LAPPEENRANTA–LAHTI UNIVERSITY OF TECHNOLOGY LUT
School of Energy Systems Department of Environmental Technology
Circular Economy
Master's thesis 2022

Frans Duldin

HOSPITAL LABORATORY PLASTICS AND THEIR RECYCLING POTENTIAL

Examiners: Professor, Ph. D. (Tech) Mika Horttanainen

MD, PhD (Medicine) Leena Setälä

ABSTRACT

Lappeenranta–Lahti University of Technology LUT
School of Energy Systems
Department of Environmental Technology
Circular Economy

Frans Duldin

Hospital laboratory plastics and their recycling potential

Master's thesis

2022

87 pages, 23 figures, 8 tables, 2 appendixes

Examiner: Professor, Ph. D. (Tech) Mika Horttanainen, MD, Ph. D (Medicine) Leena Setälä.

Supervisor: Professor, Ph. D. (Tech) Mika Horttanainen, MD, Ph. D (Medicine) Leena Setälä.

Keywords: Plastics, Hospital recycling, Waste utilization technologies, Laboratory waste, Recycle economics, Hazardous plastic waste

This master's thesis investigates Finnish hospital waste systems and plastic waste recycling potential in laboratory environment both practically and economically. The main goal is to find more sustainable practices to use plastics in heavily regulated and demanding hospital laboratory environment, in purpose to promote circular economy in whole hospital waste management systems. This thesis provides an overview of current plastic recycling practices in Finnish hospital laboratory environment and around the world.

The results obtained from the data analysis showed that major part of hospital laboratories contaminated plastic waste are mixed plastics and disinfection wipes. Significant part of waste plastic type shares are able to process into uncontaminated state by laboratory staff and could therefore be recycled in current techniques in Finland. However, case data analysis of Turku University Hospital shoves that current recycling collection practices are not necessarily capable to keep up with up-to-date plastic recycling possibilities on hand, which has a negative effect on recycling efficiency. Based on data analysis, none of developed plastic waste excluding clear film plastic are not recycled due the lack of collection procedures. Because of this, most of the produced laboratory plastic waste at this moment end up into incineration. In addition, a share of laboratory waste plastics cannot be recycled due to hazardous properties at this moment, such as formaldehyde canisters. Therefore, new recycling and waste reducing solutions are suggested to increase recycling rate. For example, pyrolysis-based recycling technologies could treat safely contaminated plastic waste due high operation temperature, however this technology is still under development in Finland.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT Energiajärjestelmät

Ympäristötekniikka, Circural Economy

Frans Duldin

Sairaalalaboratoriomuovit ja niiden kierrätyspotentiaali

Master's thesis

2022

87 sivua, 23 kuvaa, 8 taulukkoa ja 2 liitettä

Tarkastajat: Professori Mika Horttanainen, Lääketieteen tohtori Leena Setälä

Avainsanat: Muovi, Sairaalakierrätys, Jätteiden hyödyntäminen, Laboratoriojäte, Kiertotalous, Vaarallinen muovijäte

Tämä työ käsittelee suomalaisen sairaalan jätejärjestelmiä ja sairaalalaboratoriomuovien kierrätyspotentiaalia niin ympäristön, käytännön ja talouden kannalta tehokkaimmalla tavalla. Työn päätavoite on osoittaa kestävimmät kierrätystoimintatavat voimakkaasti säädellyssä ja vaativassa sairaalaympäristössä. Tavoitteena on edistää kiertotalouden tavoitteita sairaalajätejärjestelmän suunnittelussa. Tämä työ esittää yleiskatsauksen nykyisistä muovikierrätyskäytännöistä suomalaisessa sairaalalaboratorioympäristössä ja muualla maailmalla.

Tämän työn tulokset osoittavat, että suuri osa sairaalalaboratoriomuoveista ovat sekoittunutta muovilaatua, jotka ovat peräisin kertakäyttödesinfiointipyyhkeistä ja niiden pakkauksista. Merkittävä osa muovijätteistä on mahdollista saada kierrätyskelpoisiksi riittävällä pakkausten huuhtelulla ja jaottelulla muovityypeittäin, nostaen nykyistä kierrätystehokkuutta merkittävästi. Kuitenkin Turun Yliopistolliselle keskussairaalalle tehty data-analyysi osoittaa, että sairaalan nykyinen kierrätysjärjestelmä ei ole täysin ajantasainen suhteessa saatavilla olevaan kierrätystekniikkaan, joka johtaa siihen, että kaikkia kierrätyskelpoisia muovilaatuja ei kierrätetä ja että suuri osa sairaalalaboratoriomuovista päätyy polttoon kierrätyksen sijaan. Tämä työ esittääkin kehitysvaihtoehtoja tämän ongelman lieventämiseksi.

Merkittävä osa sairaalan kontaminoituneesta muovijätteestä tulee laboratorioista. Osaa näistä ei voida käsitellä kierrätyskelpoiseksi puhdasta muovijätettä vastaavaksi muun muassa juridisista, - ja turvallisuussyistä. Esimerkiksi formaldehydikanistereita ei voi tällä hetkellä edellä mainituista syistä kierrättää. Tästä johtuen tämä työ esittää uusien tai kokeellisten kierrätystekniikoiden kehittämistä, jotta kaikki muovijätteet saataisiin kierrätyksen piiriin. Yksi vaihtoehto on pyrolyysi, joka on katsottu turvalliseksi kierrätysmenetelmäksi sairaalajätteelle, vaikkakin tämä teknologia on vielä kehitysvaiheessa.

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation the staff of laboratory units at Turku University Hospital who helped me in this project. Thank you for your time and kindness despite your work pressure.

I would also like to acknowledge the assistance of my supervisor Leena Setälä for help of gaining materials on conducting this thesis.

This thesis was carried out under VSSHP (Varsinais-Suomen Sairaanhoitopiiri) research permit (T213/2021) admitted by Turku CRC.

In Pori 3 January 2022

Frans Duldin

TABLE OF CONTENTS

APPENDICES

LIST OF SYMBOLS

Abbreviations

a	year
BAT	Best Available Techniques
°C	Celsius
CAM	cross-alkane metathesis
CO_2	Carbon dioxide
cm	centimeter
e.g.	exempli gratia, “for example”
Eksote	South Karelia Social and Health Care District
EPR	extended producer responsibility
EUR	Euro
EU	The European Union
FEAD	European Waste Management Association
FT-NIR	Fourier Transform Near Infrared
g	gram
GGHH	Global Green and Healthy Hospitals
ISO	Organización Internacional de Normalización
IV	intravenous fluids
IVAR	intermunicipal companies
IH2	Integrated hydropyrolysis and hydroconversion
kg	kilogram
kt	kilo tonne
KDV	Katalytische Drucklose Verölung
KYS	Kuopio University Hospital
LCA	Life Cycle Assessment
LSJH	Lounais-Suomen Jätehuolto Oy
L&T	Lassila&Tikanoja Oy
ml	milliliter
MSW	Municipal solid waste

