One of them pointed out that she is concerned that the cutters might get lost in the room, because she just put it on the sink. In her room, it did not fit on the hanger because there were already too many things on it. The nurses found the cutting with the cutter much easier compared to using scissors. One said it cuts the time to one third and cutting all four of them goes quickly and smoothly. She used the method of placing all four bags on top each other and started going through them one by one.

The bags fit well into the basket even together with the outer packaging. One nurse had to change the bags while they were caring for the patient, she quickly cut and collected the bags and continued caring for her patient. She said it is very convenient to “park the task” for later, when she has time to go for new fluids and to the waste storage room. Both nurses said that they did not feel it extra effort compared to placing it in the regular bin in the room, and it even saves her from the trouble when the sharp edges tear apart the bag.

In the waste storage room, both nurses looked at the signs when they had to decide where to throw the dialysis bags. They were in good eyesight, very different colours, and both found them clear, but one nurse said she also remembered it from the introduction in the morning.

Neither of the nurses found the reminder stickers useful at the moment. The nurses did not look at the sticker on the waste bin, because they are too much used to the routine, and they are not in eyesight.

One nurse expressed that the reminder sticker is good for people who had not seen the presentation in the morning, but it was not needed for her because she already knew it from the morning. The other nurse said she does not need the reminders, because she feels it even makes her work easier so she would do it for herself. The first nurse expressed that the bin name signs look better visually, than current ones.

When they were asked about the whole process, both said that they would like to see this implemented and they would be happy to do it this way.
A nurse gave a suggestion that for the implementation it would be most successful if everyone was introduced personally to the process and the tools.

Collected samples

At the end of the day, the collected samples were measured in the collection bin at the waste storage room. The collection bag contained mainly the dialysis bags and their packaging, correctly. Next to that, one sodium-citrate bag and its packaging was also found among the dialysis bags (Figure 48). The sodium-citrate solution is also used at the dialysis process with some patients, but are incorrectly disposed in there, because these are not part of the separate collection.

Figure 48: The bags collected at the end of the day. From left to right: dialysis secondary packaging, sodium citrate packaging, sodium citrate fluid bag, dialysis fluid bag.

The fluid bags were correctly cut, and no connector parts were found in the bin. No other material was disposed in the bags either.

The sharp edges of the dialysis bags did not cause the material of the waste bags to tear, it seems to be sturdy enough to store them safely.

The collected amount was measured as well after the shift ended. There were twelve outer packaging in the bag and eight fluid bags, plus the one incorrect sodium citrate and packaging. This shows that the bags were collected after each change. The reason for only eight fluid bags is mentioned in the limitations section.

The number of bags produced per shift is in line with the preliminary calculations made for the amount of dialysis bags per year. The collection bag was found one third full after one shift. Based on this amount, the bags should be taken by logistics after every 24 hours and replaced by an empty one. However, this was only from one unit, and the same bin will be used by two units in the future.

Therefore, a collection of twice a day would be needed, but it can differ based on the fluctuating number of dialysis patients.

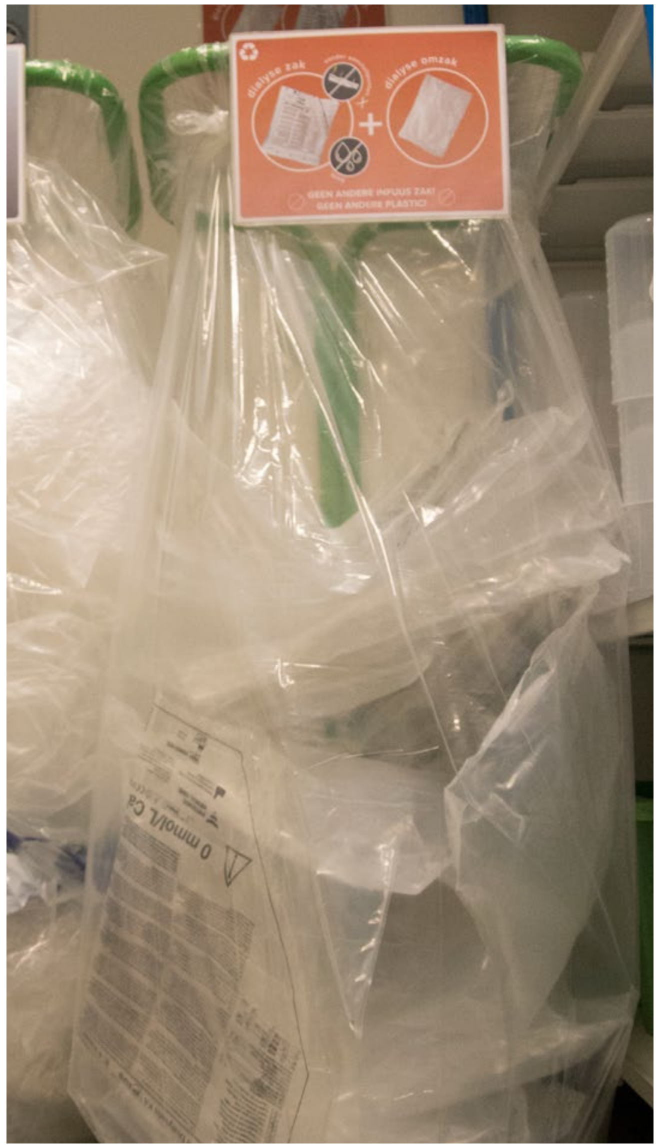


Figure 49: The collection bin at the end of the shift

5.2.4 Discussion and recommendations

The overall results of the pilot day were very positive. The participating nurses found the effort required by the process low and one even found it easier than before. They were happy with the tools they were provided and could use them as intended. The solutions are ready to be tested in a longer pilot period with some considerations based on these results.

Since the nurses collected the outer packaging in the basket as well, it can be considered to include the sign of the secondary packaging on the basket and introduce the process with that way of collection. This might result in increasing the depth of the basket to fit more materials. Currently it is tested that twelve bags fit comfortably, but maybe even the two sets (16) would fit as well. It was also seen that the stickers in the room might not add value to the staff, however a longer-term pilot can confirm or deny it better.

To make sure the cutters don't get lost in the room, a rope can be tied over their handle, which can be used to hang it even when there is limited space left. Seeing that the citrate bags can be also placed in the stream, emphasis has to be placed on communicating the matter clearly. Either the sodium-citrate bags need to be excluded and this should be shown on the signs, or it needs to be further investigated whether these can be disposed in the same stream too. They are made by the same manufacturer, so there is a high chance that the material is the same. In that case, the bags need to be included in the sign by visuals and texts.

5.2.5 Limitations

Due to the very short time of the pilot, limited conclusions can be taken from the results. Only two nurses interacted with the solutions, and went through the process, which represents a very small percentage of nurses working at the ICU.

It is advised to run a pilot in all units of the ICU for at least three weeks, so most nurses have a chance to be scheduled for a dialysis patient and the difference between A-B and C-D units can be seen as well.

Furthermore, since the nurses were just introduced to the new procedure in the morning, they were well aware of the task during the whole shift. It would be important to see how the collection goes when it is not so freshly in their mind.

During the pilot day, one of the nurses left from the side of her patient for a while and during that time, somebody changed the dialysis bags for her. It did not turn out by the end of the shift who was it and the fluid bags were not cut or collected separately either. Since all the nurses knew about the pilot days at the unit, it was an unusual phenomenon. This has influenced the results, because the nurse had less chance to try out, and the collected amount of fluid bags was less as well (eight instead of twelve).

At the time of the pilot, the ICU has already prepared a bin for the dialysis bags which were in the waste storage room for a couple of days. However, there was no explanation or introduction given to the nurses about this, so it was unofficial. The list for this bin also contained the outer packaging of the sodium citrate bags, which the nurse could have remembered. This could have been the reason for the mistake of including the sodium citrate bags as well.

Chapter 6

Conclusions

The last chapter concludes the project, explains its limitations and gives recommendations for further improvements. This part ends with a personal reflection and acknowledgement.

6.1 Conclusion on 3 pillars

The proposed process and prompts are evaluated based on the fundamental three pillars of a successful innovation as known from the Design Thinking process. The 3 pillars assess whether the design is “desirable from a human point of view, technologically feasible and economically viable.”

Feasibility

During the whole research and development, the factors of technical, safety and financial constraints were considered, and the solutions were developed with those in mind. The aim was to provide a solution that does not require technological development or long and expensive product development but make an impact in the short term. The two used systems, the Pharmafilter and mechanical recycling is already available. The physical parts can be purchased from the market or easily developed in case of the basket. In the collection of the proposed waste streams, the process is detailed in each step and validated to the insights gathered during the research. It was important to not only solve the problems on the point of generation but look at the whole waste journey. The proposed solutions do not pose risk to the safety of the patients, nurses, or waste management employees. The separated materials are safe or go through sterilization by the Pharmafilter. Despite of this, there is a potential uncertainty in the acceptance of the dialysis infusion bags by the waste management company. Even though it is confirmed by the pharmaceutical company, that the fluids are harmless, the Prezero project manager indicated, that they are afraid it might cause irritation if it gets in the eye of workers. The issue is explained further in the Recommendations section, but there are possibilities to overcome this. A cost estimation was made for the tools and posters for the dialysis collection, estimated for 370 € for the whole ICU (see Appendix R). The prices for the stickers and signs of Tonto are not estimated, as they are already a part of the daily ICU expenses and should be coverable by the budget allocated for that.

Desirability

The final design needs to be desirable most importantly by the user group, the nurses and by the hospital management, by easy implementation and contributing to lower environmental impact. In the case of the nurses, the desirability was evaluated in a User Evaluation and the development was done in close collaboration with them. Involving them on several phases of the project helped greatly in shaping the results to their needs. The evaluation session showed that the design helps them in performing the new procedures, does not increase their workload and they expressed that they would like to have the design implemented on the ICU. The solution also needs to be desirable by the Green Team and the Chief Sustainability Officer, since they have a lot of influence on the future of the project. Both of them were involved in different parts of the project and were involved in the selection of directions, therefore the final design reflects their preferences as well. As stated earlier, the proposed solution would bring considerable C02 reduction, and economic value as well. The implementation would not require complicated changes in layout or equipment. The necessary bins for the waste storage room are already purchased.

Viability

The design does not aim for making profit, but its purpose is solely to contribute to the sustainability goals of the hospital. They made commitments towards ambitious goals by joining the Green Deal Sustainable Care, and the outcomes of this project can contribute to move closer to these targets. The project does require an investment in the tools in the beginning, but the reduction in waste disposal costs each year outweighs the investments in the beginning already from the first year (see cost estimation in Appendix R). The design can continue to be used in the long term, because infectious waste will persist , while the Pharmafilter system is also going to be used in the future. The pharmaceutical companies are unlikely to eliminate the plastic packaging, due to the advantages it gives, but more will be obligated to use recyclable plastic types, so the design can be even extended. If the ICU changes to new type of dialysis fluids, their recyclability needs to be reevaluated obviously. Besides, if new type of carts are going to be used in the ICU, new connection types might be needed for the collection basket. All the proposed solutions comply with the regulations presented at Chapter 7.34, and align with the known future regulation changes and the improvements of waste management which will be implemented in the ICU.

6.2 Conclusions

The project has started with the ambitious aim to find solutions for recycling medical waste, precisely waste from the Intensive Care Unit. Through a comprehensive analysis of the waste composition, an comprehensive overview of the system was achieved. I was able to identify several key findings, which were used for the development of six proposals to a way forward.

Eventually, the final design is made up from two separate interventions, which only partially gives solution to recycling materials, and on the other hand, improves the situation of infectious waste treatment. Both solutions have the potential to decrease the significant environmental impact associated with hospital waste disposal, and valuable materials can be kept in use instead of destroying them through incineration.

The final solutions show promising scenarios for the ICU to move towards circular waste management and the main users, the nurses gave very positive reactions to the tools designed for them. Nevertheless, further pilots and possibly adaptations are needed before the actual implementation.

Apart from the final directions, there are still several opportunities from the intervention proposals that the ICU can continue with right now and can reach 33 % recycling rates in the near future.

Lastly, the project also showed that it takes small solutions at the right place to successfully implement recycling in a hospital environment. It might be not possible to start waste separation and recycling as we are used to it at home, but by understanding the steps a certain collection would require, the nurses can be equipped with the right aids to make it an integrated part of their job, without placing additional pressure on them.

Most importantly, it became clear that despite of the difficulties, there are opportunities to improve the medical waste situation and during the course of the project is has been proven that there are multiple possibilities to start with right now.

6.3 Recommendations

6.3.1 Recommendations for development

Recommendations derived from the User evaluation and the Pilot can be read at the end of those chapters. In this chapter, recommendations are given connected to the setup of the final design and future possibilities.

Adaptation to A-B unit and C

Most of the observation and testing was done in the C and D unit of the ICU. Since the location of the waste storage room and other factors are different in the A and B ward, the process might need some adaptation. For A-B unit, the packages are brought from their own storage room, opened on the ward and they need to walk with the cardboard and the plastic packaging to the waste storage room.
In this case, they collection of new fluid and waste disposal does not happen at the same place. Similarly, on the Cardiac Monitoring Intensive Care on the 6th floor, it needs to be tested whether all solutions can work there the same way as on the 4th floor.

Extend for dialysis center

The design can be extended for the dialysis centre in the hospital, where patients receive dialysis treatment. In this part, the patients do not stay on a ward, but come to the hospital only for their treatment 2-3 times a week. The solutions likely need to be adapted to the process different from the dialysis in the ICU, but it would be a good opportunity to scale up the collection of the waste stream in the hospital.

Closed loop of 3D printed parts

The 3D printed parts used for the basket can be potentially made from recycled plastic from hospitals. There is at least one project at TU Delft focusing on 3D printing from recycled medical plastic, which is looking for opportunities to use the filament for hospital equipment and create a closed loop. It might be even a possibility to use the collected and recycled PP for 3D printing its own collection box parts.

Ensuring long-term commitment

Even with enthusiastic nurses and aided processes, the motivation can lower in the long term. It was explored in the literature research (Recomed, 2019) and also confirmed during the pilot day, that appointing a few key individuals from the staff who spread the word , increase engagement and ensure that everything goes well can help in the success of the new procedures. Next to that, reporting back on collected amounts and impacts helps to show the nurses that their effort is paying off.

Setting up the collection

A difficulty during setting up the dialysis bag collection is that a large number of nurses work at the ICU and the information need to reach everyone. It was mentioned by nurses that a personal introduction would be beneficial for each shift for a while, so everyone is adequately involved and they can ask questions. However, it also needs to be done in a way, that they remember it even if they only have a dialysis patient weeks after the new procedure is introduced. The materials on the screens and info boards can help with that as well as the boxes being on the carts. It is hard to miss it when they use them.

Visible through the whole chain

Currently, the bag type used for the collection in the waste room is a transparent one. The bag itself can't be differentiated from the bags of the foils, and the content looks similar. To ensure that the bags are not mixed when they are stored in the waste collection site, the logistics could label the bags upon closing them or choose transparent but coloured bags for differentiation. As later even more waste streams can occur, this will have more necessity as well.

Confirmation by Prezero

Prezero has already officially confirmed the recycling of the dialysis outer packaging, but not the fluid bags. The ICU needs to get into an agreement with Prezero about taking the materials. Based on latest discussion with Prezero, despite of the pharmaceutical company's confirmation that the fluid is harmless, they are concerned about a safety sheet associated with the dialysis solution (Appendix Q). The safety sheet states that when the fluid gets in contact with the eye or skin, it should be rinsed for certain amount of time. This safety instruction makes Prezero think that it can be dangerous to their employees during handling of the waste. However, the fluid bags are emptied and only a couple of drops stays on the surface of the material. Furthermore, it was found that even the safety sheet of hand soap or simple Isotonic solution of sodium chloride (water with 0.9% salt) has the same instructions.

If they refuse to take the bags for this reason, it just shows how inflexible the current system is towards creating possibilities for sustainable efforts. Furthermore, the safety regulations should be re-evaluated and adapted to actual hazardous level.

When Prezero is refusing to take the dialysis bags, the ICU should consider collaborating with external partners, such as directly with plastic manufacturers. When collaboration is set up between more hospitals, the convincing power can increase due to more material of the same type. There are already examples for aims to recycle certain infusion bags, for example, NNRD is also looking into possibilities. This project has proved that it is possible on the side of the hospital to perform the collection of a large amount of valuable plastic, and it can be used for convincing recyclers.

Alternatively, the bags should be rinsed with water before collection, which would be enough to render them safe according to Prezero. This would require one more step from the nurses.

Items on the Tonto

The items chosen for the final design of the Tonto sticker were based on accumulated knowledge from nurses and the waste guide but should be certainly confirmed by experts in the topic from Pharmafilter and modified when needed.

Accessibility of Tonto room

It was observed that in some Tonto rooms, the way to the machine is blocked by some objects. This of course can discourage the staff to use them, because they need to remove or move the object first to access the Tonto. Despite the limited space on the ICU, it is recommended to store these objects on a different location.

6.3.2 Recommendations for the remaining 3 interventions proposals

Three intervention proposals were not chosen for further development during the project, but if the ICU decides to implement them, the following can be considered:

Plastic bottles -> Nutrition bottles

The proposed collection of plastic bottles can be altered to the sole collection of nutrition bottles. It is easier to do correctly, and it would also save the trouble of covering or taking off the label of the ethanol bottles and it would provide a reliable and monomaterial waste stream which is more valuable than mixed plastic waste. During the measurements, it turned out that these are the most omnipresent of the bottles and also the heaviest. On average, 3 bottles are produced per patient per day and almost every patient needs them. Calculating from that, it is already 1700 kg per year only from the nutrition bottles, which makes earlier calculations inaccurate. The nutrition bottles are a clean and safe waste stream, which is easy to recognize and differentiate. Irrelevant of the type, all of them have alight purple color cap, which could be also associated with the waste stream, and separate bin for easy connection. When this is set up, it needs to be considered together with the nurses whether they would need a bin in each room or on central locations on the corridors.

Alternatively, at some time in 2023, the new 3-unit bins are going to be also implemented at the ICU common rooms. When the nurses are willing to take the extra step of disposing them there, any plastic bottles can be thrown there without the need of extra arrangements or bins. It needs to be ensured that bottles from isolation patients are not used.

Plastic packaging

Based on the evaluations with nurses, separating only the plastic packaging would be difficult for them and would likely result in mistakes. There are too many types off plastic products or sterile packaging which should not go to that waste stream. With every item, they would need to think before they throw it away. To successfully implement the collection of plastic packaging, likely another locations should be considered. It was suggested to place a collection bin next to the storage space on the ward, but too many nurses don't use it for taking daily equipment. Further ideation sessions with the nurses could result in a solution, which ensures that it remains a clean waste type and also easy procedure.

Diapers

Packaging materials and medication containing products are more easily accepted by the nurses for separate collection than diapers. Diaper separation are perceived unhygienic according to some nurse. Although in theory there is no difference whether they throw it into one bin or another, their opinion needs to be considered. However, it also turned out that with a solution which ensures hygiene and keeps smells out, they would be more open to it.

6.3.3 Further Recommendations

This chapter highlights possible options that were not further developed during this project but could provide potential solutions for the ICU to further realize or create a new project for them.

Glass medicine bottles

Although currently the bottles are not recycled and not considered recyclable due to the fact that they are disposed with the caps attached on them, there is potential in trying to recycle them. They are already collected separately by the nurses in the Glasbak and the Type II glass material is an infinitely recyclable material. By removing the caps and the seal, the glass monomaterial can be disposed in the glasbak in itself. There are existing decapper devices, like to one produced by Laboratory Precision Limited in the UK, which can be used to easily remove these type of aluminum/ plastic flip-off caps without damaging the bottle (Laboratory Precision Limited, 2023)). I recommend purchasing a couple of these devices in the necessary size and train the nurses to remove the caps before disposing the bottles in the glasbak.

Figure 50: Vial Decapper from Laboratory Precision Ltd.

Space management

Limited space was raised as an issue in the implementation of new waste streams many time during the project, especially from logistics. In the long term, the overall waste is not going to grow significantly, only it would be divided to more category. Therefore, space can be restructured in waste storage areas to make space for new waste streams. This would involve probably smaller size of bins for the general waste stream as well.

Textile collection bags for reusable textiles

The dirty washable textiles can be collected in textile bags instead of plastic bags. This way, the textile bags can be washed together with its content and no waste is needed.

Digital watermark

There are examples for pilot projects with a special digital watermark on product packaging, which help waste sorting facilities to accurately sort the packaging by material type. A high-resolution camera can detect and read the watermark while the product is in the sorting line, then move it to the corresponding stream. By scaling up this technology and apply it to healthcare products as well, it would require less sorting on the part of the hospital employees while reaching higher quality recyclates (Pioneering Digital Watermarks | Holy Grail 2.0., n.d.).

6.4 Limitations of the project

Certainly, the timeframe of the project was a limitation, the number and especially the length of the activities were constrained, such as the waste audit and the pilot with the final design. With more time, the data gathered from these could have been more accurate and richer.

A consequence of this was also that during the course of the project, developments were made in the available information on the material of the dialysis fluid bags. The decisions earlier were based on the available information at the time, but later on, in contact with the manufacturer, new details were received. This results in the possibility that next to the Polypropylene, there is another gas barrier layer in the material of the bags, which could compromise the effective recyclability of the material, if it is significant. Since no exact document or accurate data was received about the material composition, this is not confirmed. The document received was about the material Biofine (special version of PP), which is both the outer and the inner packaging material according to earlier information. This document states that the material is recyclable (Appendix Q). It was also confirmed by the recycler. However, it does not mention the presence and type of another layer and the project ended without confirming it. Nevertheless, the recycler is advised to analyse the packaging material and decide on the matter.

Another important limitation can be that since nobody measured the amount of waste at the ICU for long enough to make realistic calculations from that, I could also only made assumptions about yearly amounts based on the available information. These were my own waste audit, the Metabolic report which is based on procurement data and the number of products used per patient per day which is based on the nurses knowledge. This makes the calculated amounts, therefore the environmental impacts uncertain and further calculations should be made through a longer waste audit or detailed procurement data.

6.5 Personal reflection

Undertaking this project has been an enlightening experience. While I knew from the start that the task at hand would be challenging, I underestimated the complexity of the topic. I didn’t anticipate how challenging it would be to navigate the various factors involved. It is especially hard for me, as I tend to get lost in the details. Nonetheless, it was a good opportunity to develop my skills in managing complexity and focusing my efforts in a constructive manner. This is an important skill to have, especially considering the increasingly complex challenges we face in today’s world. I believe that I have made progress in developing this skill, and I will aim to continue to do so in the future.

Due to the many aspects needed to be explored and considered, the research activities were extensive, and a large part of the project focused on that. This required careful planning, which sometimes I struggled to perform well, especially at the outset of the project. As the project progressed, I was able to develop my skills in planning and conducting research sessions. I gained valuable experience from these activities, especially how to prepare for and facilitate research sessions. I have never facilitated a focus group session or a pilot before. I also had to manage time constraints numerous times, as the nurses typically had 30-45 minutes for a session, so I had to ensure all aspects of the research were covered within the given timeframe.

The project also helped me in self-reflection, by learning which aspects of my work I enjoy the most. I realized that I felt the most energised during moments of activities, such as the days I spent at the ICU. Spending time with the user group and being in the context stimulated me and I felt I moved forward more on those days than sometimes in weeks.