MHz	Megahertz
NRMW	non-regulated medical waste
PPT	Pots, Tubes and Trays
SDG	Sustainable Development Goals
SOP	Standard Operating Procedures
SME	small and medium-sized enterprises
SOP	Standard Operating Procedures
SRF	Solid Recovered Fuel
t	tonne
TAYS	Tampere University Hospital
VTT	Teknologian tutkimuskeskus
VSSHP	Varsinais-Suomen Sairaanhoitopiiri
TYKS	Turku University Hospital (Turun Yliopistollinen keskussairaala)
WHO	World Health Organization
>	Bigger than

1 INTRODUCTION

Global sustainability can be summarized and described by acknowledging seventeen Sustainable Development Goals (SDG) proposed and adopted by all United Nations Member States in 2015. Among those SDG's priority, the role of sustainable material use is clearly devoted as one of the main facilitators for ensuring sustainable consumption and production patterns. For example, (Goal 12) promotes encouraging, reducing, reusing and recycling. Goal 3 promotes good health and well-being by ensuring clean medical products. And finally, Goal 13 states about climate actions by reducing burning fossil-based products and therefore reducing CO_2 emissions (United Nations, 2015.) All these goals emphasize about responsibly acts in medical sector. These goals also determine in many ways success in reaching of the SDG's, because they contribute to the health, world's economy and forms a healthier symbiosis of human–natural recourses interactions.

However, single-use plastic products are considered unreplaceable for today's society, including healthcare and in laboratory work. Reasons for this are numerous, they are inexpensive, durable and versatile. Thus, plastic consumption is estimated to grow constantly in the future, especially in developing countries (Mmereki 2017; Al-Hanawi et al. 2020; Purohit 2001; Kuchibanda 2015; Patience&Bouwer 2008). Because of growing demand, plastic has become global environmental problem as it ends in nature as untreated or without utilization (Plastoposeeni 2021) Plastic products have been produced since 1950's proximately 9,2 billon tons in total (Plastoposeeni 2021). From this amount, about 9 % is recycled, 12 % has been burned and the rest, 79 % end up in landfills or into nature. (Kohvakka&Lehtinen 2019, 9.)

In Finland and Finnish hospitals, paper, cardboard, glass and metal are well recycled while other hospital waste materials are usually incinerated for energy production, including plastics. Hospital's operation rooms are recognized as the main source of plastic waste while laboratories as the second important source.

There is still much room for improvement in plastic recycling at EU and international level. Only a small fraction of plastics, 15 % is recycled in Europe. (C&EN 2019). In addition to this, plastic strategy was accepted, which objective is to gain 100 % recyclability by 2030 for all plastic products. (EU Parliament 2018) Original target time frame was that 55% of all plastic products would be recyclable or could be reused by 2025 which has been estimated as a tight timeframe for Finland (HE 40/2021). In Finland, annual volume of plastic waste is about 200 000 tons (HSY) and recycling rate is about 27 % (L&T 2021). About 95 000 tonnes per year are currently collected, about one third of which comes from municipal waste and two thirds from industry. According to Statistics Finland, about 39% of separately collected municipal plastic waste is recycled, 60% is utilized for energy and 1% ends up in landfills. Finland has had a ban on organic waste landfills since 2016, which also prevents plastics from being sent to landfills in the future. (TEM 2019)

The specific characteristics of hospital waste and its recycling have not been much studied, even less in Finnish perspective. Hospital and laboratory plastic waste management and utilization possibilities are poorly known and less researched in Finland, when compared to other countries. When searching written academic articles and other official sources, most of the current research in this field is originated from current and former commonwealth countries. The research area is also young, as most of the articles and journals are dated in recent years, at the end of 2010's. Thus, to understand the possibilities and limitations of recycling hospital and laboratory plastics, plastic waste streams should be investigated and analyzed for both quality and quantity, because all new data is required to gain the best understanding of this issue.

Laboratory plastics consist mostly clean packaging plastics and contaminated laboratory products after use. There is much regulation on laboratory waste and heavy restriction in recycling methods. Laboratory waste may consist potentially toxic and biohazard materials such as blood and urine. Therefore, laboratory waste is partially hampered by contamination resulting in high variety of plastic waste streams (C&EN 2019). In addition, laboratory plastics often includes personal identification information which cannot dispose by regular methods and therefore requires separate and costly collection and disposal. In laboratory environment, volumes of plastic products and packaging materials are remarkable. On average, the laboratory personnel can annually equate to 70–100 kg per person laboratory level plastic waste. At the same time, hospital plastics must meet constantly high quality and hygiene standards, and recycled plastics are seldom considered as today's mainstream raw material. (C&EN 2019).

COVID-19 pandemic has increased healthcare plastic consumption and also caused challenges in MSW (municipal solid waste) management. Medical waste comprises the waste generated by for example from medical laboratories, hospitals and biomedical research facilities. Unsuitable treatment of this waste poses serious risks of disease transmission for waste collection personnel, waste workers, healthcare workers and patients. Eventually, poor waste management may emit harmful and deleterious contaminants and infectious agents effecting a whole society. For example, contamination with contagious agents such as the COVID-19 virus and the volume of the waste generated through increased use of protective garments has created remarkable instability in healthcare waste treatment and following recycling. (Das et al. 2021, 1.)

1.2 Objective

Relatively small number of academic publications have been published reviewing hospital waste management systems. Few of them consider specially laboratory plastic waste management, respectively. However, these publications are quite recent, and other articles about hospital plastic waste management are widely found, reflecting the increasing interest in this subject.

Research question

What are main plastic waste streams in Turku University Hospital (TYKS) laboratories and their grade?

Objective

- To determine quantity of generated plastic waste in a Finnish hospital laboratory environment
- To define the main plastic types and their proportions in hospital laboratory environment

Research question

Which are current treatment methods in TYKS and what is the annual amount of generated clean plastic waste and what is their grade distribution in TYKS laboratories?

Objective

- To obtain first-hand information how plastic recycling can be improved in case of TYKS.
- To determine which factors causes when plastic waste is recyclable or not.

This thesis leaves out of its scope the plastic products which are part of current TYKS deposit system, in addition plastic single use gloves and clothes. Plastic waste contaminated with radioactive or toxic substances or containing human tissue are excluded from the thesis because their value in recycling is considered minimal. Also, plastic film waste was excluded because it was already efficiently collected at TYKS. Because significant part of TYKS materials is not open for public, unofficial data sources such as e-mails must be used.

2 PREVIOUS RESEARCH AND CHARACTERISTICS OF PLASTIC WASTE

The generation, disposal and composition of hospital waste both clean and hazardous, as well as the risks, have been studied largely in developing countries. These studies focus mostly on characteristics in specialized public waste schemes such as hospitals. This is not the case in developed countries where the focus has been more household waste and MSW (Municipal Solid Waste)-systems overall, thus studies seem to be smaller in numbers. Studies considering plastic recycling potential consider mostly household plastic waste rather than hospital waste. However, there are a small number of studies carried out, specifically for hospital laboratory plastic waste, mostly from commonwealth countries and Europe. But when the scientific articles were searched by using words like "plastic" and "utilization" and "recycle" in context of hospital or laboratory, results were used to be very scarce or totally absent. When writing this thesis, there were not many hits on hospital or laboratory waste plastics. What can be drawn as a conclusion from above, previous articles are considering purely circulation potential, composition or other related characteristics considering hospital plastic waste. One reason for this might be relatively small field of operation, being at the same time under heavy regulation. This might make studying this subject relatively more challenging compared to household plastic waste or MSW, where required data is relatively more accessible. Even though previous research of hospital plastic waste is scarce, it does not mean that the subject on hand is not important. The problematics behind plastic waste are already recognized and therefore importance of increasing the studies in this field is demonstrable in the future. This field of subject in question can be seen just smaller but more accurate and complex field of operation what comes to plastic waste recycling and related issues such as composition.