However, it was also challenging to perform research activities alone, particularly during tasks such as the waste audit or user evaluation, where I felt the absence of a partner. Before, I always had my teammates or my colleagues to split the tasks and focus on less thing at a time. Now I had to adapt and learn to manage multiple roles including facilitator, notetaker and observer at the same time.

Furthermore, I had limited experience in 3D printing and laser cutting before. However, during the project I had the chance to develop these technical skills as well through the process of experimentation and adaptation.

The project also provided an opportunity for personal growth. Through the course of my work, I have gained technical knowledge about waste reduction and recycling practices. This knowledge, coupled with my heightened awareness about the impact of waste on the environment, has led to a significant change in my behaviour. I have become more mindful about the waste I generate and more vigilant about recycling. I believe this shift in behaviour is an important step towards making impact not only in my professional career, but also my personal life.

As the project progressed, I learned to let go of the expectation that I the whole problem of medical waste can be solved within this half a year, and managed to focus on smaller, more practical solutions where I, as a designer, could make a meaningful contribution.

In the end, it was intriguing to see the openness of the nurses to my proposed solutions, and in moments when they approached me to ask when they will receive more cutter or when can they officially start, I experienced the impact I was able to make.

Overall, with all the ups and downs, I found the experience of working on this topic to be highly rewarding and affirming. The project has reinforced my passion for design for sustainability and has further solidified my commitment to this field. Overall, I am honoured to have had the opportunity to contribute to this important issue, and I am proud of the work that I have accomplished.

Figure 51 : Separating waste during the waste audit

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Part 4

Context research

This part of the report explains the comprehensive research preceding the design phase of the project.

Chapter 7

Context Exploration

A Literature review

This chapter describes the findings of the literature review, exploring the context of the medical waste, egulations and laws around it, the sterilization possibilites of infectious waste, recycling technologies and the sate of the art in medical waste recycling.

7.1 Literature review

This chapter aims to explore the topic of medical waste and current development in medical waste disposal strategies. The outcomes from the literature research is presented and the insights concluded.

the chapter starts with a Background on sustainable initiative in the Netherlands and within the hospital. Then, a stakeholder analysis is conducted to identify all the relevant parties in the project. After this, the research questions are answered.

7.1.1 Approach

First, a literature review was conducted to get familiar with the context and relevant research questions. Relevant materials were received from the client and the supervisory team, which was completed by further research from scientific databases such as Google Scholar and Elsevier Journals, and from governmental websites and hospital documents.

Part of the first two main questions were answered through the literature review.

Q1. What are the challenges and opportunities of the complex environment surrounding the medical waste protocols?

Q2. What are technological barriers in the recycling of the waste specifically produced at the ICU?

In order to answer the main questions, a set of more focused research questions were formulated before the literature review. These are focusing on four main areas.

1. **Regulations and laws**
2. **Sterilization of infectious waste**
3. **Recycling technology**
4. **State of the art in medical waste recycling**

7.1.2 Research questions

RQ1: Who are the main stakeholders involved in handling the waste?

RQ2: Which laws and regulations apply to the hospital waste disposal?

RQ3: What are the different categories of hospital waste by regulation?

RQ4: What do these regulations allow in terms of recovery by recycling?

RQ5: Which recycling technologies exists currently and what is suitable for the medical waste?
RQ6: What are the main plastic types and which ones can be recycled?

RQ7: What is the current state of recycling medical waste in other hospitals?

RQ8: What kind of barriers and opportunities were experienced during these recycling pilots?

RQ9: What kind of methods are suitable for sterilizing infectious waste?

RQ10: What kind of hospital waste management systems exists, and could they be applied at Erasmus MC?

RQ11: What will be the main developments in waste management in the ICU in the coming years that could influence recycling decisions?

RQ12: What are the important market predictions to consider for the coming years?

7.2 Background on sustainable initiatives

There are many initiative the ICU is participating in nationally and on the hospital level. It is important to get familiar with them, as relevant stakeholders can be derived from these parties.

7.2.1 Sustainability initiatives nationally

Green Deal Sustainable Care
The first Dutch Green Deal for the healthcare sector was initiated in 2015 with the goal to make the healthcare industry more sustainable by a joint effort and involved healthcare institutions, producers, suppliers and clients. Since then, a new Green Deal Sustainable Care was induced partially by the Climate Agreement with more and more entries from institutions and partners. The joining members are committed to achieve the ambitious goals to reduce the CO2 emission of healthcare by 49% by 2030, to promote circular practices, reduce the amount of medicine residues in water and to create an environment that promotes health (Duurzame Zorg Voor Gezonde Toekomst | Greendeals, n.d.). The aim on circularity is to become 95% circular by 2050. A knowledge base is being built through research and practice that can help to reduce the environmental impact while maintain the quality of care. Tools can enable and motivate participants.

The Green ICU (De Groene IC)
The green ICU is a partnership among intensive care units within the Netherlands. Together they are working towards realizing the goals of the Green Deal Sustainable Care. The aim is to collect and share knowledge between the different institutions and work on adapting medical guidelines. They provide e-learning materials and tips about waste, reuse of materials and medication (De Groene IC, 2023). The community is constantly growing by new members joining, but currently there are around 35 ICUs already in the program, the Erasmus MC ICU being one of them.

From the project's perspective, the most important thing is that they provide guidelines for reducing the amount of waste and for waste separation.

7.2.2 Sustainability initiatives Erasmus MC

'A Sustainable Erasmus MC' task force
The whole Erasmus Medical Centre strives for moving towards sustainable strategies as part of the Green Deal Sustainable Care and building on the UN Sustainable Development Goals (Sustainability report 2020, 2021). To make the efforts visible and raise awareness, the hospital releases a sustainability report every year. It gives and overview the most important initiatives the hospital has set up and shows the impact

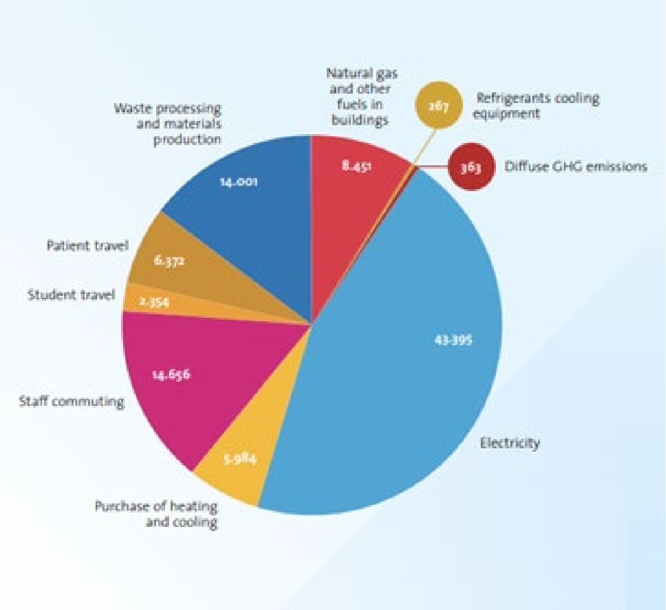

Figure 52: Erasmus MC's Carbon footprint overview (tons of CO2) in 2020 (Sustainability report 2020, 2021)

of the changes.
The 2020 report shows that Waste processing and materials production is the third largest contributor to Erasmus MC's carbon footprint after electricity usage and Staff commuting. This could have influenced the decision to set up the Pharmafilter waste management system, which was a large investment for the hospital.

Circular ICU
Next to the hospital initiatives, the Intensive Care Unit has its own strategy led by hospital Pharmacists Nicole Hunfeld. She believes it can be done faster and the aim is to become the first Circular ICU by 2030 (Marmelstein, 2021). This ambition came from the Covid-times when the piles of waste sitting on the hallways showed how much is actually wasted. The first step has been completed by the collaboration with Metabolic, who helped to measure and analyse the products entering and leaving the department throughout a year. The acquired knowledge helps to find focus points and approach the problem with concrete steps. This project is also part of the series of student projects led by Nicole in collaboration with TU Delft Industrial Design Faculty.

Green team
The help the process of becoming circular, the ICU has its own green Team with enthusiastic members from the nurses, the infection prevention unit and purchasing. Together they are trying to move forward a more sustainable ICU, questioning their current practices and looking into possible changes. They focus on all kinds of circular strategies, but mainly on reduce, reuse and recycle.

There are regular meetings focusing on setting yearly goals, evaluating pilots, and finding responsibles for tasks. They will play an important role in the implementation of waste separation and ensuring it goes according to plans.

7.3 Stakeholder analysis

The project relies on a multidisciplinary cooperation of different stakeholders, as it involves a wide range of parties. The healthcare team of the ICU, such as nurses and care assistance are in direct contact with the waste and interior of the ICU, as well as the patients and the waste management company (Prezero). Apart from them, the Erasmus MC, the healthcare equipment manufacturers, procurement, TU Delft and policy makers also play important roles.

Prezero
Prezero is of the main waste collector companies in the Netherlands. Apart from household waste, their profile also includes industrial waste collection, including healthcare waste. The waste collector for the hospital can change every couple of years, Prezero became the waste manager company by tender in 2021. The company is committed to closing cycles and turning waste back into raw materials. To help the hospital in achieving this goal, there is a Zerowaste project lead who spends one day every week in the hospital, helps to think along in separation and processing and setting up new recycling streams.
The role of Prezero is mainly collecting and transporting the waste from the site to different waste processing companies. If the load is large enough (size of a container), they can directly transport it to the processor. In some cases, they collect smaller amounts of the specific waste stream and store it in their own site until enough is collected from different sources to be economically

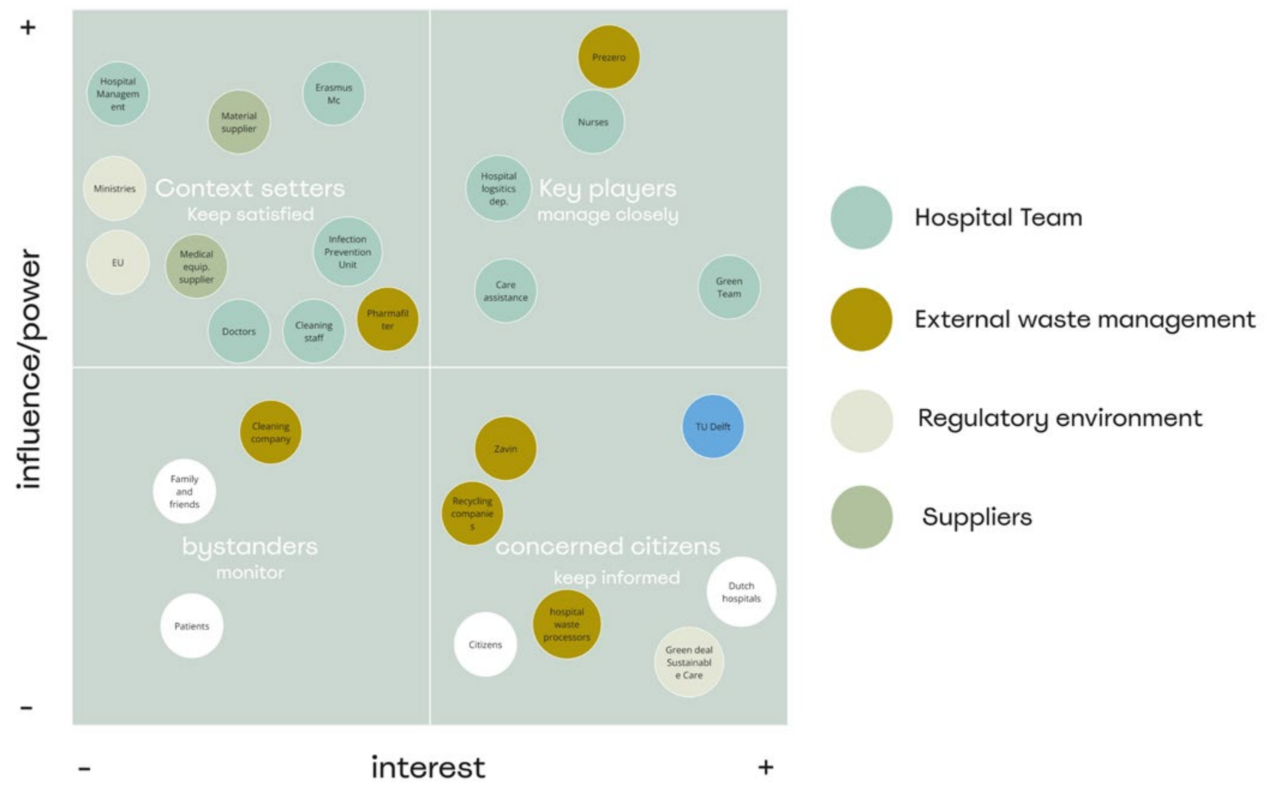

Figure 53 : Stakeholder map

viable to transport it to processing site. Prezero has certain rules about how they need to receive the waste and if it is not in an acceptable condition, they can refuse to take it. They also decide which new waste streams they are able to collect and send to recycling, thus their opinion is essential.

Zavin
The SZA waste requires special handling and only some facility has permission to process it. Zavin is the only certified Specific hospital waste incineration plant in the Netherlands, therefore all SZA waste from medical institutions in the country is transported to their facility in Dordrecht. The waste is incinerated at a temperature higher than conventional incineration to ensure all hazardous materials are destroyed. From the incineration, energy is recovered in the form of steam. Partially it is used for the processes of Zavin, the rest is transported to the neighbouring waste treatment plant, HVC (Zavin, n.d.)).
In times, such as the COVID-19 crisis, the amount of specific hospital waste increases considerably. This can result is shortage of processing capacity at Zavin (Wiva Vaten | Renewi, n.d.). When they are unable to process all the incoming waste, the surplus might need to be transported to another country.

Hospital Logistics
The logistic department in the hospital is responsible for collecting the waste from the departments, transporting it to the hospital waste collection site where all the waste is stored. This happens through the transport elevators and corridors that connect all parts of the building. When the waste collector comes to pick up the waste, they are also responsible for handing it over. When something is changed in the waste collection or new waste streams are introduced, their cooperation is essential.

Infection Prevention
The infection prevention department (UNIP) ensures that the protocols in the hospital are created to minimise the risk of infection. Diseases can potentially spread from infectious patents to other patients or staff members, but also from surfaces and from the air to the patients. At the ICU, it can be especially important to pay extra attention to infections, since the patients are in a critical condition, sensitive to pathogens and some of them carry and can spread serious infectious diseases. There are serious measures in place, and these also affect the possibilities of waste management. The disposed materials can carry the pathogens and need to be handled with care. In many cases, a change is waste disposal or storage needs to be approved by the Infection Prevention team.

Pharmafilter
There is a special waste management system in the hospital, called Pharmafilter which was installed a couple of years ago. It is able to clean the wastewater of the hospital from medicine residues and pathogens and can also sterilize certain solid waste types disposed trough their shredder. There are specialist in the hospital who are in control of the proper use of the system, handle malfunctions and monitor usage. The system is explained further in Chapter 8.

Nurses
There is a team of specialised ICU nurses present 24 hours a day on the ICU ward. They are in charge of the general care of the critically ill patients. Their job is responsible for the largest part of the waste generated on the unit, coming from all the material that is needed to look after the patients. When it comes to waste separation, they will be the ones who can act directly on proposed solutions, therefore they should be closely involved in the project. The role of nurses is further explained in Chapter 10.

Intensivists
Apart from the nurses, Intensivists, a critical care doctor, visit the patients every day. They are specialised medical practitioners, who are trained for the treatment of critically ill patients. They examine the patient and consult with the nurses. Usually there is one or two intensivist per shift who goes through all the patients. They are also producing some part of the waste, mainly from PPE during examination, but they only spend a short time with the patients compared to nurses and don’t come in contact with many types of disposable.

Specialists
Sometimes Specialists from other departments visit the patient at the ICU when their expertise is needed to provide the necessary treatment. Physiotherapists, dietitians, anaesthesiologist are in daily contact with the ICU. similar to Intensivists, they spend a shorter time with the patient, using a limited amount of materials.

Patients
On the ICU, the patients are in critical condition, administered after high-risk surgery, accidents or illness. Typically at least one of their vital body functions are not working properly and need to be taken over or require treatment. Mainly for kidney or liver functions, respiration or heart conditions. Due to this, they require constant monitoring and medication supported by advanced equipment. They are frequently in an unconscious or half-conscious state, sleeping for a large part of the day. They don’t get up from the bed and don’t eat solid food. At the end of their ICU stay, they might practice movements and standing up, but after they are recovered to that state, they are transferred to another unit, where their recovery can continue. Usually patients stay at the ICU for a couple of days or weeks, but it can vary from couple of hours to months. In the case, when a patients stays longer, they might start eating and being active during the day. Therefore ICU patients are typically not disposing waste themselves and don’t need to be aware of disposal rules.

Care assistance
Nurses are supported by Care assistants, who help with filling the storage places with the apparatus and prepare empty rooms for the new patients. They also help with emptying garbage bins and restocking the patient room every day.

Cleaning personnel
The cleaning staff makes sure that the patients are treated in a hygienic environment and provide clean working areas in all parts of the ICU ward. They also empty waste bins from the rooms and corridors frequently.

The Green Team
The Green Team of the ICU is formed by enthusiastic nurses, nurse team leaders, ICU pharmacists and members from other departments such as Procurement and Unit Infection Prevention. They are involved with making the ICU more sustainable, starting pilots and communicating changes to nurses.

Family and friends

The patients in the ICU are regularly or occasionally visited by their family members and close friends in the official visiting hours. During these times, the visitors stay inside the room of the patient and likely consult with the nurses as well. They might dispose some of their own waste in the room. In some cases, they need to wear PPE when they are inside the room.

Cleaning company

The hospital is in contract with a cleaning company who on one hand, supplies the cleaning equipment needed, including the garbage bags, and on the other hand also collects and washes the reusable textiles, such as bedsheets and towels.

Management

The management team ensures the smooth operation of the ICU department. They need to approve of certain changes made in the protocols, such as decisions made by the Green Team or suggestions from nurses, expenses and setting up contracts with external companies such as Prezero. Convincing the management to approve of expenses and substantial changes in waste management is necessary.

7.4 Healthcare waste management

7.4.1 Healthcare waste

Healthcare institutions producing medical, chemical or radiologic waste are legally and morally required to properly dispose of their waste in a way that prevents potential hazards to the environment and public health (Rutala & Weber, 2015). There are several policies from the European Union and national level that regulate the waste management of hospitals.

It is important to differentiate between the waste types produced in a hospital. Many times, the terms medical waste, hospital waste and infectious waste are used interchangeably. The largest category, hospital waste refers to every waste which is produced in the hospital and discarded. A large part of this waste is comparable to general household waste or office waste. Medical waste is that part of the hospital waste which is generated during patient diagnosis, treatment, and immunization. A portion of this medical waste is infectious waste which could potentially transfer diseases, therefore require special handling and treatment. (Rutala & Weber, 2015)

In the Netherlands, this category is called 'Specific Hospital waste', 'Specifiek Ziekenhuisafval' (SZA) At the ICU, all of these waste categories can be found, while the largest part of the waste belongs to the medical waste category. In disposal methods, the medical waste is treated together with the hospital waste. The Specific hospital waste is separated by regulation.

According to the Eural Guide these categories belong to the infectious waste: microbiologic, pathologic, blood, isolation waste and sharps. Among others, in the Netherlands by law SZA is incinerated. Alternative to incineration, sterilization treatments, such as autoclaves are used by hospitals to treat their medical waste. Other non-incineration methods are proposed, for example mechanical/ chemical disinfection, microwave decontamination, steam disinfection and compacting. After sterilization, the waste can be disposed of as residual waste. It is not an option to pathology waste.

7.4.2 Legislation for the categorization and processing of healthcare waste

All type of waste category in the Netherlands, but especially healthcare waste is subject to different regulations and legislations on the World level (WHO), European Union level (Eural guide, ADR) and National level (LAP3 and Environmental Management Act) to ensure the safe and environmentally sound management of healthcare waste. Obligations apply to the separation, collection, storage, and disposal of the waste that is released, so the potential biological hazards are not released into the environment. Hazardous waste handling is even more highly regulated from the point of production until the final processing of waste.

WHO

The WHO categorizes healthcare waste to several categories, such as infectious waste. pathological waste, sharps waste, chemical waste, pharmaceutical waste, cytotoxic waste, radioactive waste and non-hazardous or general waste. There are certain risks associated with the improper management of healthcare waste for example the infection of patients, health worker and the general public or toxic exposure to pharmaceutical products, such as antibiotics and cytotoxic drugs and to substances like dioxins or mercury. Negative environmental effects can also arise from the disposal of untreated healthcare waste or from the treatment of waste with chemical disinfectants and from the wide practice of incineration.
To improve healthcare waste management, when feasible, the safe and environmentally sound treatment or hazardous waste by sterilization should be favoured over medical waste incineration.
According to WHO regulations, infectious waste should be processed as close as possible to the generation place. On-site waste processing would eliminate transportation (World Health Organization: WHO, 2018).

EURAL Guide

The EURAL guide is the European Waste framework directive, and it determines a list of waste categories (Eural, n.d.). All waste materials fall under one of the EURAL codes. The list also indicates which waste is hazardous and the hazardous waste processing needs to comply with the Eural legislations. For human healthcare waste, 9 categories are determined, with specifications about what belongs to each category.
For this project, the important categories

of waste present at the ICU are the following:

Euralcode 180102: non-infectious body parts and organs, including blood bags and blood preserves

This category contains any body part or organs and any bags or collectors in which blood is in a liquid form. At the ICU, the blood-containing bags or collectors are present from this category. Their material is usually plastic or glass.

Euralcode 180103: infectious waste or waste which collection and disposal is subject to special requirements

This category refers to anything that contains bodyfluids and excretions which are not dried or absorbed. Additionally all waste that has been in direct contact with patients with an infectious disease, including plasters, bandages, pads, sharps, excretions (even if dried).

Euralcode 180104: waste which collection and disposal is not subject to special requirements in order to prevent infection.

This is the general waste category which is not considered hazardous, for example dressings, plaster casts, linen, disposable clothing, diapers. Blood and excretions that are absorbed immediately during release in materials specifically applied or applied for this purpose (such as plasters, bandages, pads, incontinence material, gel bags) so that a drip/ leak-free discharge is possible, can be considered as 180104. At the same time, liquid material that is "trapped" at the time of disposal (e.g., blood in closed blood tubes) should not be disposed of as 180104. Since it cannot be guaranteed that the material will remain trapped throughout the disposal chain, this waste must be disposed of as 180103. However, Minimal amounts of drop-shaped contaminants that have remained behind in materials such as infusion bags, pots and tubes (to be regarded as adhering liquids) that can be removed drip/leak-free may treated as 180104.
Waste that has been decontaminated also falls under this category.

Euralcode 180108: cytotoxic and cytostatic medicines

Cytotoxic are agents which are toxic to cells. Cytostatic refers to medicines that inhibit cell growth, frequently used in cancer treatment and treatment of infections.

LAP3

The classification of hazardous waste and the associated processing techniques have been laid down by the government in the National waste management plan 3 (LAP3 (19 Afval Van Gezondheidszorg Bij Mens of Dier, n.d.). The LAP 3 transfers the classification from the EURAL guide and determines the national processing legislations for each category, based on also the EURAL.

The categories of 180102,180103 and 180108 are classified together as Specific Hospital Waste (SZA), but their treatment process is not equivalent, while the general waste 180104 is classified as other waste from human healthcare.