2.1 Characteristics of plastic waste

Plastics are petrochemical products which require proximately 4 % of annual global oil production (Kohvakka&Lehtinen 2019, 123.), (Muoviteollisuus 2021). In 2019, plastic production and incineration emissions were like the emissions of 189 coal power plants. Emissions has estimated to have 44 % increase in crude oil consumption by 2040, where demand of plastics has suggested to be a key driver. The basic life cycle of plastic products is presented in **Figure 1** below. (HCWH Europe 2021, 8.)

Figure 1: Conventional life cycle of plastic products. (HCWH Europe 2021, 8.)

Plastics are produced in several types and each plastic types have different properties suitable for different tasks and therefore their demand varies as shown in **Figure 2** below.

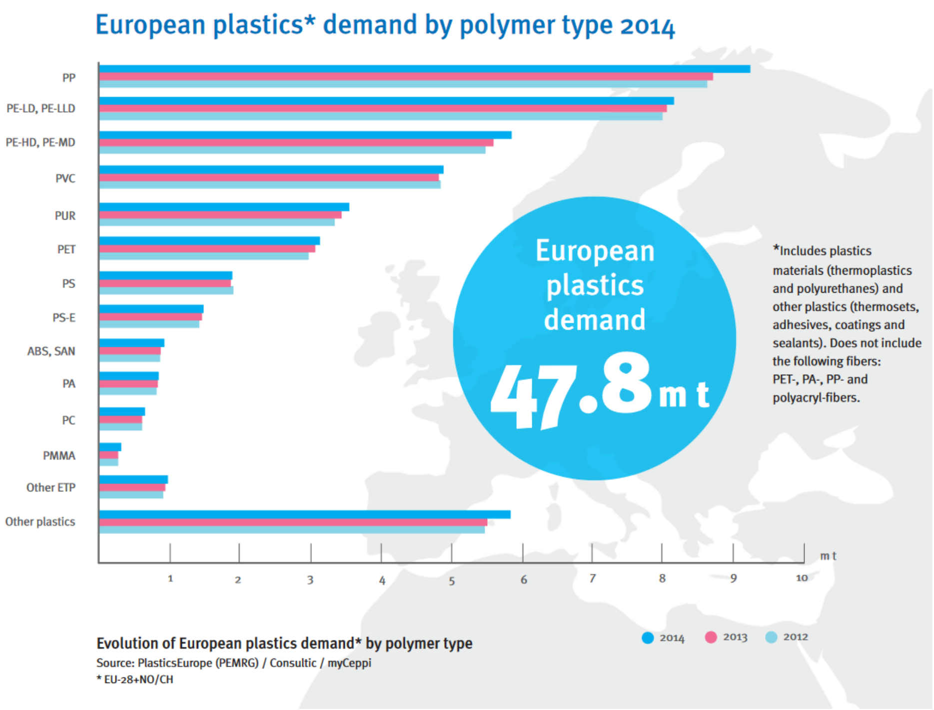

Figure 2: Evolution of European plastics demand by polymer type. Mt stands for million tons (plasticseurope 2015).

Plastics are divided roughly in three types, main plastics, technical plastics and special plastics, depending on their use. In structure aspect, plastics are divided into single use plastics and thermoplastics. Single use plastics cannot re-edit, because structure breaks up when heating. Only thermoplastics can be recycled. (Plastoposeeni 2021). In **table 1**. below is presented most used plastic types in Finland, their material markings, common properties and examples of common use purposes.

Table 1. Most common plastic types and their symbols in use in Finland. (Palpa 2021).

Material marking	Name	Common properties	Examples of use
01 PET	Polyethylene-tereftalate	Transparent, light, hard, chemical reistant.	Detergent-, soda etc. -bottles. Bottles with deposit must return to PALPA recycling systen.
02 PE-HD	High-density polyethylene	Cloudy or colored, moisture resistant, flexible, most common and economical plastic type	Plastic bottles and jars
03 PVC	Polyvinyl chloride	Multi-purpose and versatile, poor recyclebility, causes noxious chlorine gases when incinirated	Rarely packaking material, **not suitable for plastic recycling scheme in Finland**.
04 PE-LD	Low-density polyethylene	Light, soft, vaxy surface, transparent, moisture resistant, flexible, most common and economical plastic type	Plastic bags, clamping film
05 PP	Polypropylene	Most second used type in europe, stiff, hardy, multipurpose.	String, freezer packaking, plastic film, outdoor products
06 PS	Polystyrene	Transparent or colored, fragile, when foamed: Expanded Polystyrene (EPS)	Stuffing, freezer packaking
07 O	Others	Combinations of all of the above	Packaking jars, covers, bags

Marking requirements are originated from Government Decree on packaging and packaging waste (518/2014) 6 §: The packaging placed on the market may be marked to identify the materials used in it as shown in **table 1**. The marking shall be made on the package or on its label. The label must be clearly visible and legible even after opening the package.

If needed oil for energy to process plastics is also calculated, total amount of required oil rises into of annual global oil production 10 % (Plastoposeeni 2021). Annual plastic production was 355 million tons in 2016, which Europe's share was 60 million tons, most, approximately half of global production is located in Asia. (Plastoposeeni 2021). In Finland, annual plastic production is about 600 000 tons, which consist of most common plastic qualities (PVC, PP, PS, PE,) (Muoviteollisuus 2021). Most common application for plastics, is packaging industry both Finland and globally, where 40 % of Europe's plastic production goes into packaging products and 16 % for furniture and health care production, see **figure 3** below**.** (Plastoposeeni 2021.)

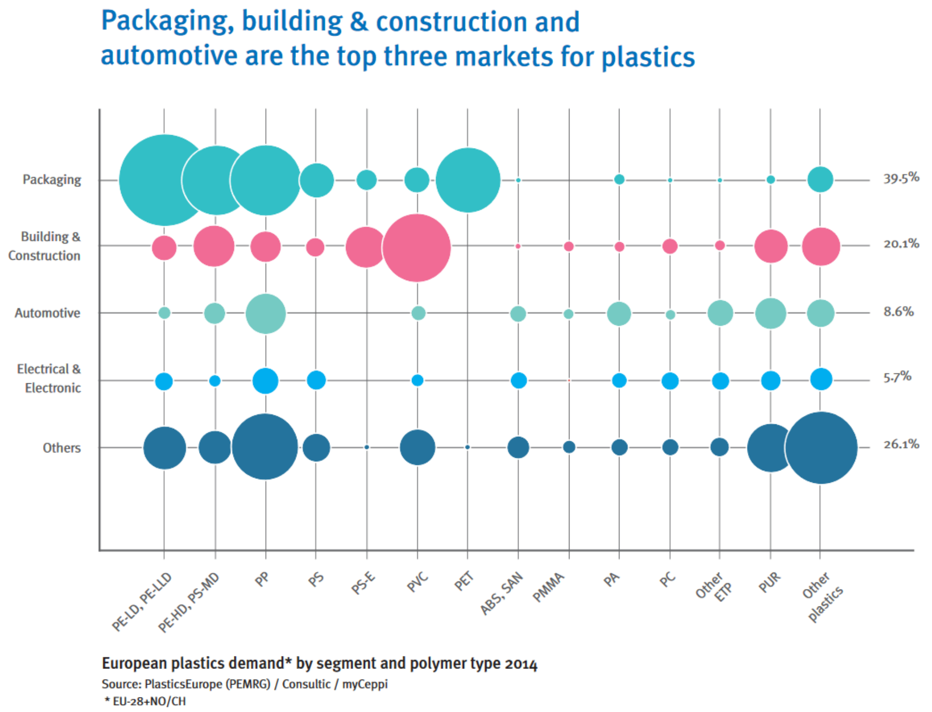

Figure 3. Plastic demand in Europe by segment (plasticseurope 2015).