Treatment of relevant human healthcare waste categories defined by LAP3:

Euralcode 180102: non-infectious body parts and organs, including blood bags and blood preserves:
Requires specific incineration at a specifically licensed incineration plant and cannot be decontaminated.

Euralcode 180108: cytotoxic and cytostatic medicines
Requires specific incineration at a specifically licensed incineration plant and cannot be decontaminated.

Euralcode 180103: infectious waste or waste which collection and disposal is subject to special requirements

Requires specific incineration, but alternatively may be decontaminated according to Decontamination Directive. In that case, it must remain separate and recognizable. The decontamination is a choice for the disposer and not an obligation. If a disposer does not wish to decontaminate the waste with a risk of infection (Eural codes 180103) the waste must be transported to a specifically licensed incineration plant or to a licensed decontamination plant.

This means that the regulation allows higher such as recycling, after sufficient decontamination.

Euralcode 180104: waste which collection and disposal is not subject to special requirements in order to prevent infection.

This category is considered to contain no risk and may be transported to an incinerator, but higher-quality forms of processing, such as recycling are also permitted. Any aesthetic aspects (such as material with dried blood) that may be associated with this waste do not play a policy role.

Environmental Management Act

Waste separation is also regulated based on the Environmental Management Act (Wet milieubeheer) (Erasmus MC,2014). For waste flow, the national environmental policy states that when generated separately, they should not be mixed with each other, meaning that separation at source should be stressed, when possible. Additionally, it also lays down the waste streams that must be kept and disposed of separately, which are the following:

- Specific hospital waste (SZA)
- Paper and Cardboard
- Hazardous waste
- Glass
- Other industrial waste (Residual waste)
- Metal
- Debris / Bulky waste
- Waste Oil
- VGF / Swill
- Wood

Hazardous and non- hazardous waste must be collected separately from each other at all times. Besides, the separated and the unseparated waste must be removed regularly by an authorised waste collector. The collector needs to keep all segregated waste separate during transport and offer it separately to the specific waste processor. These processors need to treat the waste according to its category and hazardous level. The Specific Hospital waste needs to be incinerated In the Hospital Waste Processing Installation Netherlands (ZAVIN) in Dordrecht. The optimal processing (e.g. sorting) differs per waste type, but it means that the highest possible processing (e.g. recycling or incineration with energy recovery) of the waste can always be achieved.

Requirements are also set for the manner of storage and packaging of the waste and Erasmus MC is responsible for complying with these .

ADR

The European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) defines regulations for the transportation of hazardous waste categories.
Medical or clinical wase containing Infectious substances are considered hazardous waste and fall under classification Class 6 Toxic and Infectious substances, Biohazardous substances. The SZA waste belongs to this category. For transportation, they need to be labelled under UN 3291 certification (United Nations, 2016). The SZA waste must be always transported in a box with certification, which can be closed permanently. The certified WIVA barrels are used in the Netherlands. The box needs to be destroyed together with its' content.
This is important for the safe working environment for employees who come into contact with this waste stream.

Figure 54: certified label for SZA waste

Conclusions

The legislations have shown which part of the medical waste is classified in which category and what are the required treatments by law. This will be important when the waste composition is explored and decisions need to be made about which part of it can be recycled.
Figure 55 explains summarizes the maina categories and options in a decisions tree. It can be seen that items from the general waste stream can be recycled without barriers in regulations and even the infectious waste is recyclable if it is sterilized first. However, it needs to remain separate and recognisable during collection, transportation and disposal. This shows prospects for considering sterilization options for recycling infectious waste.

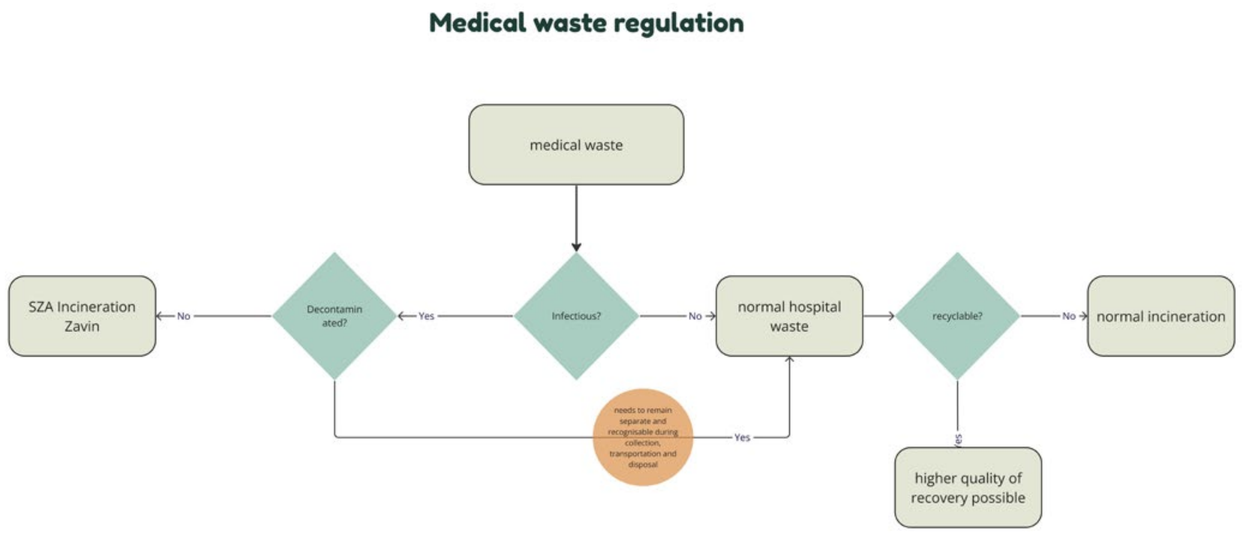

Figure 55: Flow diagram showing the waste categories and their disposal methods.

7.4.3 Sterilization and disinfection

In order to consider the recycling of the infectious waste stream, it must be first decontaminated to be treated as municipal waste, as it was explored in the previous chapter. This is a necessary safety procedure, which must be performed before the waste is handed over to processors. However, even in the case of waste types which don't belong into the infectious waste category but end up in the general residual waste stream of the hospital, disinfection is still required before the recycling process for the acceptance by the waste contractor and waste processing companies. The fact, that it comes from a hospital and was potentially in contact with patients and contains some dried blood or fluids worries the external companies. Their concern is mainly for the workers getting in contact with these products in the waste processing and recycling facilities (see Chapter 9.3).

If the hospital would like to recycle these valuable materials from the general waste stream, they should consider implementing a sterilization process that would ensure the waste is contamination-free and would convince the recycling facilities to accept the waste stream.

Disinfection and sterilization mean different levels of treatment. In sterilization, all forms of microbial life are eliminated through physical or chemical treatments including heat, ozone, radiation or plasma (Sterilization, Disinfection, and Decontamination | Office of Lab Safety | the George Washington University, n.d.). Meanwhile, disinfection refers to the process that destroys most of the viable microorganisms, reducing the level of contamination by either low-temperate steam, dry heat or chemicals.(Dockery, 2012). So, sterilization is preferred over disinfection, but the two terms are frequently used interchangeably.

The most widespread sterilization methods are utilizing heat or steam, and if the products can tolerate moisture, steam is recommended. When heat treatment is not an option, chemical and UV sterilizations are required. The methods are discussed below:

Autoclaving

Autoclaving or steam sterilization is a method for killing harmful bacteria, viruses, or fungi spores on equipment for medical or scientific use. In the Autoclave, high pressure is applied together with high temperature (121°C) for 15-20 minutes, creating an environment not suitable for microbial survival. The process happens is a sealed chamber, in which vacuum is created and air is replaced with steam. The main advantage of this method is that it is economical and requires a short procedure time. Furthermore, the technology is suitable to disinfect hollow instruments or narrow parts which could be missed with other methods. However, only certain types of plastics which can withstand the heat or stainless-steel instruments can be used with this process. For example, devices made of polyethylene, polyurethane and polystyrene cannot be autoclaved, while for polypropylene, it can be used well and moderately for Polycarbonate. (Dockery, 2012). Another disadvantage is that it needs water for the steam process, which is discarded each time after use.

Microwave sterilization
Similar to autoclaving, microwave sterilization also uses heat, but in a dry form. For products which cannot stand moisture, this is a good option. In the case of sterilizing the waste products, it is less important, since these are not sterilized to be used afterwards in medical processes, only to render them harmless. However, it proved to be effective to inactivate organisms within 5 minutes of exposure. Other dry-heat sterilizations are also available such as hot air oven, but a disadvantage of those methods is the slow rate of heat penetration, therefore time-intensive procedure. Similar to autoclaving, some plastic types are not compatible with dry-heat sterilization due to degradation (Dockery, 2012).

UV irradiation
Temperature sensitive items cannot be sterilized with steam or dry-heat sterilization methods. In these cases, exposure to certain wavelengths (Ultraviolet) of radiation can successfully eliminate microorganisms. The UV light deteriorates the DNA of the microorganisms, eliminating their capacity to reproduce. It is important to consider that the UV radiation has weak penetrating power, because many substances absorb the rays. This makes this application limited and recommended to use for small, simple objects, such as shredded material or use some kind of pre-treatment to remove particles from surface (Hariganesh et al., 2020).

Gamma irradiation
Similarly to UV sterilization, Gamma irradiation can be also used effectively. It is a high frequency ionizing radiation method, where the materials are exposed to gamma rays, most commonly Cobalt-60. The penetrating power is much greater than for UV rays.
It can potentially affect both physical and chemical properties of some polymers, so the duration of exposure should be limited. Nevertheless, it can be used for most type of common plastic, but again the gamma rays are a radiation hazard for the human body, so extreme safety measures are needed, which can be provided at an industrial level better than in the hospital (Hariganesh et al., 2020).

Ethylene Oxide (EtO)
For products which are both sensitive to heat and radiation, Ethylene Oxid gas is typically used. This is the case for many plastic types; therefore single-use medical devices are usually sterilized by EtO. All type of plastic can be treated with this technique. Similar to liquid chemicals, Ethylene oxide sterilization is also a potentially dangerous process and requires even more strict requirements. Therefore, it is mainly used and recommended for large -scale sterilizations at an industrial level (Hariganesh et al., 2020).

Liquid Chemical sterilization
Another chemical sterilization technique is using liquid solutions. The chemical agents used are hazardous since strong chemicals are needed to destroy microbial life (Warburton, 2012). Healthcare staff needs to be trained and be cautious in the process of chemical sterilization. Moreover, this method has the most negative environmental effect due to the chemical solutions. If possible, it should be avoided based on the mentioned reasons.

Conclusions

All sterilization methods have their own advantages and disadvantages, and it is very important to consider the type of material and object that needs to be sterilized. Considering the waste composition at the ICU, autoclaving seems a possible options to pre-treat certain waste types, such as metal instruments and polypropylene products, which would be suitable for recycling if their safety is ensured. However, most of the waste is composed of single use disposables made of plastic. For these, heat-treatments are not a good option, because it can cause mechanical degradation. Although it is different from sterilization during use, because it is no problem if the plastic deforms or melts to a certain level, but if the mechanical strength is affected, it can reduce the potential for recycling as well. Meanwhile UV-irradiations would not provide suitable penetration levels unless materials are pre-shredded. For in-house sterilization, chemical options would remain, but their negative environmental effect needs to be considered.

Another option would be transporting the waste to a sterilization facility, where gamma-irradiation is available and from there, it could be delivered to the waste processing facilities categorized as municipal waste.

For all of these options, some separation procedure would be needed to only sterilize the recyclable waste types. Furthermore, it would require investment in the technology and space on the hospital to perform the sterilization. Labour force would also be needed to perform the sterilization, which is a known barrier for logistics.

However, according to the Unit Infection Prevention, none of the currently available methods are reliable enough to implement in Erasmus MC.

It can be perhaps, because their viewpoint is centralized to medical devices sterilizations prior to usage or when considering reuse, which indeed requires very strict considerations for patient safety. However, in case of waste sterilization in advance to recycling, there might be no need for such strict control, since it will be in a different contact with people and in the end, all of these methods are certified and reliable if used properly.

7.4.4 On-site waste management systems

A possible solution for the ICU waste management would be an on-site treatment method which is able to sterilize the waste in a way that the materials in the end can be recovered. This way, the transportation and external waste contractors could be avoided, potentially reducing costs for the hospital. The technology needs to render the waste similar to household waste. There are existing commercially available systems which aim to provide new solutions for healthcare waste management as a whole. Their aim is to reduce emissions and make a safe and easy processing at the same time directly in the hospital. It is interesting to examine these solutions and compare it to the Pharmafilter system, then explore whether these could be potentially implemented in Erasmus MC. A set of these systems were explored, which can be seen in Appendix B.
Here, only the conclusions are given.

Conclusions

Most of the solutions focus on turning infectious waste into normal household waste and reducing its volume and weight by shredding and drying it. This way, special waste transportation and incineration is no longer necessary. Although the environmental impact might decrease with the transportation of a lower volume stream and avoiding high-temperature incineration, these do not deal with the closing the loop, the end of life still remains the same. It is possibly more important for countries, where incineration is not the primal waste treatment method, so by sterilizing the waste, it can be safely landfilled. However, in the case of Erasmus MC, the sterilized waste is just as well incinerated.

Most methods combine a type of sterilization method with shredding, making the final mix of materials difficult to separate due to the small size of the pieces.

This is exactly why the current output of the Pharmafilter cannot be used for recycling, because it is claimed to be too difficult to separate. Therefore the explored solutions would only provide additional advantage if they can separate the materials to recyclable streams.

The two systems which seem to be able to separate waste are the Ecosteryl and Curo. Still, in these two cases the exact separate categories are indistinct, and their recyclability is questionable. Additionally, they are very complex and require large installations on site. Next to the existing Pharmafilter system, finding place for them in the already limited space would be difficult. The replacement of the Pharmafilter system is not realistic or recommended after the initial investment in that system and the advantage which it can provide for wastewater management.
Based on the assumed cost of such a system, it would be also not economically viable for the hospital to invest in a second similar solution only focusing on solid waste.

Based on these conclusions and the conclusions of the previous chapter, the sterilization of infectious waste is eliminated as an option for the scope of this project and as a result, infectious waste recycling as well.

Recommendation

However, a separate purchase of the Ecosteryl sorting machine could be explored, which could be used in combination with the solid waste output of the Pharmafilter. The conditions needed for this machine to separate the Pharmafilter solid fraction can be investigated, and the solid waste could be adapted to fit the requirements, such as larges size or completely dry stream.

7.5 Current state of recycling of medical waste

Currently, only limited data is available about the recycling of medical waste.
A limiting factor in the recycling procedure is the difficulty in sorting and the risk of potential infections.
Ethical and social concerns are considered serious limitations. There is a potential health risk associated with being involved in the recycling process as a worker.

Several types of single-use plastic are used in healthcare and their correct sorting at the source based on the type of plastic and their recyclability is a challenge. The healthcare workers lack proper awareness and knowledge in this area. (Joseph et al., 2021)

Medical plastic should be sorted based on their easy of recyclability and easy recyclables should be prioritized.
Colouring of medical plastics lowers the efficiency of recycling (Joseph et al., 2021)
The few studies focusing on recyclability of medical waste investigated the proportion of recyclables in the general waste and the different material types.

In a study from 2009 in an Australian hospital, the general waste of the ICU was measured and separated for a week (the infectious waste was not included). The results showed that 60% of the waste was potentially recyclable, non-infectious material. From these recyclables, 35% was carboard, 14% was paper and 47% was plastic waste, the rest being unbroken glass (2%) and a small amount of aluminium (1%). The plastics were further separated, where PVS represented the largest category, almost half of the plastic and polyethylene, polypropylene and their copolymers the other half.
The non-recyclables were mainly gloves and a large amount of fluid. It was noted, that 7% of the waste from the infectious bin was non-infectious recyclable, mainly plastics.(McGain et al., 2009)

Another study analysed the recycling potential of plastic waste in hospitals and from non-infectious patient room waste proposed the separate collection of IV bags, their overpouch, the packaging of sharps and the irrigation bottle. It suggests making a distinction between products that were used by patients and product which were not, thus considered non-infectious

PVC is widely used in Australian hospitals, while in the Netherlands, it represents a small part of the medical plastics, likely due to the awareness towards the harmfulness of PVC.
In this study, the paper and carboard was not separated from the rest, which is already done in the ICU of Erasmus MC, indicating that the potential recyclables would be less, only 40% of the general waste, if paper and carboard is no longer included in that.

Different plastic types are not a barrier for Erasmus Mc, since the type of plastics can be separated later during processing, only soft and hard plastic has to be separated.

Since at the ICU the patients are usually unconscious or have very limited mobility, it is not the most relevant to look at wether the product was used by the patient or not. (but if it was in contact with the patient)

Barriers
Despite the potential recyclable materials, there were barriers identified towards recycling, including lack of data, financial concerns, infection control concerns, resistance towards changes, lack of interest and difficulties in separating plastic types (McGain et al., 2009). Another study also mentioned the overly broad classification of medical waste and therefore legal barriers for recycling (Lee et al., 2002).

Opportunities
Factors that help the implementation of recycling include committed staff and high doctor and nurse to patient ratio, easily accessible separation bins, correct colouring and labelling of bins, high mass of waste per patient and few nursing movement between patients (McGain et al., 2009), (Lee et al., 2002).

Recycling medical waste around the globe

Recycling PVC in Australia and New Zealand
PVC is the most widespread plastic in healthcare, because of its great material properties. Many life-saving disposable devices are made of PVC, such as oxygen masks, tubing, IV and dialysis bags. Many times, these are used on non-infectious patients, therefore it can be already sent to recycling.

Last year VinylPlus® Med already started a pilot project in Belgium recycling non-infectious medical PVC devices. The waste is transported to a plastic recycling company by the waste collection company (VinylPlus, 2021).

RecoMed is another PVC medical device recycling company, specialising in PVC masks and tubesfrom clinical sources. They provide help through the whole implementation of the collection from sourcing bins, through training to collection. The collected PVC still needs to be hand-sorted in the reprocessing centre to identify and remove any non-PVC material. The PVC is processed by shredding and melting it and turning the material into new products, such as vinyl flooring, that can be again recycled. The collected items must be not only non-infectious, but clean and removed of any starps or other parts. (RecoMed - Collection and Recycling for Medical PVC Products, 2022)

There are examples of recycling **nonwoven disposable PP gowns,** even if they are contaminated. In a study by Sofia et al., n.d. wo main mechanical recycling solution was found for these products. The first recycling method by a company called Starlinger, uses a conventional technology, the steps include shredding the material, then extruding it before it gets pelletized. Another company, the British Thermal Compaction Group, produces an oven- like equipment, in which the material is placed and melted. As the result, PP blocks around 12 to 20 kgs are produced. Although the economic value of these block is lower that pellets, it is easy to transport, and the process is simple. Since both methods use a high temperature, the material is sterilized. In order to make this recycling possible, that gowns need to be collected separately from other waste types.

Face masks were recycled as construction material with Covid-19 the urge to act in the problem of the enormous number of face masks increased.
Although the used masks were incorporated into a building material indeed, it was mixed to concrete in a 0,5 - 2% ratio. The further recovery from the concrete is not possible therefore the loop cannot be closed again. (Idrees et al., 2022).

Another items found in examples of recycling medical waste were single use metal instruments. aluminium foil and towels.

Conclusions

Very limited examples were found on successful recycling streams of medical waste and even less on ICUs. The most succesful examples, PVX reycling is not a very good option for Erasmus MC, as PVC is limited. However, other types of plastics can be similarly recycled instead of PVC.
It is important to note that high doctor and nurse to patient ratio was mentioned as an opportunity for successful recycling which is the case in the ICU, therefore it gives a good opportunity.

The most important barriers and opportunities are listed and will be considered in further research.

Barriers
Infection control
resistance towards change
difficulties in separating plastic types
financial concerns

Opportunities
committed staff
easily accessible separation bins
orrect
colouring and labelling of bins

7.6. Developments in ICU waste

There are certain developments in ICU waste which need to be considered for the decision. These are the results of a research on the market trends and information on planned developments by Prezero or the ICU. Those informations are collected from Prezero expert, F.Ottens during interviews or received from the client.

Disposable Coffee cups
From 2024 the Government introduces a ban on disposable cups and meal packaging (Ministerie van Infrastructuur en Waterstaat, 2022b). The measure aims to target single-use plastic products, however, due to the layer of plastic on coffee cups, these are also included. The cups need to be replaced by reusable alternatives in the hospitality industry and in offices. Although there are discussions about it, probably the only exemption is going to be healthcare institutions, where the patient can keep using the disposable cups, but the staff needs to replace them. It is important to note that the companies are allowed to keep using the disposables, if they ensure that 75-90% of it is recycled through high-quality recycling.(Netherlands Enterprise Agency, 2022)

Aprons
Protective aprons used in the ICU are currently single-use products. There are two types used, a long sleeve version with full protection around a body and

a sleeveless version only protecting the front of the body. The aprons are planned to be replaced in the coming years to reusable, washable ones. This is implemented already in several hospitals as a feasible option. With a 2 year lifetime, the cost of one use I around 0,55 € per use which is comparable to the price of disposable gowns, but the reusable ones are better from an environmental perspective (Sofia et al., n.d.).

Plastic Packaging

During my interview with the Prezero Zero-waste leader, it was clarified that the hospital together with the waste collector company, Prezero is going to introduce plastic packaging collection from next year onwards. This includes thin plastic packages and plastic bottles as well. A separation container with multiple types of waste streams including plastics will be placed all around the hospital. This does not include the patient rooms but focusing on common areas. The collected plastic is going to be recycled. Since this new collection is aimed for mainly the general areas of the hospital, the types of waste from the patient which is accepted in this waste stream should be specified and the collection from the rooms needs to be facilitated.

Food Waste

Together with the implementation of plastic waste collection, food waste is going to be separated as well. According to the plans of Prezero, they will collect and transfer it to a fermentation facility, where it will be decomposed by anaerobic digestion and treated with yeast. Biogas will be produced during the process. In the case of the ICU, food waste is mainly produced by nurses, therefore containers should be placed in kitchen areas to help the collection right at the source. There is almost no food waste produced in the patient rooms, as the patients are in a condition where eating by themselves is not possible. Instead, nutrition drinks are introduced through infusion.

Market predictions

Paper

There is uncertainty in the paper market in the last period. Due to rising costs from high inflation and rising energy prices, numerous factories had to close. The running paper production facilities also limit their waste paper purchasing and try to first use up own waste paper. These caused the demand for waste paper to fall, which has led to the fall in price for the waste paper and carboard (Papier En Karton | Inzamelen En Recyclen | PreZero, n.d.). It is still hard to predict if prices will further fall or stabilize in 2023, but the last period had definitely a negative impact on recycled paper production. Hopefully it will still remain profitable to collect the waste paper and carboard for recycling.

Residual waste

On one hand, there is more capacity for incinerating residual waste, because of decrease in imported waste as the results of the import levy. However, the prices for incineration are increasing due to government policy and the increasing costs for the processing the waste. The incineration tax will be also likely to be adjusted to inflation levels, which will result in further rise of incineration prices (Restafval | Zakelijk Inzamelen En Recyclen | PreZero, n.d.).

PMD (plastic, metal and drinking cartons)

From 2023 January 1st, a change in producer responsibility is going to be introduced, namely the extended producer responsibility (EPR), which means, that companies need to pay for the collection and processing of the packaging they produced. This will hopefully encourage them to take into account the end of life of their product. It applies for plastic, beverage carton and glass packaging. For the disposer of these packaging, it means that no cost can be charged, therefore the collection is free (Plastic En Drankenkartons (Pd) | Inzamelen En Recyclen | PreZero, n.d.).