The recycling potential for plastics depends heavily on the polymer type and level of contamination currently present in the waste stream. (Kleinhans et al. 2021.) Plastic shares can be explained by the diversity of size and types, specifically a share of 58% are film, 24% are bottles and flasks and 18% are pots, trays and tubes (PPT). Rigid plastic and plastic film are confirmed to be the largest plastic types in municipal commercial waste, according to Kleinhans et al. (2021). Share of generated plastic type and waste stream sources are presented in **table 2** below.

Table 2. Share of generated type and polymer of commercial and industrial packaging waste in the EU at 2014. All values are in [%]. PTT stands Pots, Tubes and Trays (PTT) (Kleinhans et al. 2021)

	Share	PET	HDPE	LDPE	PP
Bottle/flask	24	9	86	/	5
PTTs	18	27	32	0	41
Films	58	1	0	83	16

Most plastic waste consists from packaging waste. In 2016, 107 000 tons of non-pledged plastic packaging waste were generated in Finland, which is one of the lowest in Europe of its class. About 62 % of all plastic waste in Finland ends up in energy recovery. According to estimates, about 220,000 tons of plastic waste still ends up in mixed waste in Finland, where the majority ends up in energy recovery. It is not common in Finland to sort plastics mechanically from mixed waste and the efficiency of the processes in this respect varies depending on the technology used. The profitability of post-sorting is noted to be weak with current technologies compared to pre-sorting method. However, these methods combined would remove the last percentage of plastic from mixed waste, which would cost, according to some estimates, as much as the first 50%. (TEM 2019)

The goals for the recycling of municipal waste (including preparation for re-use) for 2025, 2030 and 2035 in accordance with Article 11 of the Waste Framework Directive are seen very strict timeframe for Finland. The new rules for calculating the recycling rate under the amendment to the Directive are likely to reduce Finland's current recycling rate by a few percentage points (approximately from 43 % to 41 %), which will increase the challenge further. Based on a statistical comparison, Finland is currently at the average level of EU countries in plastic recycling. However, it’s worth the mention that the statistics are not comparable between different countries, as the methods for calculating the recycling rate and the definitions of municipal waste still differ considerably. (HE 40/2021).

However, plastics can be made from alternative materials than fossil-based oil, e.g., bio-based plastics. They have similar properties compared to crude oil-based plastics. This means that bio-based plastics will not necessarily decompose. According to EU-standard EN 13432, to be included into bioplastic, it requires that the compostable plastics must disintegrate after 12 weeks and completely biodegrade after six months. This means that proximately 90 percent or larger share of the plastic material will have been converted into CO_2. The remaining share must be converted into water and biomass. (European bioplastics 2021)

Most of plastics can be produced from bio-based materials but this business is still marginal. At this moment, bio-based plastics are expensive, affected by problematics in synchronization into plastic production line and high adaptation requirements compared to crude oil-based plastics. (Kohvakka&Lehtinen 2019, 116.) However, business is growing in this field constantly. It has been estimated that in long term, proximately 85 % of all plastics can be produced as biobased. As stated before, most important reasons to move towards bio-based plastics are sustainability reasons. Most known materials for biobased plastics are sugar cane, animal fats, mushrooms, algae and bacteria. However, these plastics are rarely 100 % biobased, because mixing these materials into crude oil is common practice. (Uusitalo 2017, 115, 1.). However, biomaterials compete with the cultivation area for both food and biofuel production. Despite this, biomaterials are seen as a global answer to littering problem and is a way towards carbon neutral society, for practical and feasible solution.

There are solutions that would not compete limited recourses such cultivational land area. One solution would be to utilize waste streams for plastic production. (Kohvakka&Lehtinen 2019, 116). In Finland, there has been some interest to use cellulose as bioplastic raw material. However, when considering required land use, emissions and eutrophication incompatibility of bioplastics are not necessary more sustainable option when compared to conventional plastics. (Uusitalo 2017, 234.), (Kohvakka&Lehtinen 2019, 127, 21.). Consumption and the resulting emissions play a key role to solve these issues. (Plastoposeeni 2021)

Both PE and PET products are by tradition considered as non-biodegradable plastics. However, by using microbes they able to be able to make biodegradable by using different methods such as transforming degrading and metabolizing. However, there are many problematics to make this possible. The main problem considers the degradability because it depends on remarkably of the nature of molecular bonds in plastic polymers. Therefore, new kind solutions are required which includes the integration of mechanical, biotechnological, thermochemical and chemical recycling techniques. (Drzyzga&Prieto 2019).

According to Kleinhans et al. (2021) numbers of studies are limited what comes to the recycling potential of hospital waste materials or other non-household sources. Major part of

plastics, which are major part of mixed commercial waste, can be recyclable. However, because of technical problematics like disassembling of composites or contamination, this has not seen economically practical. Therefore, plastic waste is generally utilized as solid recovered fuel (SRF) because plastic waste has a high caloric value with low content of water. It is a shame, because there is a big potential to increase plastic recycling rate from mixed waste because plastics from mixed waste can be considered mostly as cleanable and therefore recyclable by conventional methods. In EU, potential for increasing recycling is recognized while share of plastic waste from non-household sources are evaluated to be between 10–30 % in the future. (Kleinhans et al. 2021.)
According to Orion pharmaceutics company, substantial pharmaceutical operator in Finland, their empty medicine plastic packages are recyclable by normal recycling methods. (Orion, 2020).

Table 3. Waste stream sources of recycle rate [kt/a] in Australia by polymer type (2015–2016). Percentages are the shares of collected plastics into recycling for each plastic type. (Kleinhans et al. 2021)

Polymer	Municipal		Commercial and industrial	
PET	64.20	40%	8.40	5%
PE-HD	63.90	40%	31.00	20%
PVC	1.60	1%	2.70	2%
PE-LD/LLD	2.80	2%	66.00	42%
PP	19.00	12%	21.40	13%
PS	4.10	3%	4.10	3%
PS-E	0.10	0%	7.80	5%
ABS/SAN	–	0%	4.00	3%
PU	–	0%	6.20	4%
Nylon	–	0%	0.50	0%
Other	5.50	3%	4.20	3%
Unknown polymer	–	0%	2.50	2%
Total	161.2	100%	158.8	100%

As shown in **table 3**, PE-HD with PET are most collected plastics in municipal sector, where PE-LD is most collected in commercial and industrial sector. Collection costs of non-household waste are significantly lower compared to post-household waste as there are more consistent and the amounts are generally large. (Kleinhans et al. 2021)

2.2 Plastic waste treatment methods

What treatment methods are required that recycling of laboratory plastics can be done sustainably and safely? In **figure 4** below is presented the shares of most usual plastic treatment methods but also shares of untreated waste streams presented as leakage. As a note, some part of the waste ends up untreated into nature as a litter or dumped in landfill in global scale which is a major concern. In context of Finland, plastic waste is the most common type of litter in the Nordic countries. Baltic Sea coast marine litter has social, environmental and economic impacts with on both commercial activities and ecosystem services which have affects to Finland (Fråne et al. 2015). Therefore, plastic waste must be treated efficiently to avoid the problems mentioned above.