A deposit system will be introduced for metal cans from April 1, 2023, therefore this waste stream is no longer going to be collected as part of PMD for organizations. In preparation for this system, Prezero already changes PMD to PD from the 1st of January 2023, excluding the metal cans from this waste stream. This means that it will be introduced in Erasmus MC already without metals (Plastic En Drankenkartons (Pd) | Inzamelen En Recyclen | PreZero, n.d.)..

EU plastic strategy

The EU is focused on plastic waste management; therefore their 2030 plan also includes strict regulations for plastic waste. They focus especially on packaging waste, because two thirds of plastic waste currently come from packaging. Currently, by far not all type of plastic is recyclable. By 2030, the producers are compiled to make all plastic packaging from a recyclable type of plastic or a reusable packaging. There are targets in place for plastic recycling rates as well, 50% should be recycled by 2025, while this number should be increased to 55% by 2030. The recycled content of plastic packaging should be also 30% by 2030 (European Commission, 2018). This means, that by 2030, the plastic packaging of products used in the ICU should also be made of recyclable or reusable plastic. This will allow 100% possible recycling rate for the plastic packaging, if they are all collected separately. The regulations, however, does not specify where the plastic recycling rates for each sector, therefore this regulation can be easily overlooked for hospitals, not resulting in direct impact.

These changes are visualised in a timeline and need to be considered in decision making later on.

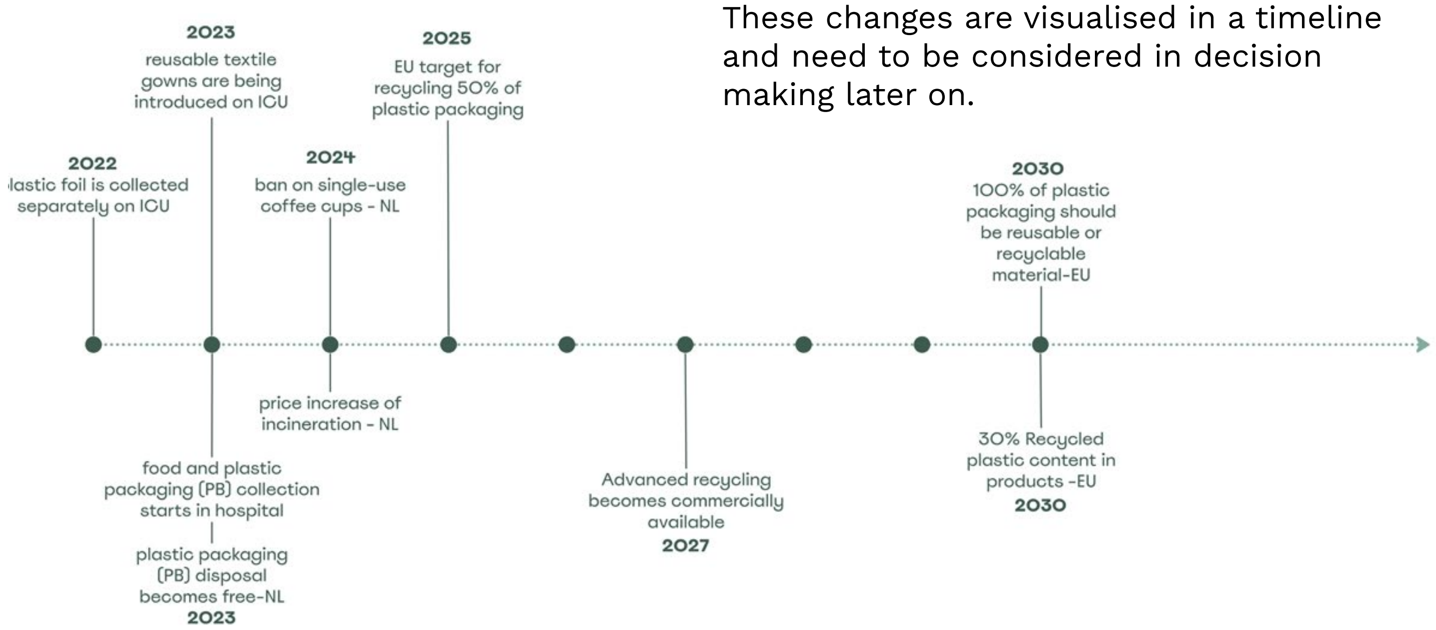

Figure 56: Timeline visualizing the developments in regulations, markets and new protocols in ICU

7.7 Recycling

Recycling is transforming a product or component into its basic materials or substances and reprocessing them into new materials. Embedded energy and value are lost in the process (The Circular Economy Glossary, n.d.).
The goal of recycling is keeping the value of the materials by turning it back to product, so they can replace virgin materials. By avoiding incineration and the production of new raw materials, greenhouse gases, produced toxics and energy is saved.

The best option is always preventing waste from happening, "designing out waste" but if the waste is already there, recycling helps to deal with it. This is the case for disposable healthcare options. Until we found ways to replace them and avoid the waste to be generated, the accumulated waste can be treated better than incineration.

7.7.1 Types of recycling

Single-stream recycling

In the category of Single-stream recycling, all recyclables are collected in one container together, instead of collected as paper, plastics, and glass. This practice is widespread in countries such as the United States. This type of recycling often leads to more contamination and therefore lower efficiency.

Multi-stream recycling

Multi-stream recycling requires more effort from the persons collecting recyclables, since consideration is needed for the different types of categories. It also requires more complex logistics system for the collection and transportation to different facilities. However, this is the preferred method in many countries, when you have the necessary infrastructure, much higher recycling efficiency can be achieved.

7.7. 2 Plastic Recycling

In the last decades, disposable products have replaced reusable medical equipment and with that change, plastic have replaced materials such as steel, glass and ceramics. Similarly to domestic products, the properties of plastics, such as easy of processing, resistance to heat and chemi-cals, transparency, lightweightness and cost effectiveness, have made them suitable to medical equipment and packaging. (Joseph et al., 2021)

Plastic recycling is the most complex and also te most relevant, since a large part of the products on the ICU re made from plastic, therefore it was decided to explore further.

The first step in recycling is the identification of the materials, before the sorting starts.
Even if a specific waste stream is collected separately, it needs sorting before it can be processed. This includes the further sorting of a waste stream by types or sorting out the materials which don't belong in that stream. Usually, the sorting happens by multiple criteria, materials, shape and colour. The sorting can happen manually or in an automated way. Manual sorting is labour intensive and slower, therefore automated systems are increasingly popular. One of the sorting technique uses near infra-red (NIR) which provides identification for plastics and works properly with transparent plastics. For separating PVC from PET, X-ray fluorescence technique is effective. Other techniques like density separation, air sorting, electrostatic sorting are also applied (Joseph et al., 2021)

Recycling techniquies

The collected, sorted and cleaned plastic can be recycled in different routes. There are four common plastic recycling techniques. The smallest loop is the **Primary recycling,** which means that used products are recovered for making similar products with some addition of virgin materials. It can be applied only for single plastic types with minimum contamination, therefore it's application is limited. In the next route, **Secondary recycling,** plastic is recovered by mechanical recycling. After the cleaning and removal of organic and other matter, the material is grinded to reduce its size. If the waste is highly contaminated, it becomes difficult to recycle this way. The mechanical properties are often degrading (Joseph et al., 2021). The recycled material is used in downgraded products. the main challenges are the identification and sorting of the plastics, and it's economic competition with the virgin plastic production. The third category, **tertiary recycling** refers to chemical recycling, which takes a larger loop, converting the plastic into liquids or gases in a molecular level. As a result, the petrochemical components in plastics are recovered, which can be used as feedstock to generate fuels and chemicals. find more source for clearer description. This method has a high tolerance for contaminants and can process mixed plastic waste, on the other hand (Kökkılıç et al., 2022)
Chemical recycling could process contaminated materials since these are subject to high temperatures eliminating microorganisms, this technology is not yet developed at a larger scale.
The final recycling solution, **quaternary recycling** is a waste to energy process which equals to incineration. This is the common method for seriously contaminated waste. It also successfully decomposes toxic and infectious waste types, such as hospital waste. As the end result, the waste volume is reduced to approximately 1% and energy is recovered. However, the process releases highly polluting gases, which can be controlled by additives like ammonia and activate carbon.(Joseph et al., 2021)
Through going downwards in the 4 methods, the quality of the recovered material decreases significantly.

Plastic types recyclability

There are seven main types of plastic differentiated with associated numbers, called Plastic resin identification codes (Figure 59). Each plastic product should have a sign indicating which type of plastic category it belongs to. All of the 6 main types of plastic can be found on the ICU, but not alls of them is easily recyclable.

Figure 59: Plastic resin identification codes

1.PET
Polyethylene terephthalate (PET) is an easily recyclable, very common type of thermoplastic. It is lightweight and strong and typically transparent. Despite being widespread in everyday products, it can be found in the ICU waste only in a small percentage (<1% of plastic waste). This can be partly due to the fact that it can absorb bacteria and odors.

2. HDPE
High-density polyethylene,a rigid and strong plastic type, resistant to moisture and chemicals. Easily recyclable and economically viable to recycle. A large part of the ICU plastic waste (10%) is made of HDPE.

3.PVC
Polyvinyl chloride (PVC) has valuable properties for healthcare products, since it is impermeable to germs and easily disinfected, therefore reduces the risk of infection. However, it also contains dangerous substances which are released throughout its whole lifecycle. Nevertheless, it is difficult, but possible to recycle it, which is better than incineration, but it is advised to avoid altogether. Despite its commodity in healthcare, Erasmus MC recognised the risks and already makes an effort to purchase PVC- free products, therefore less than 5% of plastic products in ICU are made of PVC.

4.LDPE
Many packaging materials are made of Low-density polyethylene (LDPE), because it is soft and flexible. It is possible to recycle it, but as a rather cheap and low-quality type of plastic, not all recycling facility can process it. It is the second most common plastic type in the ICU (15%), therefore has a high importance.

5.PP
Polypropylene is also amongst the most common types of thermoplastic polymers. It is also the largest proportion in the ICU (25%).

6.PS
Polystyrene is mainly used in its foam form in packaging materials on the ICU. It has great insulation properties, therefore used for cooled medicine transport for example. It can also leach harmful toxins, such as styrene, so not advised in close contact with food or medications. It is more difficult to recycle it, but possible.

7.Other
All other type of plastic belongs to the number 7 category, and these are typically hard to recycle or contain harmful components.
At the ICU, 14 types of plastic can be found, so there are many belonging to this category. Among others, PC (polycarbonate), PA (polyamide/nylon) and Nitrile are the most frequent types.

Conclusions

Currently, mechanical recycling is only possible for part of the plastic types and sorting is still not effective. If the plastics remain mixed, it results in a poor quality material with low mechanical properties. Another factors, such as plasticisers and additives used in plastics make it more difficult to recycle, as well as multilayer laminated packaging from multiple type of plastics.

However, chemical recycling is still on a low TRL level (Technolgical readiness) and it is still going to take years for the technology to be developed large-scale.

Currently, mechanical recycling is the best option for recycling plastics and also other types of waste such as paper, metal and glass. With current developments in technology such as near infrared spectroscopy, plastic recycling is easier. However, the recycled materials are not going to be used for the same quality (healthcare) applications, but lower-quality products.

For longer term, chemical recycling is a promising option, because it can deal with multilayer plastics and the possible contamination at the same time. It would not require the separation of plastic types, only separation of plastic from other materials. It would also make it possible to produce raw materials which are suitable for healthcare products.

However, because chemical recycling is one more step towards breakind down the material to components, its environmental effect is also higher than mechanical recycling. When possible, based on current knowledge, mechanical recycling should be used.

From the seven plastic types, Prezero focuses on HDPE, LDPE, PS and PP recycling (Recycled Material With PreZero Polymers, n.d.).

Chapter 8

Erasmus MC waste management

In this chapter the waste management system of the hospital is explained with a focus on the ICU and the different waste streams journeys are explored from the moment of generation until processing.

8.1 Approach

Semi-structured interviews and visits to sites were used to get an understanding of the how the waste is handled in the hospital and after it leaves the hospital, who is involved in the process and what is currently being collected separately and how is it processed. The first site visited was the ground floor of the hospital which is used for the storage and distribution of incoming products and for the collection and internal processing of the waste from the whole hospital. Next to that, the special waste purification site, the Pharmafilter system was explored and the process was followed. The interviews were conducted with the Logistics coordinator, the Safety and Environment Manager, the Prezero Zero waste project leader and the Pharmafilter personnel. (an overview of the conducted interviews can be seen in Appendix G.)

Research questions:

RQ1: What are the logistical challenges inside and outside of the hospital?

RQ2: What kind of waste categories are currently used in the hospital and how can be these utilised for the recycling aims?

RQ3: How does it work and what are the problems and opportunities with the Pharmafilter system?

8.2 Journey of waste

Waste generation

The largest part of the waste on the ICU ward is produced inside the patient rooms. Next to that, there are waste bins in the kitchen and common rooms. The main waste stream in the patient room is the residual waste, but there are small bins on the counter for sharp hazardous waste and medicine glasses. When the patient is categorized as infectious, the nurses bring in a separate bin for infectious waste. Next to that, only paper and carboard is collected separately and recently soft plastics, such as foils and bubble wraps. These only have a large collection bin in the waste storage rooms (milieustation) in the 4th floor, and an additional 4 small bins on the ward of the 6th floor to ease the separation. There are 2 waste storage rooms per floor.
The nurses dispose of the waste in the room or if there is no separation bin (like for papers and foils) they take it directly to the waste storage room on the ward. Paper and carboard and the soft plastics are mainly generated at the opening of large packages, which is either next to the waste storage room or on the corridor. Some waste products are taken to the Pharmafilter room and disposed of there (see chapter 7.2)

Waste collection in the ward

The bins in the rooms are emptied by the nurses assigned to the patients or the cleaning staff and collected in large containers in one of the two waste storage rooms on the wards. The bins in the common rooms are emptied by the cleaning personnel. The waste generation and collection points on the ICU can be seen in Figure 60.

Internal transport

From the waste storage room, most of the waste is taken multiple times a day by the logistic staff. They move the bins through the transportation elevators, which is used for the transportation of goods and patients. It is many times busy, and patients always receive priority over products and waste. This can cause long waiting times. The waste bins are transferred to the waste collection site on the ground floor where they are collected by type and loaded into large trucks.

In the hospital waste collection site

This is the point where all waste from the different parts of the hospital comes together. This logistic space spreads through the whole floor of the main building and is always busy with staff members. The bins are connected to small electric vehicles which helps to move them around the floor to the right place. Some waste types are compressed to decrease their volume before transportation. The different trucks for collecting the waste are located outside for space optimization. There is already a limited space inside for storing the bins and moving them around.

Transportation from the hospital

The waste is transported once there is a truck full of that waste type. The time needed for this varies greatly from a day to a couple of weeks or even months in case of smaller waste streams. Prezero plays a connecting role in the process. They are responsible for the collection and distribution of the waste to specific waste processor companies. They barely process or store anything themselves. There are large differences in the prices the hospital needs to pay to Prezero for transporting each waste category. The prices are determined per weight and an additional cost per each transport (100€ - 300 €). The SZA and sharp waste cost the most per ton (595 €), almost four times as much as the residual waste (158 €). The recyclable materials, such as paper and carboard are the least expensive (38 €), the main cost here is the transportation.

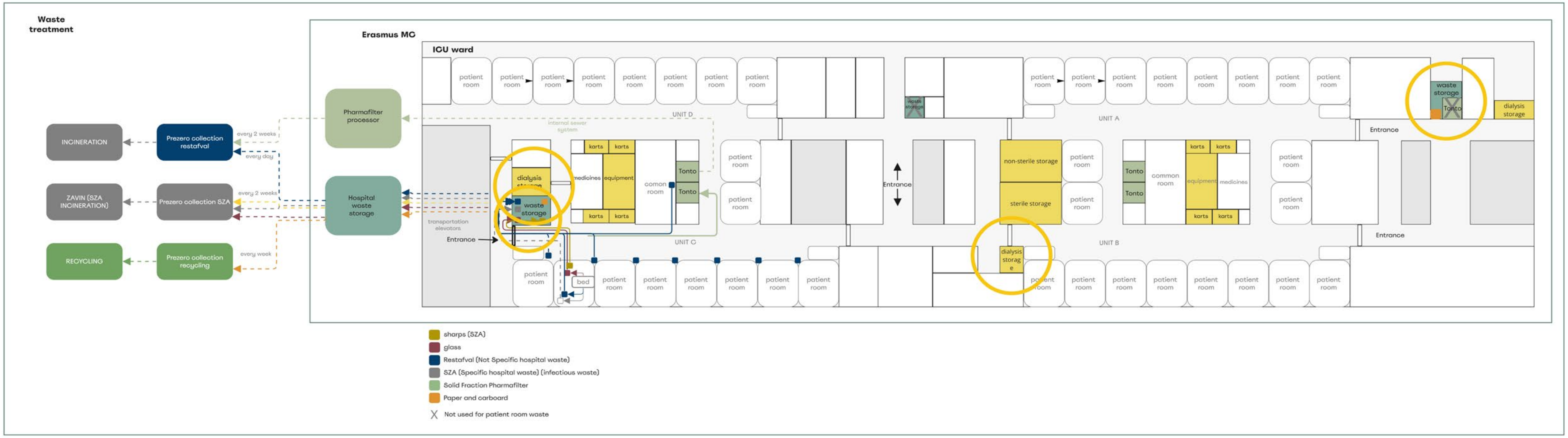

Figure 60: Floorplan of the General ICU with waste generation and collection points and waste routes

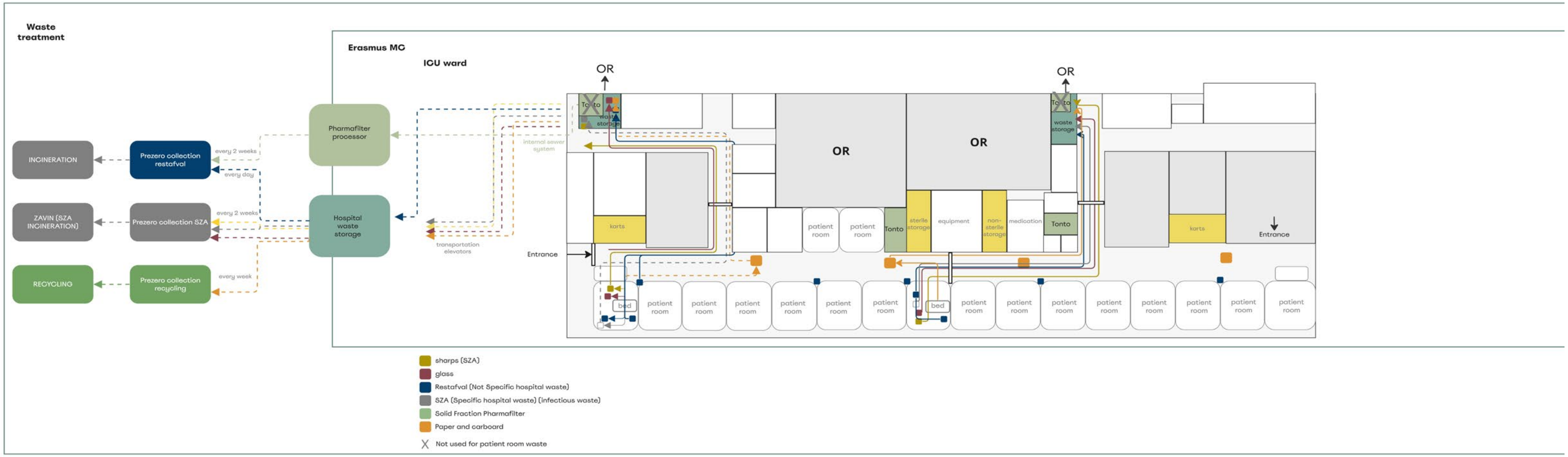

Figure 61: Floorplan of the Cardiac ICU with waste generation and collection points and waste routes

Figure 62: Compressors on the waste collection site

8.3 The Pharmafilter

Erasmus MC have installed a waste management system called Pharmafilter in 2019 (Sustainability report 2020, 2021). The installation is connected to the sewer system of the buildings and cleans hospital wastewater for reuse and in theory converts organic waste materials to energy. The system consists of purification installations on the ground level and the so-called Tonto grinders on many parts of the hospital.
The solid waste can be placed in the Tonto machine, which grinds the waste to pieces small enough to transfer through the pipes of the sewer system. The grinded waste is then mixed with wastewater to transport it to the purification site, where it is filtered and separated to water and solid waste again. It disposes of any harmful substances, such as pathogens and micropollutants, rendering both the water and the waste safe to dispose of and even to reuse (Pharmafilter, 2019). The water's quality in the end of the process is equivalent to drinking water. Due to the fact that it is coming from a hospital, however, permission is declined by authorities to even reuse it as grey water. The hospital needs to dispose it as sewage.
According to the original plans, the organic part of the solid waste is turned into biogas, while the plastics and fibres are cleaned and sent for recycling. Unfortunately, these plans are not realised. The biogas production is not possible because the system was built to an input of organic waste 10 times as much as now flows through the system. The current infrastructure is not suitable for such a small amount. It would require the replacement of a chamber to a

smaller one, which is a large investment. It is unclear how the recycling of plastics and fibres was planned because the final solid waste is a mixed waste of all types of plastic and fibers grinded to almost sawdust sized particles.
The original objective of the hospital was to dispose of the majority of the residual waste through the Tonto grinders.

However, due to the burden on the sewer system and frequent blockages, this plan has been abandoned. The scope of the system waste was limited to the disposal of a small portion of the Specific Hospital waste, such as bedpans. It is good to note, that the Tontos replaced the bedpan washers on the wards. The bedpans used to be reusable and washable ones, but to increase safety they got replace to disposable ones with the introduction of the Pahrmafilter.

With these limitations, the Pharmafilter's main role currently in the solid waste management system is to disinfect a part of the infectious waste, so the hospital can dispose of it as municipal waste, which costs much less than as infectious waste. However, due to the dutch waste management system, incineration is the primary waste treatment for municipal waste, meaning that the waste is still incinerated, only not at a higher temperature used for SZA waste.