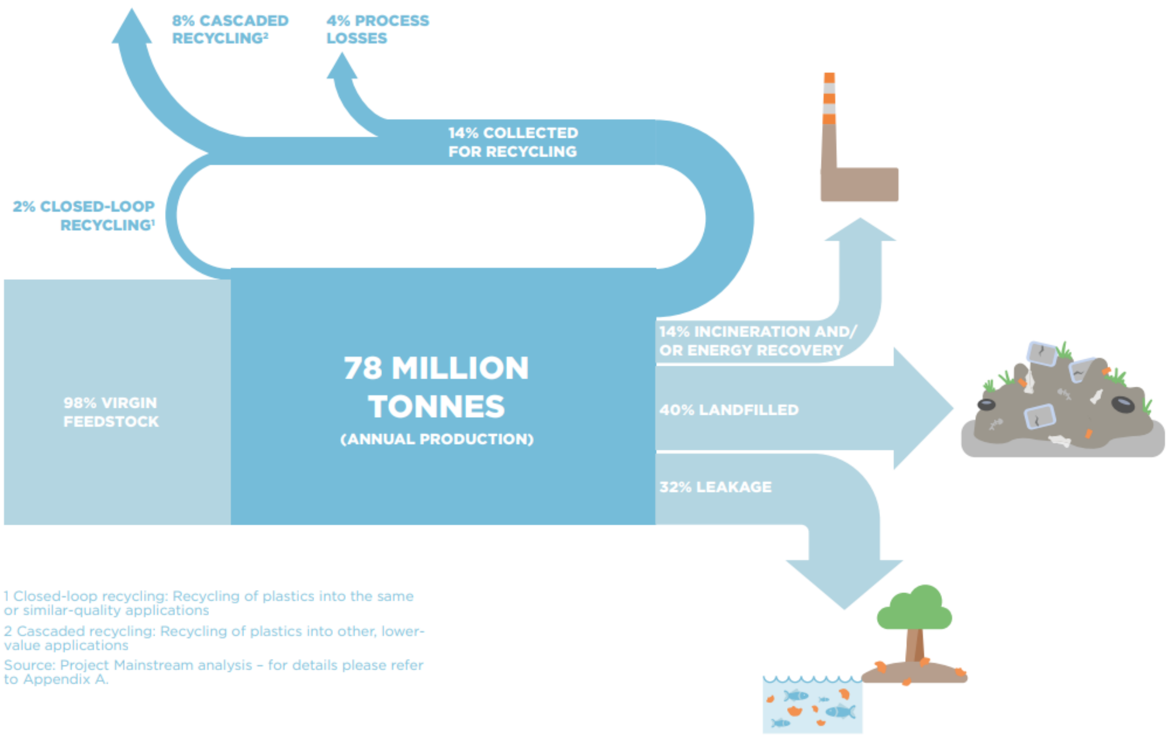

Figure 4. Global flows of plastic packaging materials in 2013**.** Cascaded recycling stands for mechanical recycling. (World economic forum 2016)

2.2.1 Landfilling

While most of global plastic waste ends up in landfill, the landfill disposal method for plastics and hospital plastic waste became in Finland illegal practice since 2016 (see **Figure 5**). In 2018, the Directive amending the Landfill Directive (2018/850 / EC) entered into force, which transposed into national legislation by the July 2020. The directive promotes the implementation of the waste hierarchy, aims to increase recycling and re-use and seeks to promote the transition from landfill to waste incineration. Restrictions on landfilling apply to all waste that is suitable for recycling or other recovery of materials or energy, including a few exceptions. The main addition to the directive is that, from 2030, no waste suitable for recycling or other recovery should be landfilled, especially with municipal waste, unless landfilling is the best option for the environment. (Suomen ympäristö 2018, 18.)

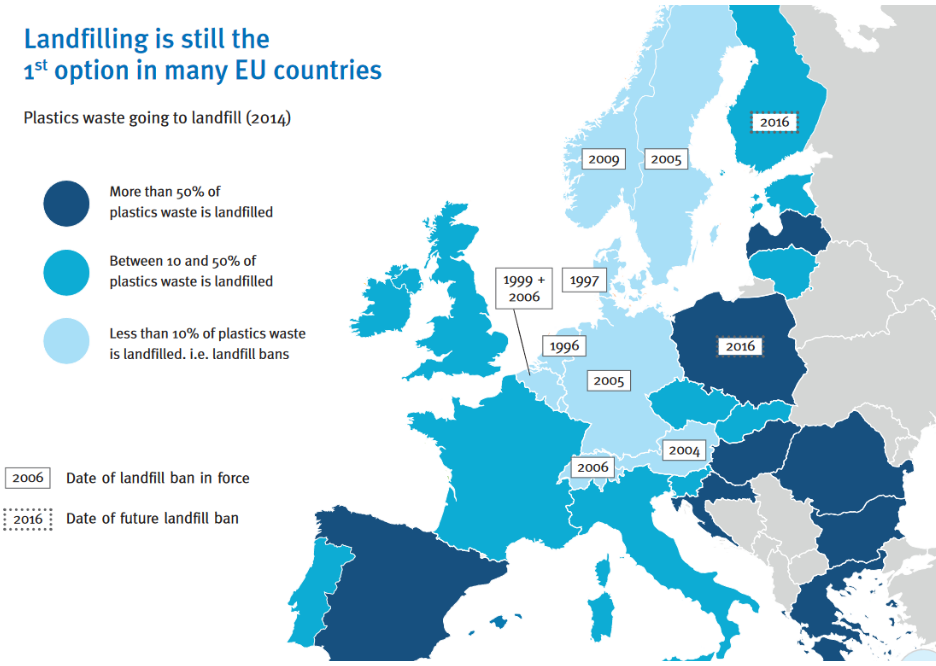

Figure 5. Approximate proportion of plastics going to landfill and landfill bans in force in Europe. (plasticseurope 2015)

However, rapid increase in healthcare waste volumes caused by COVID-19 has led in Teheran into situation where all the collected MSW are now being buried/landfilled, approximately 7500 tonnes per day, without carrying out any further process. After the outbreak of Coronavirus, landfilling of wastes in Tehran increased by 34.7 %. Approximately 37.9 % of the total wastes generated at Tehran’s hospitals were infectious before the COVID-19 pandemic. This is significantly greater than value for hospitals (< 15 %) estimated by WHO (Zand&Heir 2021). As presented the Teheran situation above, same kind of situation is not credible scenario to happen in Finland where incineration plants are plenty. But if Teheran’s scenario happens in Finnish conditions, most of hospital plastic waste end up incineration any way due to this day.