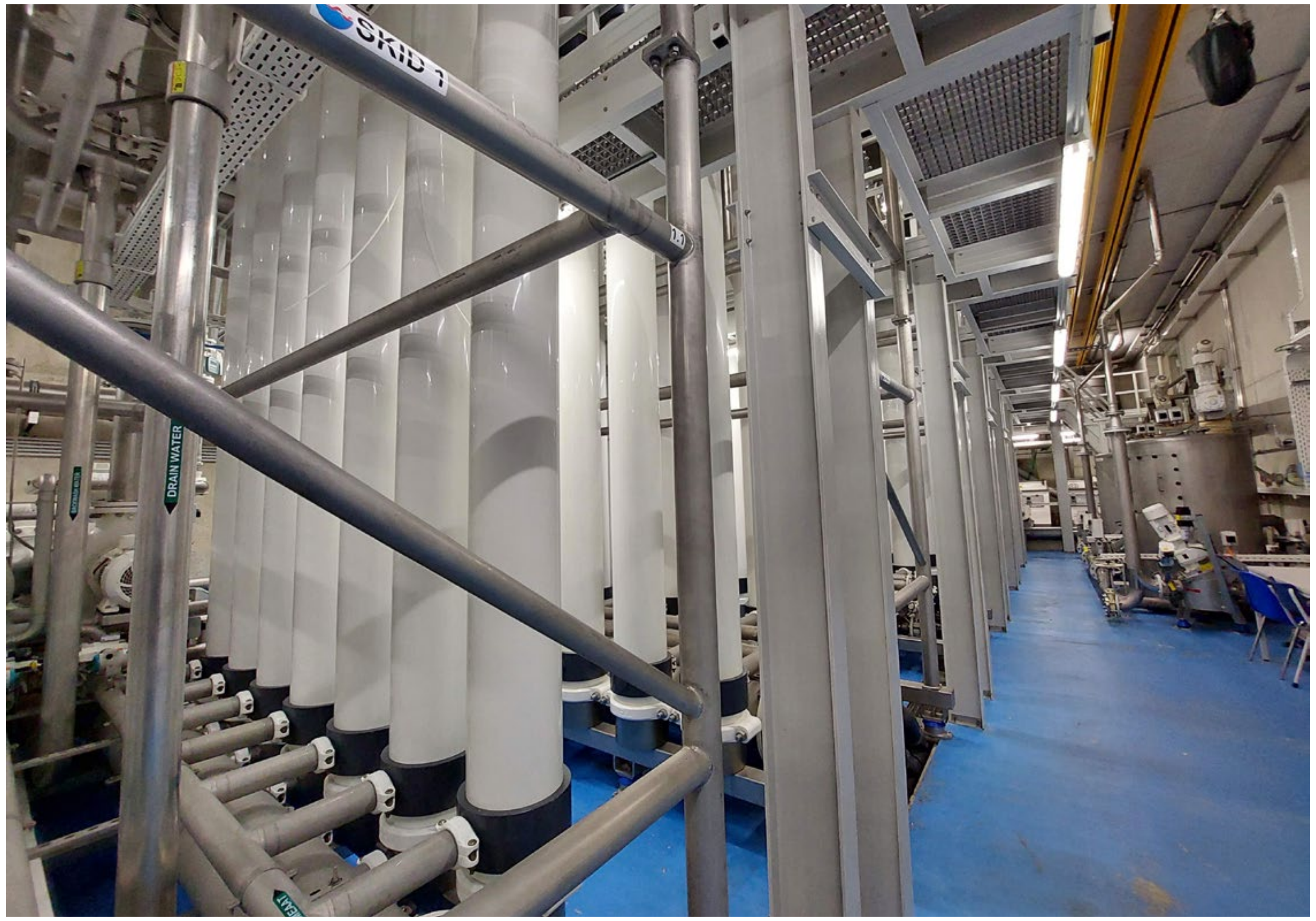

Figure 63: Pharmafilter disinfection site

Figure 64: Solid waste mixed with wastewater before sterilization (left) and after sterilization (right)

The Tonto

The Tonto machines are an important part of the system. In Erasmus MC there is currently 100 Tonto grinders installed all around the hospital, of which 4 is situated on the wards of the 4th floor ICU and 2 on the 6th floor ICU. It is able to grind up any materials except glass, metal, office paper and batteries. Very thin metals and glasses are accepted. The opening of the machine is in an ergonomic height and the user needs to have minimum contact with the machine and the waste, due to the pedal for closing and opening the door (there is no sign on how to use it). It takes a couple of minutes for the machine to grind the waste and it cannot be opened until it finishes. A nice animation is shown on the screen during this process. After each use, the tonto automatically cleans itself from the inside and it performs daily self-cleaning. Each Tonto is connected to a data centre, which records all operation so the number of times it was used can be monitored and notification can be sent in case of a breakdown (Pharmafilter, 2019).

Garbage Bag for Tonto

A special garbage bag was designed and supplied by the company specifically for the tonto machines. It is made from extra strong material to ensure safety, which is a biodegradable plastic, so it would be converted to energy (which does not happen). The size of the bag (40 litre) and “special handles” ensure that nurses don’t need to push the bag into the machine, avoiding further contact with the trash. Despite its smaller size, it was made to be compatible with the 60 litre bins that are used for other waste flows.

Tonto usage

Based on first preliminary information, it was suspected that the nurses don’t use the Tonto as much as they could due to inconveniences experienced with the system. Therefore, the data from the Tontos was analysed to see how much it is actually used. It seems that only the half of the Tontos are actively used. Figure X visualizes the frequency in which each Tonto is used. It can be seen that the 4 Tontos on the general ICU (green lines) are among the top 15 most frequently used ones. This result seems to either contradict with the thought that nurses don’t use it enough or it is not sufficiently used in other department either.

Unfortunately, there is no data about the weight or volume of the waste disposed though the Tonto, only the number of times used. This can lead to misleading information depending on user habits in each department. In some cases, it could be a full bag, while in other times, only one product. However, it is know that the outcome of the solid fraction (the disinfected waste) is 5000-6000 kg every two weeks. From this, it can be roughly estimated, that every two weeks it is around 700 kg from the ICU. That means 18 200 kg per year from the ICU. This calculation contradicts with the data from the Metabolic report, where it was calculated that it was 6580 kg per year in 2019. It might be due to the fact that it was installed in 2019 and after an initial period, they scaled up from 2021.

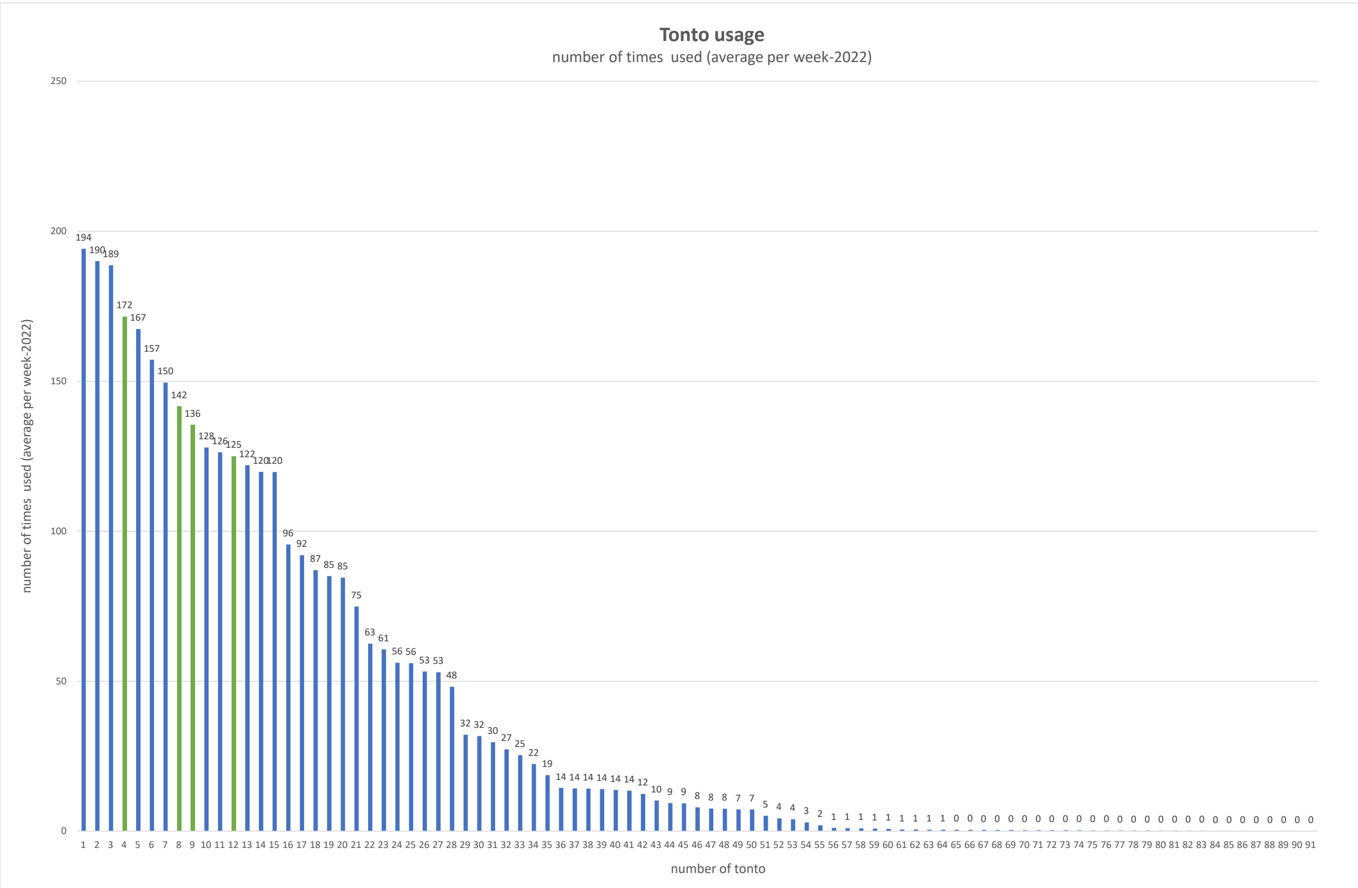

Figure 65: Number of times each Tonto in the hospital is used per week (2022)

Figure 66: Person placing a waste bag in the Tontog grinder

The process of disposing waste through the Tonto.

1. The waste is put in a special bag from the company

2. The door of the tonto is opened by the pedal

3. The bag is placed in the Tonto machine

4. The door is closed by the pedal

5. The tonto grinds the waste to smaller pieces

6. The grinded material is mixed with wastewater and through hospital's internal sewer system it is transported to the purification system in the basement

7. The purification process separates the solid waste from the wastewater

8. The solid waste is further shredded

9. The medicine residues and bacteria are cleaned from the water and the waste

10. Clean wastewater is produced

11. Disinfected solid waste is produced

12. Solid waste is collected and transported to incineration

8.4 Waste streams on the hospital level

Although the ICU produces a lot of waste daily, it is still a relatively small part of the hospital, and the whole waste production. Because the collection and transportation system requires a relatively large amount of waste from the same type, it is important to consider what type of waste is already being collected separately from other departments of the hospital. This was explored during the visit to the hospital waste collections site and in consultation with the waste information guide.

In total, the hospital identifies 25 different types of waste stream. Half of which is hazardous waste, including medicines, chemical waste, infectious waste and radioactive materials.
From the non-hazardous waste, the residual waste represents the largest part of waste collection, but different materials are collected separately for recycling purposes. From each waste stream, different recycling efficiency is achieved. The hospital collects empty and clean, uncontaminated glass containers, which is 100% recyclable, paper and carboard waste, which is 90% recyclable and Styrofoam packaging, which is again 100% recyclable. Confidential papers are also collected separately in a special bin. Next to these materials, computer equipment, electronic devices (white and brown goods), metal and wood are collected and stored in large containers. Bulky waste (unsorted industrial waste) is also collected, containing large waste which are not metal or wood materials.

From this category, 60% is suitable for recycling and reuse. Recently, a program has been started in which hard plastics, soft plastics (plastic folie) and PP (polypropylene) surgical blue wrap from the operation rooms are separated. The wraps are used for sterile materials and don't get in contact with patient. On the other hand, a generous amount is produced from it in a hospital, so it is possible to set up a separate collection. PP is also an easily recyclable plastic, and if collected separately on-site, it can go directly to the recycling without further sorting.

In many cities and countries, only hard plastics are included in recycling programmes, because soft plastics, which are the made of a thin layer and usually stretchy plastic can potentially be stuck in machines and cause problems. However, soft plastic are also recyclable materials, but require different kind of machinery. Fortunately, Prezero can collect and send them to a recycling facility. This category includes shrink wrap and bubble wraps that are usually used in packaging of products when they are delivered, moreover the bed covers which are also made of plastic foil.

In the Sofia Children's hospital, recently started to collect the plastic bottles separately, since there is an abundance of feeding bottles. They collect it in a 40L bag on the ward. Logistically it is complicated to arrange a separate request like this. The staff needs to know about it, so everyone needs to be informed and educated what to do with it.

Figure 67: Separate collection of styrofoam, blue wraps, hard plastics and SZA kegs in the trucks in Erasmus MC

8.5 Waste journey maps

The information from the different aspects of the waste management system has been visualised in a waste stream journey map focusing on different waste streams in the ICU and in a waste journey process from the perspecive of the users. For this, the information from the user research was also used(detailed in chapter 10). Figure 68 summarizes the journey of the different waste streams in the ICU from the point of generation to the processing and end of life or recovery of the waste. Figure 68 explains what happens at each step of the journey and also shows the stakeholder handling the waste at each phase.

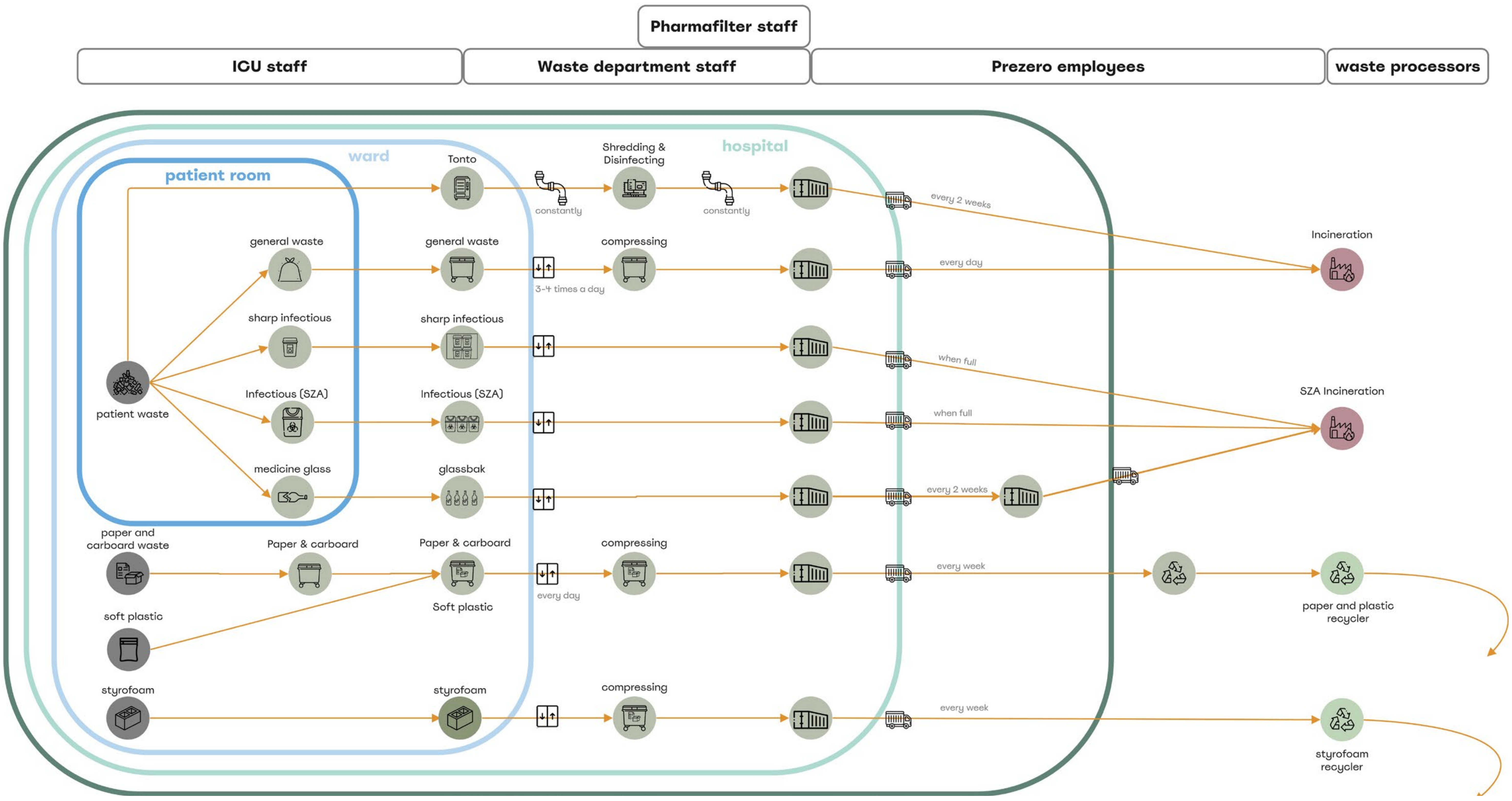

Figure 68: Waste journey of different waste streams from the point of generation until processing

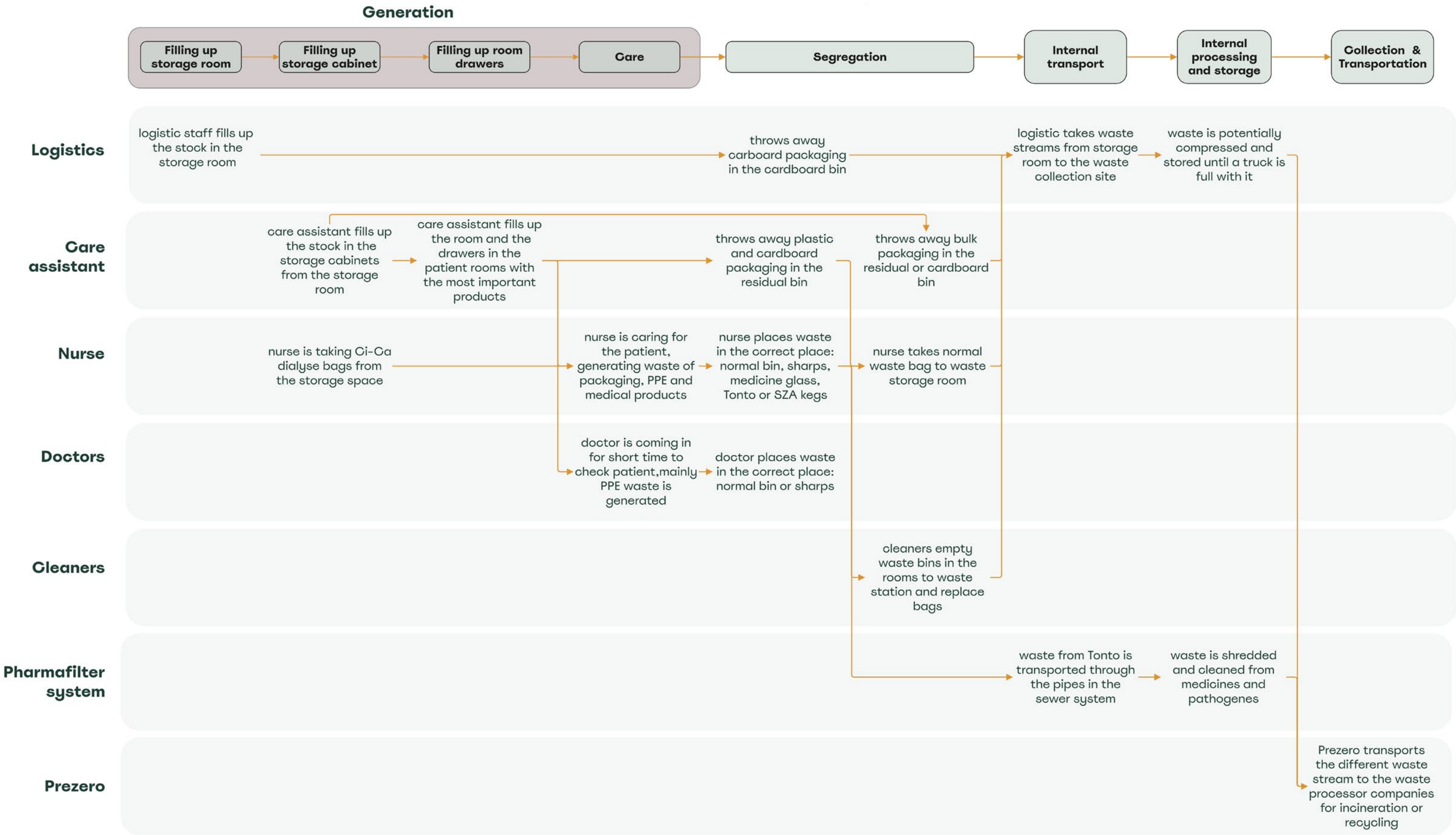

Figure 69: journey of waste and relevant stakeholders from the point of generation until processing

8.6 Conclusions

The main challenges and opportunities derived from the information in this chapter are summarized below.

CHALLENGES

Waste type need to be large or combined with other streams from hospital
Waste type need to be large enough to fill a truck every couple of months. Since it is quite difficult to achieve only by ICU waste, the waste streams needs to be combined with already existing or future waste streams from the hospital. This means it needs to be the same material type.

Cardiac ICU waste storage room is together with operation wards

Since the two department uses the same waste storage rooms, collaborations is neede to create a new waste stream collection. Space and rules needs to be agreed on.

Waiting times at elevators can increase

With new waste streams the waiting times can increase at elevators, which can slow down to process of the logistics deparment

Pharmafilter system cannot be used for biogas or recycling

Although the Pharmafilter was designed for making biogas and recycle the remainng solid waste, this is not feasible to do. Therefore the positve aspects are limited to infectious waste sterilization

OPPORTUNITIES

Significant costs can be saved

There are large differences in waste disposal costs, which can be greatly reduced for recycling waste streams or by reducing Specific Hospital waste. This gives good convincing power for the hospitalmanagement to invest in the new sterams (if investment is needed)

Separation units are implemented for plastic and food

From 2023, the new waste streams of plastic and food are going to be started and separation units will be implemented in common areas. This will reduce the food related waste and creates possiblities for combining waste with the plastic stream.

Tonto reduces waiting time at elevators and transportation time

Tonto has the potential to reduce waiting times at elevators when more waste is disposed in it

Tonto can be scaled up

The pharmafilter system has the potential to scale up tonto use now that initial flaws has been fixed

The criterias derived from this part:

1. **Waste stream needs to be large enough to fill a truck over couple of months maximum need to be placed together with other waste streams**
2. **Waste bin needs to be compatible with internal collection system - connectable to small electric vehicles**
3. **The collection time should not increase considerably**
4. **The logistic staff should not have considerable extra work**

Chapter 9

Research on waste composition

In this chapter the waste composition of the ICU general waste stream is analysed and categorized into waste types. the waste types recyclability is determined and the main barriers are identified

9.1 Approach

In order to identify the waste composition at the ICU, two sources were used. First, the Material Flow analysis (MFA) made by Metabolic from 2019. This shows the material inflow and outflow on major product groups. The amounts were based on procurement data and were completed by additional measurements, desk research and interviews with Erasmus MC staff members. On the far-left side, the material distribution of product types is shown. The flows connect the materials to product types. This gives a good understanding of mai product types used at the ICU, but was not prepared by looking at the waste, only from procurement data. It is not included what product end up in which category and in what conditions. However, for recycling aims, it is nonetheless important.
Therefore, a Waste audit was conducted for a short period of time to have an understanding about the product and materials composing the residual waste stream at the ICU. The SZA waste was not analysed due to safety and legislative reasons. Based on the waste audit, conversations were performed with the recycling specialist from Prezero about each product type.
Together the following research questions are answered in this section:

Research questions
RQ1: What is the scale and composition of the ICU waste?

RQ2: Which material streams are suitable for recycling?

RQ3: What are the main barriers of recycling each waste type?

9.2 Material Flow Analysis

The Material flow analysis is based on the yearly procurement data from 2019 (Browne-Wilkinson et al, 2021). The materials used at the ICU are listed and their amount and materials were analysed. Based on these calculations, 51.000 kg waste is produced in a year on the ICU. The non-infectious, largest part of this waste is disposed through general waste stream and incinerated. This is around 39.000 kg per year. Part of the infectious waste is sent through the Pharmafilter and treated to be classified as general waste as well and be incinerated with it. The remaining part of the infectious stream is disposed as Specific Hospital Waste and incinerated with special conditions.