It is true that burning hospital waste instead of recycling is not the most efficient utilization method, but it is safer method compared to landfilling. Therefore, waste management officials would most likely give incineration permits to conventional MSW incineration plants for all hospital waste with fixed duration and terms instead of landfilling. In addition, crude oil-based plastic products of all sorts have commonly high energy content. Despite this, when plastics are burned it causes carbon dioxide emissions with toxic fumes and causes corrosion. When compared to laboratory plastic waste, their contamination is based on chemical and biological substances which will become harmless when burned in high temperatures. Therefore, contaminated plastics will not end up into waters or into nature. Incineration plants in Finland have high efficiency rate with advanced flue gas cleaning systems, designed to incinerate plastic waste safely. Same plastic types are presented in laboratories as in MSW, so no changes are required into incineration process from this aspect. (Uusiouutiset 2013; Plastoposeeni 2021)

In conclusion, if plastic waste cannot be treated by using traditional methods, in emergency it would be both heath and emission prospect better to incinerate contaminated plastic waste rather than dump it into landfill by fulfilling minimal safe burning temperatures set by WHO (WHO 2020). Incineration will be discussed further in chapter **2.2.3**.

2.2.2 Mechanical recycling

Mechanical recycling suits the most common plastic waste types, such as bottles, bags and wraps. Mechanical recycling process includes sorting, washing, melting and molding when processing into new products. However, there are still problems to make mechanical recycling process efficient. Especially multi-layer plastic films cause problems in technical aspect. Also, the quality of plastic decreases when going through the number of recycling loops. Eventually the plastic comes unable to be recycled. Thus, separately collected plastic in Finland may end up into incineration in some cases. The amount of this is proximately 40-60 percent of waste which can be considered high, despite the limited numbers of plastics recycling loops. (VTTNews 2019)

For example, Netherlands have invested in the post collection or mechanical separation of plastic waste since 2013. What has been found is that the costs of recycling plastic waste using post-separation seem to be lower than for home/ on-site separation. Data has shown that costs for post-separation are lower in remarkable way. Therefore, it can be concluded that cost-effectiveness may increase when using a post-separation method. (Gradus 2020, 12)

In mechanical recycling, laboratory plastics with impurities or contaminants can be seen problematic. Washing the plastic products may be a solution but all containers cannot be reasonably washed for practical or environmental reasons. For example, formaldehyde, which is commonly used in pathology laboratory, cannot be poured in communal sewer in Finland. Consequently, different waste plastic products may require wide scale source separation based on their content residues. As a result, post separation would be problematic solution in mechanical recycling. Thus, pre-separation may be required for mechanical recycling. This could be pre-sorting by plastic type and/or contamination lever. However, the presence of wide variety of contaminated plastics for mechanical recycling will pose risks for reaching the safety and quality requirements of plastic granulates. As a result, recycling of all hospital laboratory plastics by using only mechanical recycling cannot be seen as a preferred and only solution.

2.2.3 Chemical recycling

In chemical recycling process, depolymerization breaks down plastics into their raw materials for conversion, back into new variety of polymers (C&EN. 2019). Thermolysis (pyrolysis) of plastics means thermal or catalytic decomposition of a material in an oxygen-free environment or in presence of steam into liquid product for fuels or chemicals (VTT 2019). Oil from pyrolysis can be distilled into separate monomers. For instance, into diesel and other fractions, where some of can be utilized directly as fuels and some as raw material for plastics and other chemicals. (VTT News 2019) However, chemical recycling is not practically feasible unless it is deployed at large scale. (C&EN 2019). For instance, industrial chemical recycling processes for polyurethanes require imperatively a residue separation. This makes difficulties for its applicability. (Simón et al 2018.)

So far, for pyrolysis the supply of plastic waste in Finland has been considered as inadequate. Despite this, calculations show that a network of approximately ten pyrolysis plants could prove economically sufficient. This could be possible if plastic waste is attached with wood waste when running pyrolysis. This is the reason why pyrolysis plants are suggested to be attached into conventional waste recycling units in Finnish conditions. (VTT News 2019)

In **table 4** below is presented mechanical and chemical recycling methods, properties, advantages, and challenges compared to mechanical recycling.

Table 4. Summary of used techniques, advantages and challenges of mechanical and chemical recycling. FT-NIR stands for Fourier Transform Near Infrared, IH2 stands for Integrated hydropyrolysis and hydroconversion. KDV means (Katalytische Drucklose Verölung) or the catalytic pressureless depolymerization process. (Ragaert et al. 2017. 60, 61.)

		Technique	Advantages	Challenges
Mechanical recycling	sorting	Flotation (sink-float)	Well-known technology	Efficiency determined by density differences plastics
			Cost-effective Particle size	Mainly limited to binary mixtures
		Melt filtration	Useful to remove non-melting contaminants	Potential pressure fluctuations in production
			Additional melt pressure	
		FT-NIR	Post-drying not required Well-known	Black undetectable Plastic should be dry
		Tribo-electric (electrostatic) separation	Efficient for various plastics Small particle sizes allowed	Pre-treatment
		Froth flotation	Efficiency	Precursor step required In development for recycled plastics
		Magnetic density separation	Improved density-based technique Multiple polymer fractions in a single step	Density overlaps remain
		X-ray detection	Accuracy Useful for PVC	Cost-effectiveness
	Reprocessing		High value recycling Well-known technology Straightforward	Thermal-mechanical degradation Challenging for complex mixtures Miscibility of polymer blends
Chemical recycling	Chemolysis		Generates pure value-added products	Requires high volumes to be cost-effective
			Operational for PET	Mainly limited to condensation polymers
	Pyrolysis		Suitable for highly heterogeneous mixtures of plastics	Complexity of reactions
			Simple technology	Requires high volumes to be cost-effective Low tolerance for PVC Stable waste supply
	Fluid Catalytic cracking		Narrow product outcome Less stringent reaction conditions leads to favourable economics	Deactivation of catalyst Absence of suitable reactor technology Presence of inorganics
	Hydrogen technologies	Hydrocracking	Quality of produced naphta Suitable for mixtures of plastics	High cost of hydrogen High investment and operational costs
		IH^2 process	Promising technology for the production of liquid fuels out of biomass Different elements already commercialized	Further research required
	KDV process		Also suitable for oxygen and halogenated compounds	Chemistry still unknown Lack of technical information
	Gasification		Syngas is a valuable intermediate Cost of air Well-known technology	Amount of noxious NO_x Specific drawbacks of air

2.2.2 Thermo-chemical energy recovery and disposal methods

Incineration is one of the most common thermo-chemical post-treatment method in Europe as shown in **figure 6** below. Incineration is a high-temperature dry oxidation process which reduces combustible and organic waste to incombustible, inorganic matter and results in a very significant reduction of waste weight and volume. This method is used when wastes cannot be reused or recycled any other way. Because of process safety of compromising biohazard materials and simplicity, it is most selected utilization method for hazardous health-care wastes. WHO has recommended to treat healthcare wastes at temperatures between 900 °C and 1200 °C (WHO 2020).