9.2.1 Material composition

The solid materials entering the ICU yearly adds up to 66 450 kg. The medicines are excluded, but their packaging is included in this calculation. The liquids are also excluded. From all these solid materials, 72%, 47 800 kg is synthetic plastics or fabrics made from synthetic plastics. Almost 10.000 kg is glass (the packaging of medicines), 8000 kg is biobased material, and only 770 kg is metal. This composition shows how much plastics have overruled all other material types and became the primary materials in healthcare apparatus.
This enormous amount of plastic is built up from 14 different types of plastic. Sometimes even laminated or woven together. The main plastic types are PP,

LDPE, Nitrile and HDPE and PE/PP fabric. Together these compose almost 70% of the plastic, therefore these are the most important ones. Furthermore, PP, LDPE and HDPE are recyclable plastic types. Nitrile is difficult to recycle, while the PP/PE fabric is two types of plastic woven together.
The biobased materials are mainly Fluff pulp and carboard or paper. The fluff pulp is the material of the diapers, while the carboard is mostly packaging material. The metals on the ICU are largely the stainless-steel instruments, such as stitch cutters and aluminium packaging.

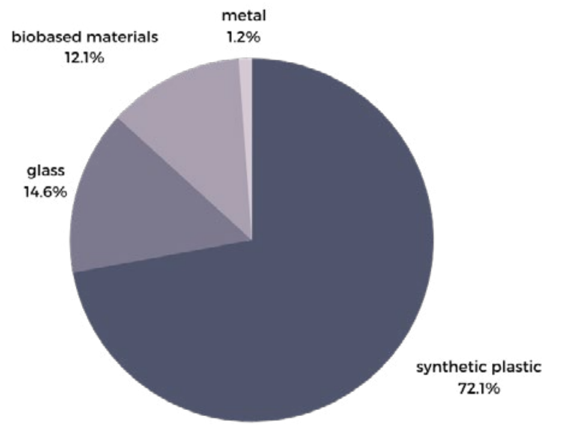

Figure 70: Composition of materials in ICU based on 2019 Metabolic data

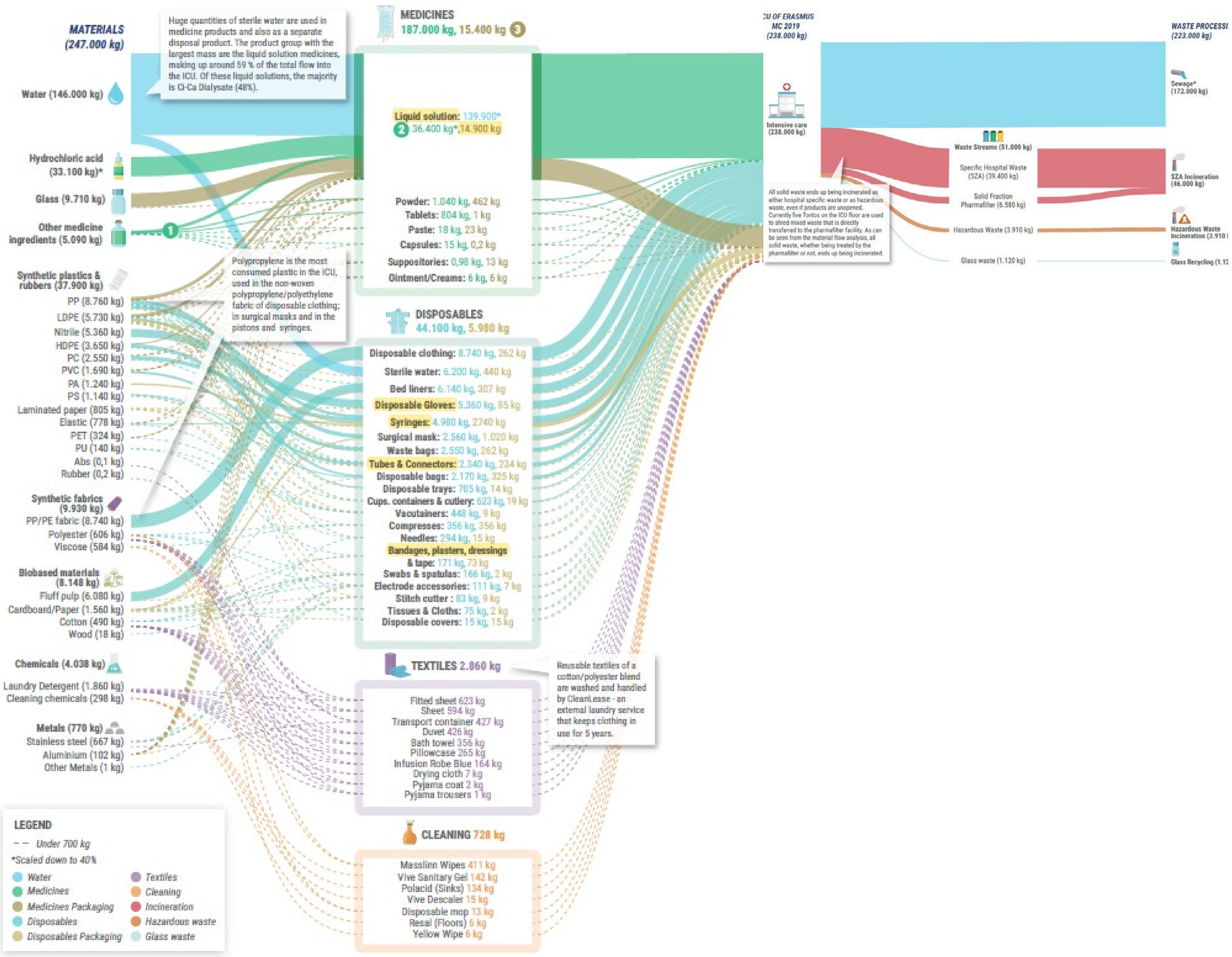

Figure 71: MFA of ICU materials 2019 Metabolic data (Browne-Wilkinson et al, 2021)

9.3 Waste audit

To collect more realistic information about the Waste compositions, a waste audit was performed for the ICU waste. During the Audit, the residual waste of the General Adult ICU was analysed. The waste was collected from a night shift (8 hours) and analysed during the day. The collected waste is the result of around 30 patients treated from all 4 units. The waste was analysed inside the hospital's waste collection site.

9.2.1 Aim

The goal of the audit was to get familiar with the disposed product at the ICU, categorise the products based on product and material type and determine which categories have potential for recycling. Next to that, it was important to see the condition of the products in the garbage since this can also affect the recyclability. The research was more qualitative then quantitative, as it is difficult to have reliable numbers in such short period.

9.2.2 Apparatus

Scale
bins for measuring
gown
face mask
gloves
sheet
paper and pencil

9.2.3 Procedure

First, the bags were removed from the containers and weighed individually. Most of the bags were blue 60 L bags, used in the patient rooms, while some of them were smaller white bags, from bins in communal areas. The total weight of all the bags together were 85.6 kg.
After weighing them, the bags were opened, and their content was categorized. The categories were not predefined but were decided during the procedure based on what was found. Overall, 26 categories were created, which can be seen in Figure 73.
During the audit, PPE was used for opening and touching the bags' content.

9.2.4 Results

The categories weight was measured, and the final proportion can be seen in Figure 74. It can be seen that the largest category is food related waste from kitchen and team room areas, such as soup cups, plates, cutlery and leftovers. This it out of scope for this project because it is not healthcare related and the collection of food waste will be already setup in 2023.
After the food contact waste, the largest categories include the infusion bags (18.8%), the syringes (10%), the gowns (9.7%) and the diapers (6.7%). From the material perspective, more than half of the waste is plastic, while around 6.3 % is a plastic-paper combination. The rest is paper, diapers and the other and unsorted categories. Metal could be only found in a very small proportion (0,1%), and no glass was collected in the general bin. The largest categories (syringes and infusion

Figure 72: Waste separated during audit

Figure 73: Waste separated during audit

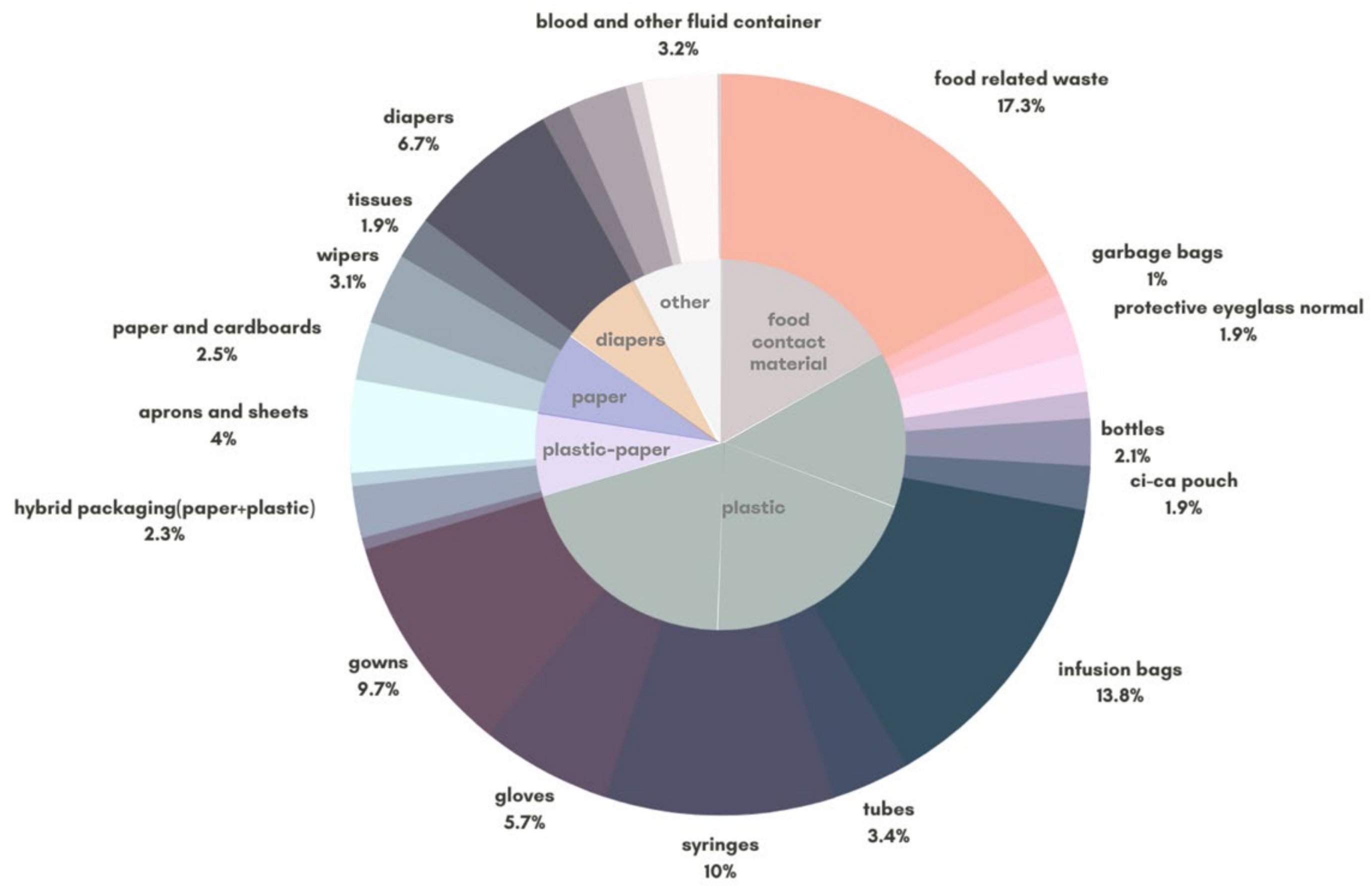

Figure 74: Waste audit results

bags both contained a small amount if liquid medicined inside, which affected their weight.

9.2.5Limitations

Waste was measured only from a short period, therefore can't be used to represent the average waste. Was measured only from the night shift, therefore it is not representative of the whole waste produced during a 24-hour period.
The categorizing was time intensive and there was no way to leave the categories on the site. In one day, only half of the waste could be opened, measured, and categorized, so it only represents half of a nightshift's waste.

Some bottles and IV bags still contained some liquid; therefore, the weight of liquid is included in the results. It should not be included, if the materials that can be recycled is considered, however it still valid to include if it is calculated how much waste is derived and from the general waste and how much disposal costs are paid.

9.2.6 Waste types and their recyclability

During the waste audit, the Prezero's Zero Waste coordinator was present, and his insights were used to determine what can be currently accepted for mechanical recycling. Using the main waste audit categories, the main information influencing recyclability is collected for each category and their potential is described.

Infusion bags
There are several types of infusion bags used in the ICU from multiple brands. They differ in size, material and content. A large proportion of the infusion bags was the largest packaging containing Ci-Ca dialysate. All of them are made of plastic, but the plastic types are different and due to their application, it is possible to be made of multilayer material with more type of plastic. All of them have connectors on the top part, made of likely different types of (coloured) plastics or metal. Sometimes they have leftover liquid inside which is not accepted by Prezero. In order to recycle them, the bags need to be empty, the connectors should be separated from the bag itself and all of the medication and plastic types need to be identified and considered safe.


Figure 75: Different infusion bags found in the waste

Overpouch dialysate bags
Large plastic packagings of the dialysisate bags are clean, dry and made of one type of plastic, recyclable PP.


Figure 76: dialysate overpouch

Plastic bottles
The plastic bottles are recyclable, because they did not contain medication and made of recyclable type of plastics, such as PP, HDPE and PET. When there is a dangerous sign on the bottle, it needs to be removed before the collection. The bottles need to be empty before collection, some drops are accepted. It is no problem to have lids on the bottles because the recycling system is already adapted to this.
As discussed in chapter 7.6 plastic packaging bins are going to installed at the whole hospital in common areas. The bottles can be disposed in this waste stream because it is already a mixed plastic waste.


Figure 77. plastic bottles

Plastic soft packaging
Similar to plastic bottles, the plastic packagings can be possibly collected in the new plastic waste stream. They are dry and clean, soft plastics, but made of different types of plastics as well.


Figure 78 plastic packagings

Syringes
Syringes are complicated products. They consists of one type of plastic for the barrel and a different type for the plunger rod. Apart from this, there is a rubber part attached to the plunger rod. Many times, the medicines are still trapped within the syringe. In order to recycle them, it needs to be emptied and cleaned of medicine, the two parts and the rubber separated. The rubber is not easy to remove by hand. They were in contact with the patients, which makes it questionable for recycling companies.


Figure 79. syringes

Tubes
There are long plastic tube sets used for infusion, ventilation, sucking machines, blood collection and so on. The inside of the tubes can contain liquids, which are not absorbed either from liquid medication or human fluids and it is difficult to clean the inside of the tubes. They are frequently disposed of in sets, meaning that other plastic accessories are attached to them, which would again need to be removed before separation.

Figure 80. Tubes

Gloves
The gloves are made Nitrile, which is a plastic type hard to recycle and current recycling facilities are not equipped for it. The other problem is that there are at least 3 different types used in the hospital. It is because of the zero-risk applied in the hospital, meaning that they can't be dependent on one supplier. It needs to be ensured that they are not contaminated, which is difficult as they are used for patient contact.

Figure 81.Gloves

Aprons
The aprons or gowns are made of nonwoven PE/PP synthetic fabric. They are multilayer fabrics, which is not easy, but possible to recycle. However, the cuffs are made of different textile, and should be removed. There is sometimes blood or other body fluids on theme, however these are absorbed by the material, therefore considered non-infectious. If there is visible blood stain on the apron, it can cause problems for staff working with the waste at recycling company.

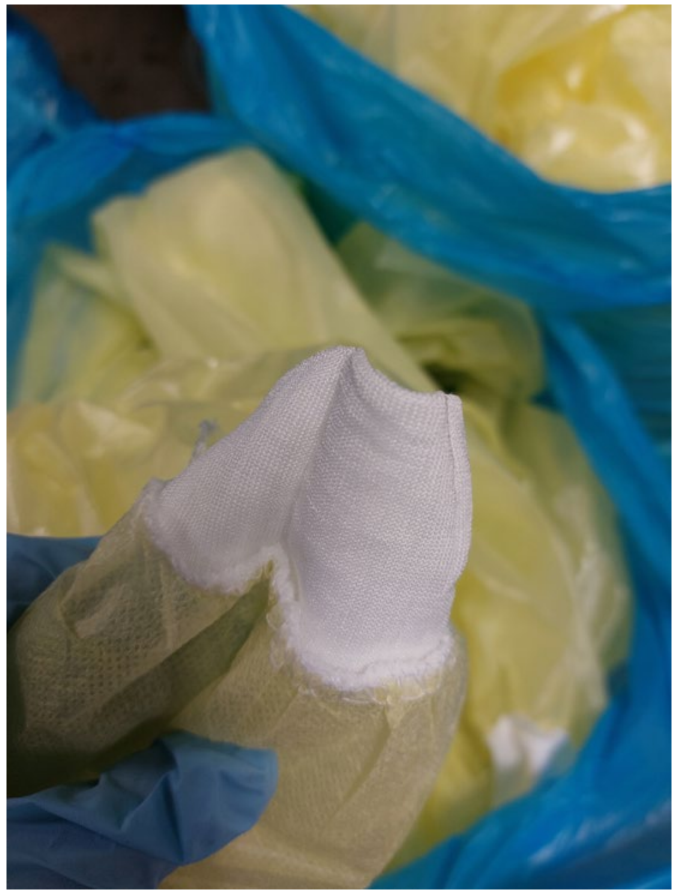

Figure 82.Aprons

Protective Eyewear
Plastic goggles are used for cases when there is a risk for split of fluids. Mainly it is transparent hard plastic with a different coloured plastic for the temples. Later it was confirmed that these are collected until the bag is full for several days, so this amount is not a result of one night shift

Figure 83 Protective eyewear

Face masks
It is currently not possible to recycle masks due to the different layers or woven plastics, strings, and metal nose wire connected inside.

Figure 84 Face masks

Diapers and incontinence pads
Although diapers are both patient contact and multilateral products, with plastic and fluff pulp inside, there are special diaper-recycling facilities in the Netherlands which make it possible to recycle them. This makes them exceptional among products with similar barriers. This also shows that with proper technology, other difficult products could be recycled, if companies would specialise in their recycling. Note, that later research showed, that the recycling is not value-retaining recycling, but downcycling. Nevertheless, calculations prove that the environmental impact is considerably reduced.

Figure 85 diapers

Tissue
Tissues can be recycled together with paper if there not much contamination on them. There is sometimes blood or other body fluids on theme, however these are absorbed by the material, therefore considered non-infectious. However, blood stains and other contaminations can be visible, which would disturb the workers or recyclers.

Figure 86 tissues

Wipes
Wipes (plastic) can be also recycled if there is not much contamination on them. There is sometimes blood or other body fluids on theme, however these are absorbed by the material, therefore considered non-infectious. However, blood stains and other contaminations can be visible, which would disturb the workers or recyclers

Figure 87 wipes

Sterile packaging
Sterile packagings are made of plastic on the one side, while paper or Tyvek on the other side. the two side needs to be disposed of in different streams in order to recycle. Many times, for sterile packaging, the plastic layer is also laminated multilayer film.

Figure 88 sterile packaging

Paper-plastic sheets
The disposable sheets and some aprons are made of paper on one side for absorption and of plastic on the other side for isolation. This double layer makes them unsuitable for recycling. because even after shredding, the layers can stick together.

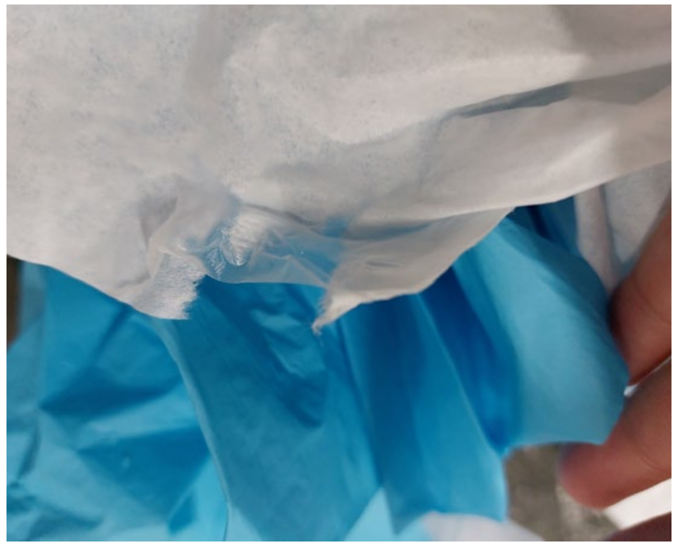

Figure 89 paper-plastic sheet

Paper and carboard
Some paper and carboards are improperly disposed of in the general bin. They can (and should) simply be disposed of in the paper collection bin.

Figure 89. paper and cardboard

Paper cups
Paper cups for coffee and soup are largely made of paper, with a thin plastic layer on the inside for insulation. The layers of different materials are fused again. Currently, they cannot be recycled, but only downcycled.

Figure 90 paper cups

Aluminium packaging
Aluminium packaging are recyclable monomaterials, but there were only very small quantity

Figure 91 aluminium packiging

Medicine glass bottles
The medicine glass bottles are not collected together with the general waste stream, but already separated in the 'glasbak'. They are collected from all parts of the hospital and sent to hazardous waste incineration (different from Zavin). The glass consists of Type II glass, which is a treated soda-lime glass, frequently used in pharmaceutical applications (Fresenius Kabi, n.d.). This type of glass is very similar to the most common regular soda-lime glass type, therefore a recyclable type of glass. However, the product itself can't be recycled currently because the bottle is designed in a way that the aluminium/plastic flip-off cap is not removable with hand and disposed together with the bottle. Under the cap there are also halobutyl stoppers, which together make a mix of 4 different types of materials.
If the bottles are plain glass without

cap, empty, rinsed and without a danger label, they can be placed in the glass container and picked up by Prezero (Van Olffen, 2022). This means, that if the caps were removed from the empty medicine glasses, they could be recycled with the glass waste stream.

Figure 92 glass vials

Glass ampoules

Although not found in the general waste stream or a as a separate disposal, according to the Metabolic report, 80% of the glass waste comes from glass ampoules (7650 kg). It is likely disposed in the pharmacy, because the nurses are rarely in contact with it. The material of these ampules is borosilicate glass or Type I glass. It is frequently used in Pharmaceutical packaging due to its resistance to heat and cold. It's high melting point however, makes it unsuitable to recycle together with conventional soda-lime glass, as that melts in a lower temperature. Unfortunately there is not enough borosilicate glass being used and disposed of overall to create recycling possibilities for them. Most products made from this type of glass are designed for long-term use, as opposed to single-use glass containers. Currently it has no viable market for collecting, cleaning, and reintroducing them to a new manufacturing stream.

Figure 93 Pharmaceutical glass ampoules (Temperature Measurment in the Production of Glass Ampoules, n.d.-b).

Single-use metals

On the ICU, single - use metal instruments are used, which cannot be reused and must be discarded after on-time use, according to manufacturer instructions .The nurses sometimes reuse them for non-medical applications. Similarly to the medicine glass vials, single-use metal instruments are also separated by an individual initiative of a nurse. These are collected and every couple of months are sent to sterilization and transported to Africa. In healthcare institutions in Uganda, they are reused and sterilized 4-5 times before they are disposed. The waste treatment method is unknown, but if the material is recycled after that, even with the transportation it is environmentally better than if the ICU would recycle it without reuse.

Figure 94: Separately collected single-use metal instruments

Conclusions - Overarching patterns in barriers

It is important to see the patterns that influence the recyclability of the waste. The main barriers found in this analysis can be grouped into these six categories. With each category, the affected product types are added.

Product is built up from multilayer materials (different plastic types or paper-plastic combination) woven or fused together. The layers are hard to separate to monomaterials.

The affected product types:
infusion bags
gowns
sterile packaging
face mask
paper-plastic sheet
paper cups

Liquid medicine is trapped inside the product. Due to the medicine, it is not accepted by waste handling company.

The affected product types:
Tubes
infusion bags
syringes
glass bottles

The products consist of different parts made of different materials connected together which need to be separated by hand or by other means, before the recycler can accept.

The affected product types:
Tubes
infusion bags
syringes
gowns
protective eyewear
facemask
sterile packaging
glass bottles

Danger signs on products cause fear for employees working in recycling chain. Even if material is recyclable, not accepted.

The affected product types:
Ethanol bottles
Glass bottles

Dry blood stains on products causes fear for employees working in recycling chain. Even if material is recyclable, not accepted. Note: Dry blood stains are not dangerous and not considered infectious.

Affected product types
wipes
tissues
aprons and gowns

Product is made from a material, which is not recyclable economically with current technologies.

Affected product types.
Gloves
Glass ampoules

Already recyclable waste types

Some of the products are presenting multiple of these barriers at the same time.
However, there are still product types identified which do not pose any of these barriers. These are the following:

Aluminium packaging
Tissues without visible contamination
Wipes without visible contamination
paper which could be discarded in paper - collection bins.
plastic foil packaging
plastic bottles (without danger sign)
diapers (downcycled)
plastic secondary packaging of dialysis

Looking at these waste categories, and their amounts form the waste audit, it can be quickly seen that most of this waste represent a smaller category of the waste by weight put together from many small-size products. Furthermore, separating all of these into suitable categories would require 4 different waste streams on multiple locations (paper, plastic, metal, diapers). This shows that there is probably no quick way of recycling a large part of the waste. The diapers are the only category, which have a considerable amount and already recyclable, but the recycling quality has to be considered. Second to the diapers, the outer packaging of the dialysis bags are quite large and frequent, and only one type of product, which is easy to recognise.

9.2.7 Conclusions

There are several barriers found in the large part of the ICU product types for recycling them. It was seen that waste separation simply by material type (plastic, paper, glass) is not possible in case of the ICU waste. The products are too complex to be simply categorized into these categories. The nurses would need to recognise recyclable or non-recyclable plastic types and separate product components from each other, with hand or with extra necessary equipment. Such complex separation system cannot be fit into the routine of ICU staff.

Therefore, choices need to be made for focusing on part of the waste and overcoming the difficulties in their recyclability. The largest amount of waste types are difficult to recycle from multiple perspectives. There was no obvious product type found in the waste which would be a large amount and easy to recycle at the same time.
A compromise needs to be found between effort required to overcome the barriers and waste quantity. The main barriers found were hard to separate or inseparable multimaterial or multilayer products, products with fluids inside, unrecyclable material types, hazardous labels, or blood stains. However, there are opportunities for some already recyclable groups as well (from the technical perspective), with the compromise that these are smaller amounts. Products which can be considered both larger amount (7%) and recyclable is found the diapers, with a partially downcycling approach due to material complexity.

This chapter showed the possibilities and the difficulty in recycling the waste based on product categories and concluded that specific categories need to be chosen for recycling. These products are going to be needed to separate on the ICU by the staff. The next chapter is going to focus on the processes at the ICU, in order to find opportunities for the separation

Chapter 10

Research on ICU practices

In this part of the research, a closer attention is given to the specific scenario, where the waste separation can happen: The Erasmus MC ICU. This chapter describes the research activities followed at the General Adults ICU to understand the nurses perspective and their processes and presents a set of opportunities

10.1 Method

The research questions were answered through a set of interviews and observations (a list of all interviews and observations can be seen in Appendix G). Two observation days were done at the ICU, in which the nurses' activity was followed from the beginning of their shift until they transferred information to the next shift. The observations included the nurses' general workflows within the patient room and on the corridors; with special attention to waste disposal movements; and relevant part of the ward, such as storage rooms and waste disposal locations. A sensitizing material was prepared and filled out by several nurses during the first observation.
Next to the observations, several interviews were performed with nurses, one interview before the observations happened about general waste disposal practices and two interview after the each of the observation days with the observed nurses focusing on questions that came up during observing them. These were more informal interviews. without a fixed set of questions.

Research questions

This chapter aims to find answers to the following research questions:

RQ1: What is the nurse's workflow of waste disposal?

RQ2: What problems do nurses experience with current waste disposal?

RQ3: In which locations the waste is generated?

RQ4: What type of waste is generated in which moments of patient care?

RQ5: What are the main obstacles of recycling in the current ICU practices?

RQ6: What are the nurses approach towards recycling and separating the waste?

RQ7: How can waste separation be fit into a nurses process?

10.2 The Intensive Care unit

Before the research activities are presented, a short introduction is presented on the Intensive Care Unit for better understanding of further parts.
The Intensive Care unit provides specialized and intensive care to patients in life-threatening conditions. This can happen after a serious accident or surgery or due to a serious illness.
Special equipment is used to monitor or in case it is needed, substitute bodily functions.
There are two adult sections in Erasmus MC, one for general Intensive Care (general Intensive Care Adults) and the other one focuses on patients with heart problems or after heart surgery (Intensive Care Adults/Cardiac Monitoring). There are 40 bed in the General IC and 18 beds in the Cardiac IC. Each patient has their own private room.
The goal is to ensure that the vital body functions of a patient is no longer endangered. Then, the patients who no longer need intensive care are

transported to a nursing ward.
Next to the standard IC treatment, Erasmus MC IC department also focuses on specific disorders, certain operations and transplants and major accident injuries. Patients are often transferred to Erasmus MC from other hospitals due to their specialized condition.
In the ICU, special attention is placed towards patient wellbeing. For example, loved ones can write the preferred name of the patient, family member's name, radio, or television program preferences of the patient to get a personal background about them.
There is also a collaboration with other departments. There is daily contact with specialists from other departments in order to treat the patients as well as possible.
The 24 hour day is divided into three shifts starting at, 7:30 am, 3 pm and 11 pm.
During every shift there is a permanent nurse who cares for the patients and checks their condition. The patients are visited every day by an intensivist as well. The specialist examines them and if necessary, the treatment plant is adjusted in consultation with the nurse. The patients' body functions are continuously monitored, such as heart rhythm, blood pressure, breathing and blood oxygen level. The nurses are alarmed by the equipment if urgent action is needed.
Each shift a nurse and a doctor is linked to every patient.
Due to the higher chance of having an infection, special attention is placed on hygiene.
To some patients, special isolation matters apply (Erasmus MC, n.d.-b)

10.2.1 The Ward

The General ICU ward is made up of 4 units and built in unit pairs, in which each unit is a mirrored version of the other one. The common rooms are situated in the centre and many is accessible from

Figure 96: The ICU ward

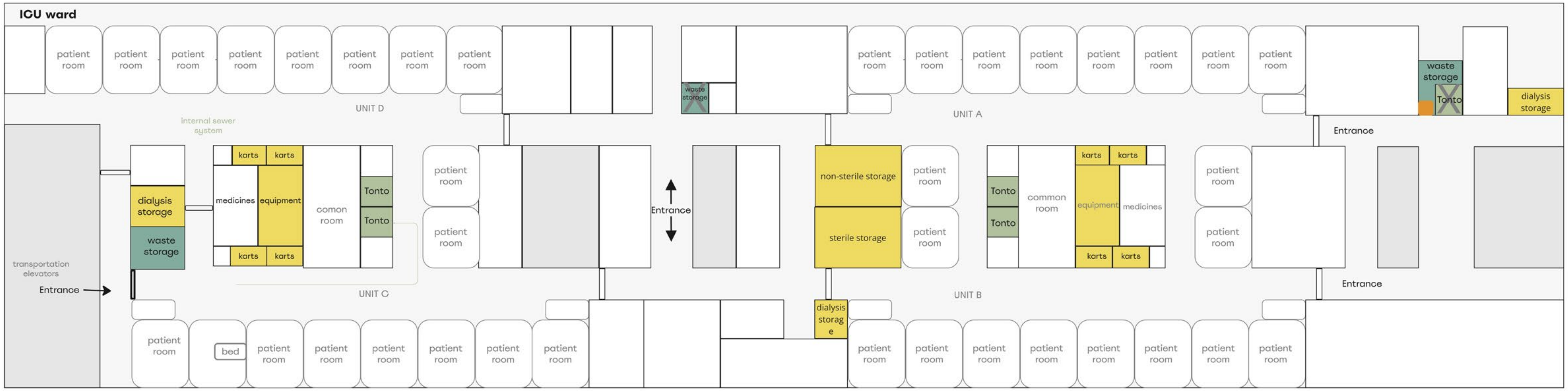

Figure 95: Floorplan of the General ICU

both units, while the patient rooms are located on the sides of the building. this makes it easy for the nurses to work on whichever unit they are scheduled to and to contact with the nurses from the other unit. The relevant rooms from the waste perspective are the equipment storage rooms, patient room and waste storage room.

10.2.2 The patient room

The patient room is the main are where the waste is generated during the care for the patient. The activities here create the seven bag per day per patient.
The main part of the patient room is the bed surrounded with the complex monitoring equipment. The infusion bags also hang from there. Opposite of the bed, there is a cupboard with equipment needed for the daily care, two waste drawers and a sink (Figure 97).

10.2.3 The waste collection points for current waste streams

The waste which is generated in the patient room is disposed is multiple waste streams. The majority of the waste is disposed on the movable bins in the room (part of the cupboard), which is the general waste stream. There is one bin for the waste, and one for the dirty reusable textiles, which are sent for washing. The two bins are differentiated with a small sticker and the bag colour. When sharps need to be disposed, these are done in the certified yellow sharp bin on the counter. Empty medicine glasses can be collected in the red sharp box next to the yellow one (Figure 99) When and infectious waste type is produced, it needs to be taken to the infectious room, where there are two options: The waste is disposed in the Tonto and sent through the Pharmafilter for sterilization or disposed in the Certified infectious (SZA) bins. There are certain rules apply to what can be disposed in the Tonto, while everything can go in the SZA kegs. When the general waste bag in the patient room is full or needs to be disposed due to smell issues, the nurse needs to walk to the waste storage room. It is located outside of the ward, one in each unit pair.

Figure 97. The patient room

Figure 99. The glass and sharp boxes

Figure 98. The waste and textile bins in the room

Figure 100. The infectious waste room with the Tonto and SZA kegs

The waste storage room

All waste categories eventually collected in the waste storage room before the logistics department comes to take it into the collection site in the basement. The paper collection bin for paper and carboard recycling is only located in this room, and not on the ward, so the paper waste needs to be directly disposed in this bin. Similarly, some foils from the bed covers of new patient beds are collected separately here. The full SZA kegs are collected here as well. The room is already quite full and many times the bins are moved to other locations, which can result in some signs not being in the correct place to indicate the waste type.

Figure 100. waste storage room

10.3 Nurses approach towards recycling

During coffee breaks, a sensitising material was spread to nurses (Appendix D), to map their approach towards separating waste. The sensitizing material consisted of an introduction to the project and asked them simple questions about waste management and their job to find what motivates or discourages them. Overall, 12 staff members filled the sensitizing material, one care assistance, one physician assistant and 10 nurses. A detailed summary of the results can also be found in Appendix E, while the main results from the nurses' answers there were the following:

In general, the nurses approach towards contributing to recycling is positive and many of them would like to see some progress, because they are aware of the tons of waste they are producing. They mentioned that they are happy that some progress is being made towards reducing environmental impact by the Green Team.

All nurses expressed that they are open to changes in the process of waste disposal if it does not require extra effort, while almost all of them still agreed that they would be open if It required a small effort, with one staying neutral. Similarly, 92 percent said that they would like to contribute to recycling in the IC.

It was also seen that most of the nurses are annoyed by all the plastic, and that everything is packed in it. They think not enough is done and not all the waste is separated which could be possible. However, they have several concerns in the separation of waste. Many of them mentioned that lack of space can be a problem and the lack of time. There were some who think the barrier is the behaviour of the nurses and the complexity of the issue.

They were asked generally which moments of their work gives them most energy, the two most important aspects were their colleagues and improving the patient's condition. These are important motivators, which can be potentially used later when designing for them.

Since the nurses were asked with questions to agree or not agree on a pressing issue, they might have felt societal pressure to answer more positively than they would act in reality. This limitation could have altered the results.

10.4 User Journey

A user journey was made to highlight the main steps the nurses need to take during waste disposal process. The journey has been highly generalized, since depending on the exact activity, the process can be different and can be consist of more steps. It is also used to identify opportunities and difficulties in their process.

It was seen, that many different waste is produced in the room especially in the morning care routine, from packagings, through Personal Protective equipment, to syringes and infectious waste. These are mainly produced at the bedside and at the cupboard. Separating waste during these moments can be problematic and needs to be very simple for nurses to perform correctly.

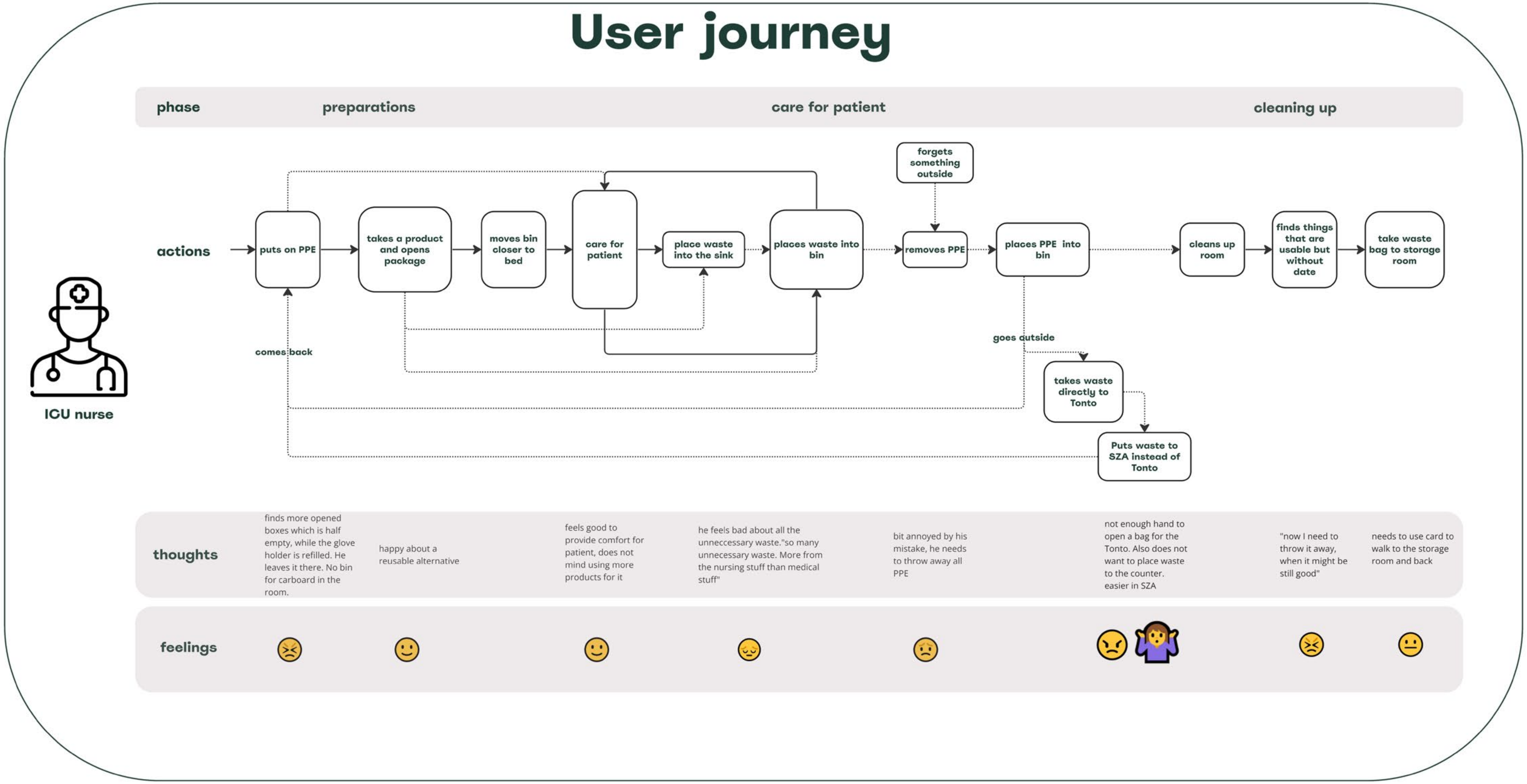

Figure 101 user journey

10.5 Opportunities

10.5.1 Product packaging journey

It was also found that during the process of stocking up storage spaces, there are small amounts of packaging waste generated at many locations (Figure 102) These mainly cover cardboards and foils, and plastic and plastic-medical paper sterile packaging. The filling is usually done by the care assistance, but when nurses are missing something, they also go to the storage room and bring it into the room themselves. This could provide opportunities for collecting clean packaging waste which were not in contact with patients. However, later it was discovered that the amounts for this waste in each location is still quite small.

10.5.2 Peak during admission

Another finding from the interviews were the differences in waste generation during the stay of one patient. During admission, when the room is prepared and the patient arrives, there is a peak in waste materials. It fills 2-3 full bags in a very short time. However, these moments are usually very busy for the staff with multiple nurses working at the same time with that one patient. Admissions are very irregular and most of the time unpredictable, thus they cannot prepare for it and need to act in the moment. This makes it difficult to focus on waste separation at the same time. While the waste composition is also very variable, so it cannot be easily disposed as one type of recyclable. A mobile waste station with the necessary waste streams could be prepared for these moments which could be taken into the room during this time. Another option could be leaving all the packaging on the counter or collecting it in bags and separating it later when the busy part is over.

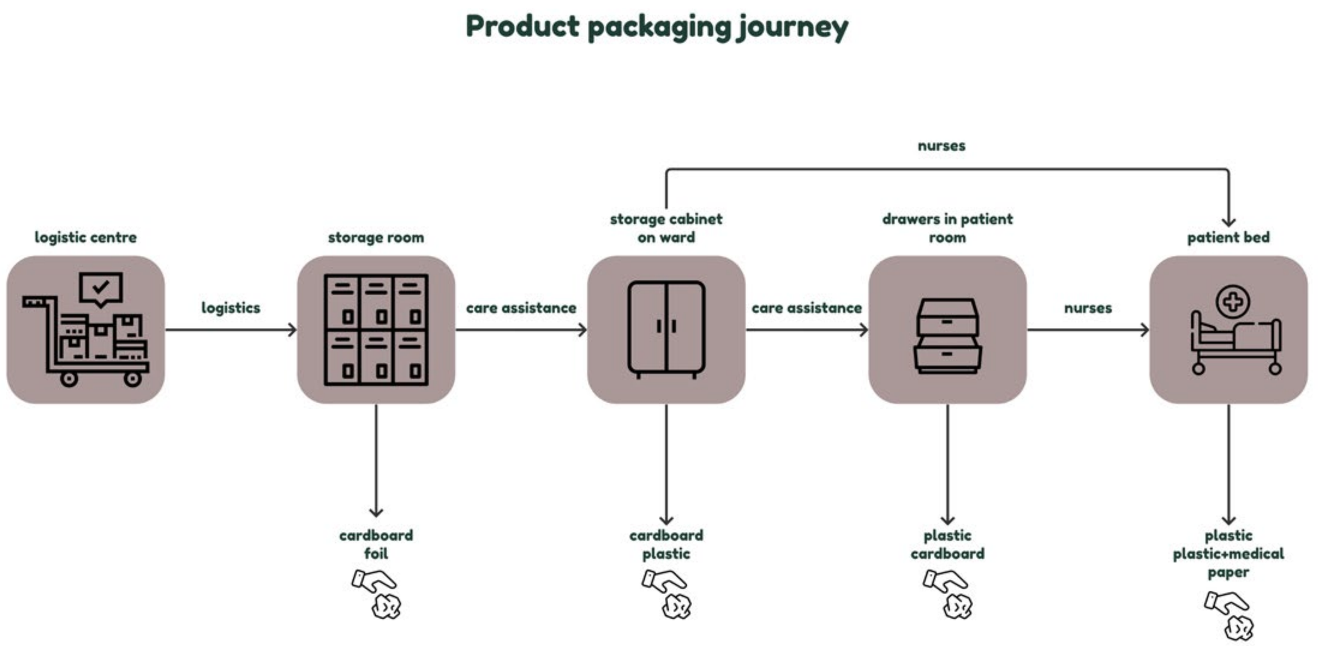

Figure 102. Product packagign journey

Figure 103: Typical equipment needed for the admission of a new patient. The materials are needed for the IV system, the feeding system, the catheter system and for the blood pressure measurement. This is usually complemented with other systems depending on the needs of the patient.

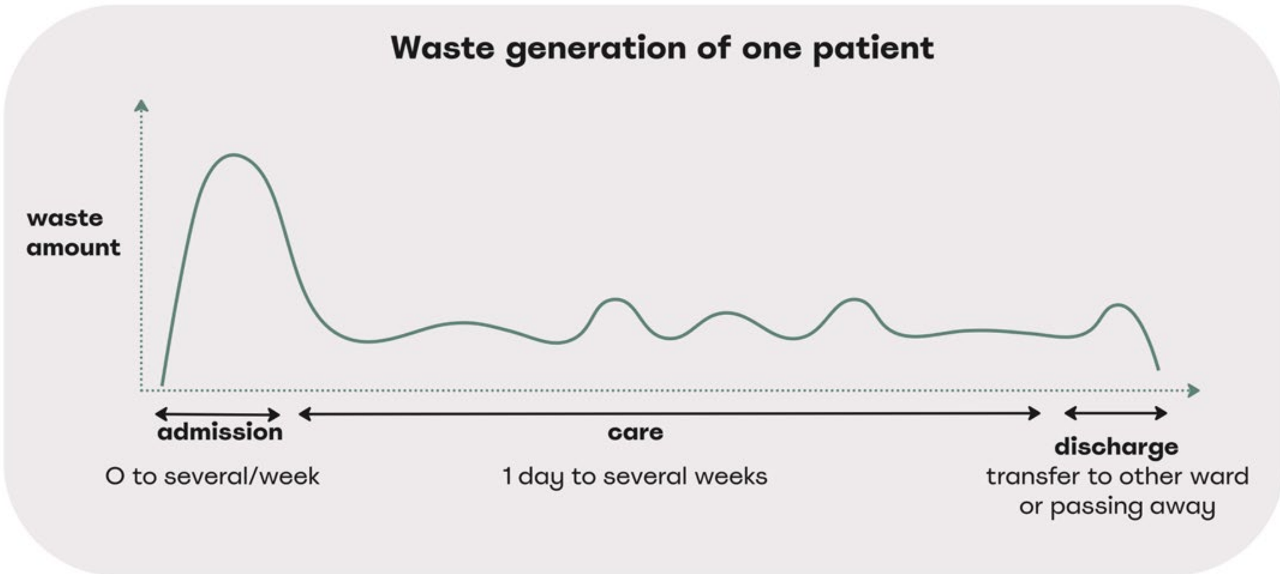

Figure 104.Peak in waste generation (not proportional)

10.5.3 How the Tonto is used

The Tontos are used in both 4th and 6th floor ICU and each of them has multiple (2 in the 6th floor and 4 on the 4th floor). The role of the Tontos and the Pharmafilter system was originally to cover the waste management overall, but the system was overloaded. Therefore the current role is to dispose of infectious waste in there, because that way it can be sterilized and disposed as general waste. It makes sense from the environmental point of view as well, when the special incineration of SZA waste in the Wiva barrels can be avoided.
There was opportunity to see the usage of the Tonto by the nurses. As could be seen from the sensitizing materials, there is a difference in preferences among the nurses. Some nurses really like that there is Tonto, while others are more distanced or frustrated by it.