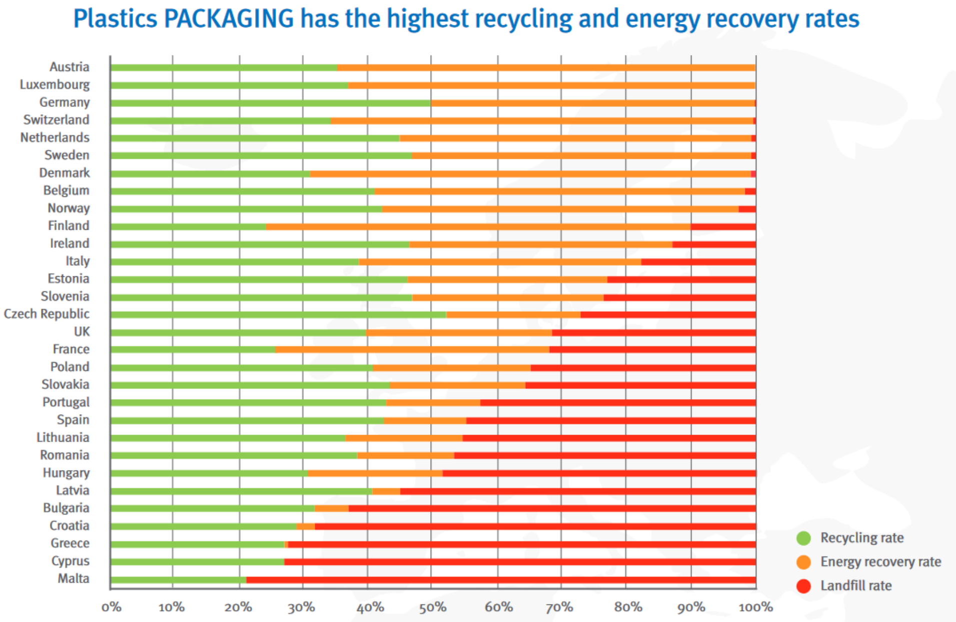

Figure 6. Packaging recycling and energy recovery rate by country (Referred to post-consumer plastic waste) (plasticseurope 2015)

The combustion of organic compounds produces mainly gaseous emissions, nitrogen oxides, carbon dioxide, particulate matter and toxic substances like halogenic acids and solid residues such as ashes which may include toxic compounds. If the burning process is not happened in correct conditions, toxic carbon monoxide may also occur.

Finland has winter seasons with cold climate. Most modern, big scale incinerators include energy-recovery possibilities to produce hot water and steam for urban-district use. Pyrolytic incineration is the most used and reliable treatment process for health-care waste. For hospitals, specific technical characteristics of pyrolytic incinerators are designed. Based on this, there are different suitable facility types. For instance, thermal decomposing is happened in the pyrolytic chamber process the waste where the temperature is about 800–900°C. (WHO 2020)

Studies on the environmental impact of plastic waste have presented for thermo-chemical post-treatments, such as pyrolysis or incineration. Studies has resulted further decrease of the environmental effects, in comparison to landfilling for instance. Furthermore, incineration has dropped from the European Commission's list of green investment label criteria. This may lead into conclusion that waste-to-energy-method is not classified as sustainable utilization method which may cut off the investments completely according to European Waste Management Association (FEAD). Individual countries can still fund and commission new incinerators. These plants could still make profit from waste-disposal fees and by selling heat or electricity. But incinerators are found to be expensive to build, and countries often depend on EU funds to help fund for them. Scandinavian countries already have enough capacity to treat unrecycled waste, and some are even closing facilities in a bid to meet their climate ambitions Fråne et al. (2015) states. The reason for EU to back down from incineration utilization method is that EU does not want to move from landfilling to incineration instead. Therefore, totally different utilization method towards recycling shall be aided instead. Once built, incinerators undermine recycling, because municipalities are often locked into contracts that make it cheaper to burn trash rather than sort and send it to recyclers. Incinerators have also released out an estimated 95 million tons of CO_2 in 2018, about 2 percent of total emissions for the EU and the United Kingdom. However, presence of leftover waste that cannot be recycled is today well recognized, especially hazardous waste such as all the COVID-19 medical waste are to be incinerated. (BAN 2021). Considering funding possibilities, limitations to waste incineration solutions into future have therefore impact also on Finland. However, there should always be possibility to incinerate contaminated plastic waste to secure safe waste utilization in all situations despite the presence of other suitable recycling technology as a back-up system.

2.3 Future potential solutions for laboratory plastic recycling solutions

Despite plastic waste current limitations for recycling, one of the most promising future chemical recycling technologies are rapidly increasing. Chemical recycling approves the plastic qualities which cannot be recycled or are difficult to recycle. For instance, plastic remnants from other recycling processes, heavily contaminated and multi-layered plastics. Coherent understanding and definition are in key role to improve the potential in chemical recycling. (Plastic Recycles Europe 2021). For example, Paraschiv et al. (2015) have studied the evolution in thermochemical behaviors of hospital plastic wastes, and changes in chemical composition and characteristics of pyrolysis liquid products. (Simón et al. 2018.)

Zhao et al.'s (2018) study indicates that separation of multi-plastics is effective and efficiently enabled by the magnetic levitation process, which provides an environmental and promising approach for mitigating plastic streams and therefore improving mechanical separation. However, this technology is not in industrial scale use. (Zhao et al. 2018)

However, end-of-life treatment options for plastic solid waste are limited in practical level what comes to mechanical and chemical recycling. Presorting of plastics before recycling procedure is found to be both time-intensive and labor costly, recycling requires huge amounts of energy and often tends to lead to low-quality polymers. Hence, current technologies cannot be applied to many polymeric materials. Recent Garcia & Robertson's research (2017) introduces a possible future option towards chemical recycling. These options include methods with compatibilization of mixed plastic wastes to avoid the need for sorting and expanding recycling technologies to traditionally non-recyclable polymers and with lower energy requirements. (Garcia & Robertson 2017)

Other potential future plastics recycling method would be fluidized bed pyrolysis of waste, where polymer composites for oil and gas recovery and polystyrene are particularly suitable feedstocks for this kind of process. For the bigger part of this residue, pyrolysis process is found to be an appropriate method for utilizing the plastic material. It is evaluated that with more reliable process of fluidized bed pyrolysis, it could compete with incineration plants. (Goodship 2010)

Moreover, pyrolysis offers the advantage via bio-oil and char production with high calorific value. This bio-oil can be used as fuel. (Antelava et al. 2019) However, according to EU-legislation of fuel producing, is not considered as recycling. Despite this, pyrolysis may offer in the future potential opportunities to utilize more efficiently potentially hazardous plastic waste as raw materials where in other way they are ending up as thermal energy into thermoplants. Incineration basically means downcycling, meaning that the recycled plastics cannot be recycled for the same kind of purpose as the original products have been. Downcycling of plastics is not necessarily considered “poor”, if the displaced products caused by recycling have the same effect as the manufacture of new plastics for a new goods. For instance, recycling processed plastics for plastic bottles will eventually displace plastics from the same market as products with requirements for clean plastics which do not include contaminants. (Vingwe et al. 2020)