One of the problems why nurses are hesitant to use the Tonto is the number of roles around it.

There is a long list of what can and cannot go into the Tonto as a sticker on the machines (Figure 105). Nurses need to go over it and look if the product in their hand can be placed in Tonto, because they don't know it by heart. Next to that, there are rules for the maximum amounts for some common items. Each cycle of a Tonto is a couple of minutes, which can result in waiting times and discouraged nurses.

Apart from these, some strategies need to be used to 'trick' the mechanism of The Tonto, because it cannot handle certain shapes such as little tubes and cause it to break. To avoid this, you need to tape or fold them back like in Figure X. There tricks are not written down or communicated around the Tonto, so not everyone is aware of them.

Figure 105. The rules about what can go into the Tonto, what cannot and maximum amounts.

Also when you place something in the Tonto, you should first put it in the special Tonto bags, which is hard to open when your hands are already full with the waste. On these occasions it is much easier for the nurses to just put it in the Wiva barrels which is right next to it.


Figure 106 collection bin for waste that can be placed in Tonto and Tonto bags

It was reported by the nurses that Tontos still break down often and they need to wait for somebody to fix or change them. in these cases, they need to walk to the other side of the units, which increases the effort. When all of them is broken at once, they don't have other choice but to throw the infectious waste.
Another barrier is seemingly bad planning, such as the storage of wheelchair in front of the narrow room on the Tonto, blocking the way to the machine. Also in this room, there is no storage for Tonto bags.

Figure 107. small tubing of the dialysis bags is folded back into a hole on the package to avoid being stuck in the Tonto

Favouring the Tonto is due to the fact that it is seen as an all-in-one, therefore easy solution, where (almost) everything can be thrown. This is true, but it does not mean that it actually makes sense to throw everything in there. for product that don't need the SZA waste disposal, it will end up in the same waste processing, municipal incineration. The only difference is for products with a lot of liquid or air inside, because the Pharmafilter separates the liquids from the solid waste.
Most nurses are not aware of the actual advantage of the Tonto and cannot make informed decisions about what should be disposed in it.
It cannot be realistically observed, what the nurses directly put into the Tonto, but it can be observed what they put it

bag that is prepared to go into the Tonto. Many things are not infectious waste which does not necessarily has to go through the Pharmafilter.

Figure 108. picture of the bag prepared for Tonto, containing a banana.

The problems discovered around Tonto are clustered in a problem tree (Figure 109)

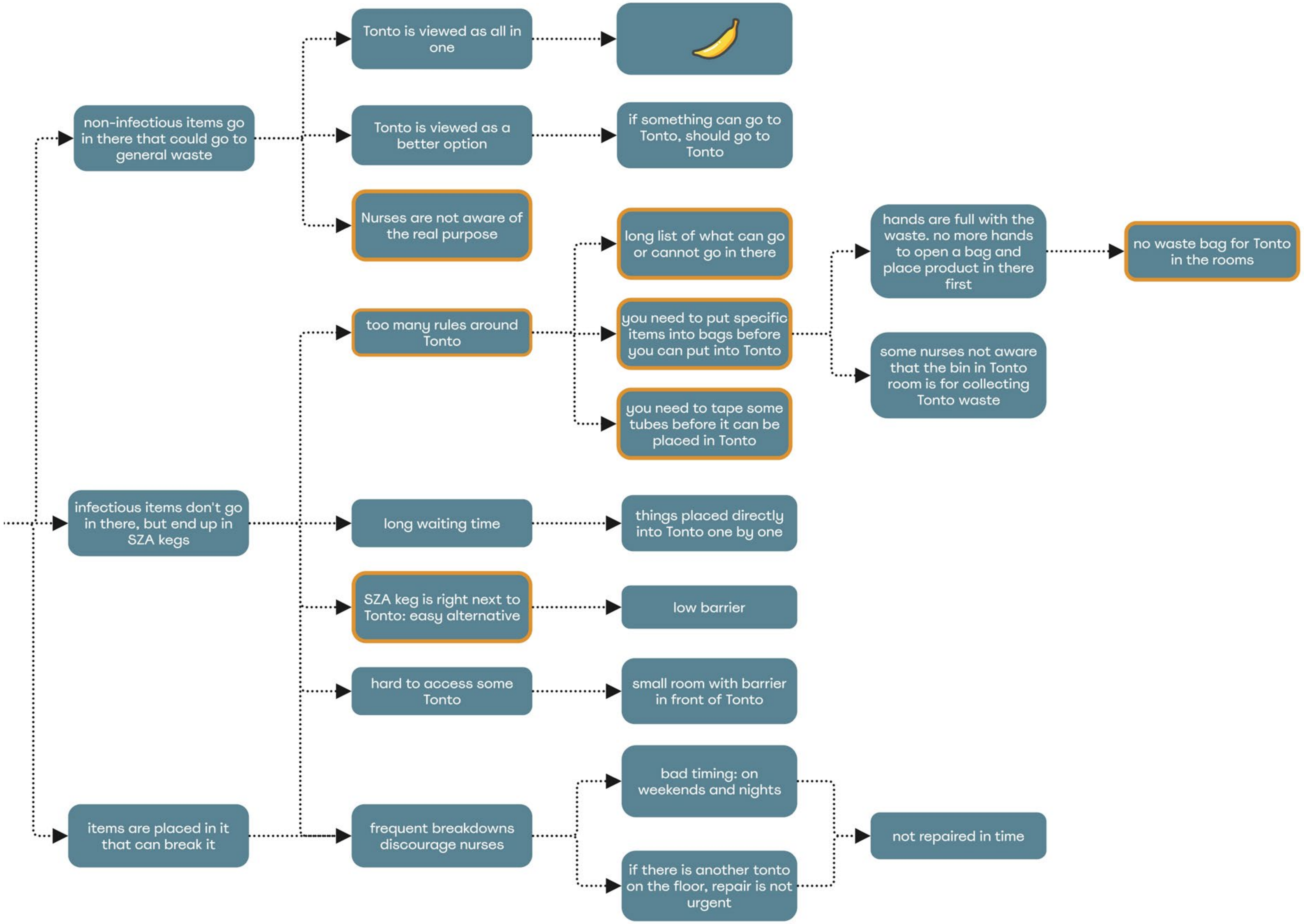

Figure 109 problem tree about proper Tonto usage

10.6 Conclusions

The main challenges and opportunities derived from the information in this chapter are summarized below.

CHALLENGES

Separation of materials with many item type not realistic

It needs to be easy to decide for the nurses what goes to which category. With the rising number of accepted product types, the complexity increases and mistakes are made

Tonto is not used to its potential

View on Tonto is not clear, too many rules around it, and tricks need to be done to avoid breakdowns. these are not written anywhere. Many products disposed in SZA kegs instead because that is easier

Peak in waste

There is a moment when lot of waste is produced in a short time, the patient admission. However, many types of waste is generated and it is a busy moment

Crowded rooms

Many different types of waste is produced during patient care and the room is already full with the waste and textle bins. When more nurses is in the room, it becomes too busy.

OPPORTUNITIES

Nurses are open to recycling

Nurses attitude towards recycling is positive and even with some extra effort they would be willing to take steps in separation. They are especially annoyed by plastic.

Clean packaging waste

During stocking up storage spaces, there are small amounts of packaging waste generated at many location. It is a sclean packaging waste which were not in contact with patients. The amounts for this waste in each location is still quite small.

With stable patients, time is not of the essence

Patient care moments are usually not very busy unless there is an emergency. the nurses are not in a rush, some time can be spared for separating waste

Dialysis infusion bags

Dialysis requires 4 infusion bags per set per patient, which is a lot of amount during 24 hour. these are also quite large and easy to differentiate from the rest

The criterias derived from this part:

1. **clear instructions are needed about separation**
2. **separation needs to be intergated into the nurses processes**
3. **patient comfort and safety cannot be compromised**
4. **The bins need to be easily accessible**
5. **Separation should remain optional. nurses should not be pressured to separate in critical situations**
6. **Because the opening of packages and using devices differs, bins need to be easily movable**
7. **The size of the bin should be considered based on the amount of waste generated**

Chapter 11

Research on system of Dutch ICUs

In this chapter an exploration of the waste disposal strategies of other ICUs in the Netherlands is presented. A questionnare was used to get general data from multiple hospitals, while one hospital was personally visited.

11.1 Waste disposal in dutch ICUs

11.1.1 Aim

The aim of this research area is to identify the waste disposal strategies and research aims of other ICUs in the Netherlands. As stated in Chapter 7, there are many efforts going on among hospitals and ICUs in the country to make their practices circular and this involves waste management as well. It is important to explore their practices, since maybe there are already well working recycling strategies in some of these ICUs. By learning from their failures and successes, Erasmus MC can potentially save some time by starting from the point other might have achieved. Sharing knowledge in pressing matters such as sustainable innovation is crucial, so that nobody has to reinvent the wheel.

Furthermore, by aligning plans and the direction of efforts through forming alliances, it is easier to change the system, make precedent, and even negotiate with waste processors with the convincing power of producing larger waste streams together. As a collaboration, the ICUs can use their power to stimulate the demand for accepting products from hospitals by recyclers.

11.1.2 Method

Due to the time constraints of the project, it was not possible to personally visit multiple hospitals, even though much more information could have been gathered that way. Instead, an online questionnaire was prepared and sent out to the ICU's participating in the Green ICU initiative (see further in Chapter 7.2) to map the current practices and strategies of other Intensive Care units within the Netherlands regarding their waste disposal, separation, and recycling. The questionnaire was filled by a representative from each hospital's ICU who is acquainted with the waste management system. The list of questions and answers can be seen in Appendix F.
The questionnaire took overall 10 -15 minutes to fill out and focused on having a general idea of the recycling schemes in the ICUs. Based on the results, one hospital was chosen to be visited for further information.

Research questions

RQ1: What are the waste disposal strategies of ICUs of other hospitals in the Netherlands and what can we learn from them?

RQ2: How are other ICUs performing at recycling and what barriers or success they experience?

RQ3: What are their plans and ambitions in the near future and how can the efforts be aligned?

11.1.3 Results

There were overall 18 responses from 17 different hospital. From one hospital, two separate answer was received, therefore one of them is excluded from the result analysis. The excluded answer was chosen based on consistency and level of detail in the response. Therefore, the final sample size is 17.
The final list of hospitals responded can be seen in appendix F.

The most important results from the questionnaire are explained in this chapter.
Most of the hospitals (90-100%) separate general waste, specific hospital waste, sharps and paper & carboard. A large part of the ICUs also separate glass (70%) and textile (47%). Although in much lower proportion, but there are examples separating organic waste (18%) and plastics (23%). In some individual case the respondent indicated that they are also collecting PET bottle caps, metal instruments, reusable items (not detailed) and leftover medication including half-empty IV bags and syringes. Products not necessarily in connection with the ICU care, such as used batteries, empty ink cartridges for printers, soda cans and Nespresso cups are collected.

The most frequently indicated reasons behind the separate collection are recycling and infection prevention. Decreasing the cost of disposal and reusing items are less important reasons, with 35% and 41% of the respondents selecting these reasons respectively. In the specific case of the PET bottle caps, it is collected separately to offer it for a charity. One respondent said they are separating (next to recycling and reusing purpose) because it is required by the waste processor.

From the separately collected streams, Paper/Carboard waste is the most recycled waste stream (70%), followed by glass (59%), only one hospital (6%) replied that they don't recycle any of the waste. Interestingly, more answered that plastic is recycled than who indicated that plastic is separated. This leads to the question whether plastic is recycled from separating later in the process from the residual waste. Apart from that, 35 % of the responding ICU's are stated to recycle textile and plastic waste, and 30% of the respondents stated that general waste and SZA waste is recycled. It is interesting, because the SZA waste would require sterilization before recycling. However, only 2 responded that they use a sterilization method for infectious waste, and all respondents claimed that they don't recycle infectious waste after sterilization. General waste recycling is also problematic as this is a mixed waste stream.

A possible explanation can be that they consider the 4th form of recycling, incineration with energy recovery. 24 % of the respondents also said that sharps are recycled. Similarly to Specific hospital waste, it is unlikely that sharps are actually recycled with mechanical recycling, since it is not allowed for safety reasons.

Two hospital recycles (probably composts or turns into biogas) their organic waste. An answer mentioned that they wash (and reuse) the protective clothing of staff or that scissors and forceps are sterilized. Form these kinds of answers we can question if the participants were all aware of the difference between recycling and reuse or the meaning of recycling in general. This seems a serious limitation of the questionnaire results.

Apart from what they already recycle, many ICU has plans for recycling other waste streams in the coming years. There were many differences in the responses on this topic. A very large part (70%) plans to recycle plastics, while 47% plans to keep recycling or implement the recycling of paper and cardboard. Very similarly, with glass, 41% Some also plan to recycle sharps and SZA waste. Food waste and textiles are also on the list with 28% and 18% respectively.

Two hospital (12%) is planning on the recycling of incontinence materials. There was one very specific answer for planning of recycling PVC and IV bags.

In general, 17% of the participating ICUs don't have any recycling programs. It seems, that even if a recycling program is implemented, it is not very easy to ensure it is going as intended. 69% of the respondents with a recycling program indicated that they experience some problems with it or that it does not go well (7%). Only less than one third confirmed that it goes according to plans. The reasons mentioned were the improper segregation of waste, the lack of commitment or awareness, or the cooperation of the hospital or other departments in the implementation of new recycling streams. Other reasons are related to the lack of space and lack of bins at the source of generations, therefore large distances between waste generation and separation points. This was mentioned in relation to paper and plastic waste specifically.

The nurses are the main persons responsible for separation, but almost everyone also indicated the doctors (88%). The care assistance and the cleaning staff also separates the waste in 70% of the cases. The waste management staff is only responsible for it in 30% of the ICUs.
More than half (59%) of the respondents think that these persons are quite knowledgeable about separation (7-8 out of 10). 30% believes that they are only fairly knowledgeable (5-6 out of 10%), while in 2 hospitals (12%) that staff has perfect level of knowledge in the matter of separation (10 out of 10).

The separation opportunities differ greatly, but more than half of the ICU's have separation bins either at the bedside or somewhere else in the room. Only a small portion has the bins on the ward corridors, (12%), while 30% only has the collection bin in the waste room on the ward.

Almost half of the ICUs recycle only 0-15% of their waste. 24% states that they recycle more, between 15-30%, while only one ICU recycles between 30-50% and 2 more between 50-75%, which is high recycling rate. 12% does not recycle anything. This contradicts with the earlier reply, where 17% said they don't have a recycling program.

There is no univocal opinion about the main barrier that retains the ICU from recycling more. There are many different angles, with the logistic problems being the most common with 23.5% together with the concerns about infectious risk (18%). Although it was not on the list of options, 12% also mentioned the waste processor as the greatest barrier, the same proportion as the financial reason was chosen. The rest of the reasons was only stated by individual ICUs.

In only 2 ICUs a segregation is in place after it was collected, one of them is through the Pharmafilter system (which is technically not separating the materials from each other, only the liquid from the solid waste and filters the harmful components), the other is unknown.

These ICUs also indicated that they have a sterilization process in place, through the same Pharmafilter system and another method which is not known. However, none of them recycles the infectious waste after sterilization.

11.1.4 Discussion

Limited results

Based on the inconsistencies found in the results, limited reliable conclusions can be derived from the questionnaire. The persons who filled out either did not have the necessary knowledge to answer the questions or did it in a quick and superficial way. It is also possible that the questions were not precise enough or could have been interpreted in multiple way. Although much time and energy was put into formulating and selecting the questions, the difficulty of the topic and expressions could still cause these issues.
As a result, the recycling claims are many times unrealistic, especially when the sharps and SZA claimed to be recycled. Many of the answers open up new questions and the persons who filled out should be contacted to clear up these questions. Setting up the questionnaire and receiving answers took a long time, therefore it is decided to not contact the persons further, but only visit a promising hospital for more details.

Despite of this, limited conclusions can be still taken from the research, and the the robustness of the conclusions can be improved with further investigations.

11.1.5 Conclusions

Recycling rates are generally low, with a few exceptions. Other ICUS are still at the beginning of this journey. Generally, most of the hospital staff is involved in the waste separation, especially nurses and doctors, but including cleaning staff and care assistance. Their knowledge about waste separation could be improved, but overall good. This shows that it is generally a lower barrier in the process.

About recycling compositions, the waste streams collected in Erasmus MC ICU are also collected in almost every other ICU. However, apart from that, plastic, organic waste, textile and half-empty leftover medicines are collected as well. These can serve as an example and are options to consider for Erasmus MC.

Plastic
Although the details of these recycling streams are unknown, already running plastic recycling schemes show possibilities in this direction. For further research for Erasmus MC, it would be interesting to know what kind of plastic they collect and where. It is unlikely that they collect all plastic waste together, unless they are referring to recycling islands in common rooms, which do not include care related waste. Therefore, likely some plastic types or items are selected, and the collection is set up with waste management companies. It is a promising direction for Erasmus as well.

Textiles
For textiles, it was seen in Erasmus during observations, that the textiles are mainly washed and reused, and only thrown away when they are too dirty. This happens on rare occasions, and although these textiles are incinerated, the amounts are quite low for a separate stream. The textiles are not separated in other departments of the hospital either. This area does not seem

Organic Waste
As it was found In the waste audit, organic waste is not produced directly in patient areas, but in kitchen and team rooms, as a results of leftover food or food related waste. With the plans to place organic bins in these rooms and composting it (see further in Chapter 7), the majority of this waste stream is already handled.

Leftover medicine
The leftover medicine direction seemed interesting, since it was seen in the Metabolic report and in observations that these occur often. However, it was discusses with Pharmacy specialist N.Hunfeld, that the unopened medicines are already sent back to the Pharmacy from the ICU, and the opened leftover medicines are not accepted, therefore their separate collection would not yield in better waste management.

Success of recycling schemes

In many cases, the ICUs expressed that some problems occur, and the efficiency could be improved. The most common problems, which they mentioned were the improper segregation of waste, the lack of commitment or awareness, or the cooperation of the hospital or other departments in the implementation of new recycling streams. Other reasons are related to the lack of space and lack of bins at the source of generations, therefore large distances between waste generation and separation points. These barriers are important points which should be considered when designing for waste separation.

It was also seen that the most important barriers are very different, so each hospital needs to find their own way around them. Logistic issues seem to be the most common, which also correlates with the experience at Erasmus MC.

Infectious waste treatment

Almost no ICU has waste sterilization system, the Pharmafilter is the most advanced option, which Erasmus MC already has. There is no precedent for recycling the infectious waste after sterilization. This supports the findings from literature and the conclusions made from there. With current technologies, the best option is to make the most out of the Pharmafilter.

Future plans

The most interesting part is that 70% of ICUs are planning to recycle plastics in the coming years. Collaborating in the decisions, development and setup of this would be beneficial for all these ICUs, it would reduce the time and resources needed for the setup and by coming into agreement with the recyclers or waste management companies could be done together.

11.2 UMC Utrecht waste collection site visit

Since the results of the questionnaire were still vague, it was hard to make a systematic and informed decision about which hospital should be visited. The Zero waste manager of Prezero mentioned that he is also working for UMC Utrecht hospital, and their recycling rates are considerably higher than in Erasmus MC and have other type of waste streams. Due to the convenience of this connection and the location, it was decided that UMC Utrecht is visited, and the waste department and waste system is observed. The following part concludes the main findings during the visit. All information is derived from the observations made there and the questions answered by the Prezero Zero Waste project leader, F.Ottens.

11.2.1 Recycling

UMCU is very proactive, their goals are more extensive than Erasmus, with a 45% recycling rate currently, which mainly comes from food and plastic collection. For comparison, Erasmus MC is around 18%. recycling rate.
There were certain improvements observed compared to EMC, the most relevants are listed below.

The hospital collects and recycles diapers, from departments where large number of diapers is produced. From children's hospital, the diapers are collected in the room, form adults, in the waste storage room because of the smell. White bins are used for the collection. The collection this way works very well, even though the nurses need to walk to waste storage rooms for collecting adult diapers. The distance this requires in not known. Based on the success from this hospital, it looks an interesting direction for Erasmus MC.

The food and organic waste (green colour) and the plastic (orange bin) 3 units are setup all over the hospital (overall around 600 units) and contribute to the recycling rates considerably (Figure 110). Apart from these units, the plastic waste is also separated in orange bags in the operation room for example (Figure 111). However, in the patient rooms, it is not used in UMC either.

A small but noticed improvement was that reusable textiles are collected in textile bags instead of plastic bags (Figure 111), as they are done in Erasmus MC. the textile bags can be washed together with its content and no waste is needed.

Figure 110. collection unit for food, plastic and residual waste

Figure 111. Waste separation bins for textile, plastic and residual waste in the OR

11.2.2 Infectious waste management

UMC Utrecht utilizes a sterilization device (Sterilwave 250 – discussed in literate review) used for part of (around 25%) the infectious waste, mainly coming from labs. The sterilization device is much more compact in size than the whole Pharmafilter system, but also the capacity is much smaller. The difference also is that the shredding happens only in the machine in the waste management unit, not on the departments.

The waste is more dust-like (Figure 112) than the output of the Pharmafilter. Instead of incineration it is being used as a substitute to sawdust for absorbent material. It is interesting approach, since the Pharmafilter output is just incinerated, following this example would be already a better option for that waste stream.

The use of the machine is in a pilot phase, and it took a long time to get permits and set up the even the pilot. These topics are handled very seriously, and it would take a long time also for Erasmus MC, but the precedent maybe already helps. According to F. Ottens, setting up an external sterilization and processing system would take years and years and many permits would be needed.

Figure 112. waste after sterilization in Sterliwave

11.2.3 Conclusions

This part of the research showed what type of waste is collected and recycled in other ICUs which are part of the Green ICUs initiative, what are their future plans and what problems they experience when waste separation is implemented. It was found in the research, that from examples of successfully implemented waste streams, plastic collection and diaper collection can be promising directions for the ICU in Erasmus MC and in the future collaborations should be made for plastic recycling with other ICUs as more than two third of them has the aim for this separation.

There is no known solution for recycling the infectious waste after sterilization and in-house sterilization is not a widespread solution for infectious categories. Erasmus MC is already further in this matter than most of the hospitals. However, the possibility of using the sterilized shredded waste as a substitute for sawdust in industry application was seen and could be explored for Erasmus MC as well.

Where a new sterilization is implemented, lots of permits and time is needed. Erasmus MC needs to invest in time and make it work next to the Pharmafilter, therefore this does not seem a feasible scenario. This conclusion was already made in previous part of the research (Chapter 7)

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