VTT (Teknologian tutkimuskeskus), is Finland's largest applied research and technology institute, which is owned by the Finnish state. VTT’s mission is to promote the exploitation and commercialization of research and technology both in business and society. (VTTinfo 2021) VTT has recognized the bottlenecks for chemical plastic recycling but also possibilities. The major challenges are the lack of technological maturity and scalability, current status of chemical recycling and lack of legislation. In addition, permitting issues of REACH-regulations set by EU, within Finland's possibilities to affect EU-legislation causes friction. In addition, handling of plastic waste requires lot of post-processing, feed quality may be deteriorated, and recycling and incineration competes same materials. However, the pros for chemical recycling are rising interest as a business opportunity as a refinery feed and possibility to straightforward value chain. Also, LCA-review could be possible to carry out in full scale and further possibilities as a replacement for conventional fuel. Also, the possibilities to upgrade recycled plastic raw-material for higher-value products are also present. (VTT 2019. 38)

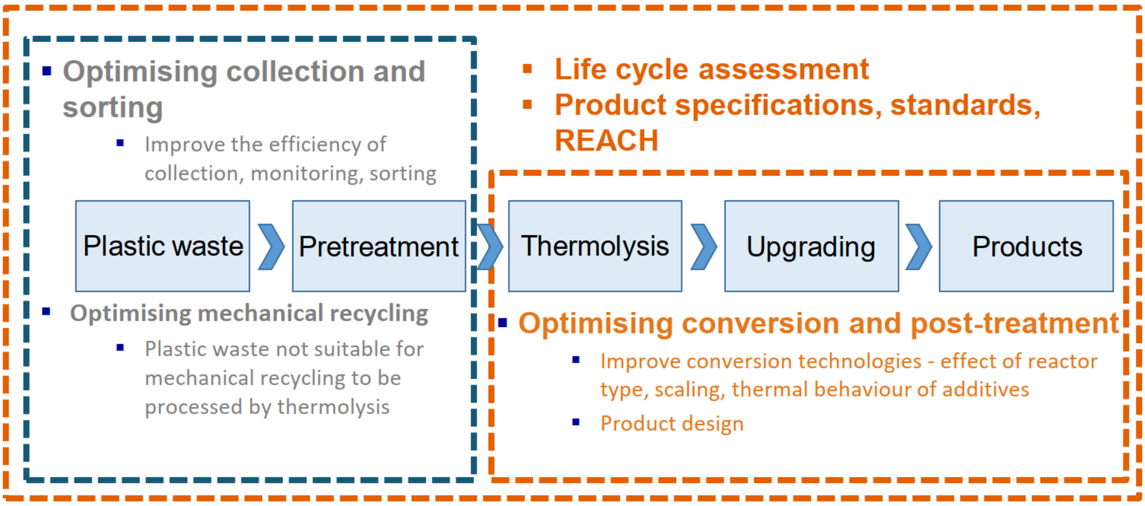

Figure 7. Integration of mechanical and chemical recycling. VTT's optimization proposal of the whole value chain from plastic waste to specified products (VTT 2019).

As a resolution, in chemical recycling is very flexible for all plastic types, despite impurities left in plastic containers or products. It requires less work for share separation and therefore decreases workload for staff. However, technology is still under development and therefore requires time to develop economically suitable solution as shown in **figure 7** above.

Furthermore, in Finland, the supply of plastic waste has been considered too tiny for pyrolysis treatment. However, researchers in the WasteBusters-project disagrees this view. The researchers have calculated that a network of about ten pyrolysis plants could operate profitably if they combined the treatment of waste plastic and waste wood. According to them, combined pyrolysis plants should be located in connection with waste recycling plants. One incentive for chemical treatment of plastic is that incineration of plastic waste is not without problems for the climate. Contaminated mixed plastic waste can be incinerated and energy recovered from it. At the same time the generated carbon dioxide can be recovered. This makes whole process more sustainable when captured carbon dioxide can be used as a raw material. The slowdown in the chemical recycling of plastics is pointed that Finnish or EU legislation does not yet recognize chemical recycling alongside mechanical ones. (Uusiouutiset 2019) At least one pyrolysis plant for waste wood is in operation in Joensuu, Finland. However, the plant does not work efficiently in cold environment which can be seen a problem in Finnish operation environment. (YLEuutiset 2014). In Japan however, in island of Hokkaido is operating world's largest pyrolysis plant dedicated for mixed plastic waste for all plastic types with input of 15 000 tonnes per year of input waste with 90 % plastic recovery rate while producing heat and electricity into the grid according to their websites. (KleanIndustries 2021) Despite the technological efforts in pyrolysis field, today the return rate as a plastic raw material is considered to be modest. However, the pyrolysis method is constantly under research so rising recycling efficiency can be expected to occur into future.

2.4 Legal characteristics of contaminated plastic waste

The main law regulating plastic waste, as well as other waste in the EU, is the EU Waste Directive (2008/98 / EC), which has been implemented in Finland by the Waste Act (646/2011). According to Section 1 of the Waste Act, its purpose is to prevent the danger caused by waste and waste management and harm to health and the environment, as well as to decrease the amount and hurtfulness of waste, encourage the sustainable use of natural resources and raw materials, ensure efficient waste management and prevent littering. The objectives of the legislation are best achieved when waste is diverted to sustainable recovery, where natural resources are saved without at least a significant increase in the risks of adverse effects on health or the environment. The EU's goal of becoming a 'circular economy' by 2050, further emphasizes the need to recover waste in production processes and to reduce disposal problems and the use of raw virgin materials. (EUVL 2013)

In addition, the recycling of plastic packaging is regulated by the Government Decree on Packaging and Packaging Waste (518/2014) that sets recycling targets for packaging and obliges companies using and importing package materials (with a turnover of more than 1 million EUR) to be responsible for packaging recycling in accordance with producer responsibility. In Finland, municipal waste management regulations regulate the separate collection of plastic waste. (Rinkiin 2021) For example, Turku region in Finland has its own both non-legally binding guidance and instructions and legally binding regulations concerning waste logistics, storage and technical requirements and responsibilities both private and business life of waste management in its administrative district. (Turku waste management 2021)

As mentioned, EU and Finnish waste legislation are today based on the waste hierarchy. The primary aim of the hierarchy is to prevent the generation of waste and where this is not possible, to increase the efficiency of the recycling of municipal and packaging waste. The reuse and recycling of waste material has a higher priority than the energy recovery of waste. (TEM 2019)

The EU waste hierarchy emphasizes reducing the amount and harmfulness of laboratory plastic waste generated and preserving materials as products to improve sustainability by using following order: reduce, reuse, recycle and recovery as presented in **figure 8** below. The most sustainable option should be preferred. In 2015, the EU published the Circular Economy Action Plan, which includes amendments to the Waste Directive, the Packaging Waste Directive, and other related legislation changes, which must have been implemented nationally by 5 July 2020. Action plan sets out measures to promote the reuse and recycling of products towards closed loops (closed loop of product life cycle). In addition, the EU Waste Legislation Package entered into force in 2018. This Package requires increases for separate collection and recycling both municipal and packaging waste. Also producer responsibility has to be extended and adapted on the basis of product sustainability, recyclability, reusability and hazardous substances. Furthermore, also monitoring has to be developed to improve the comparability of waste data by harmonizing EU Member States' calculation methods. (TEM 2019)

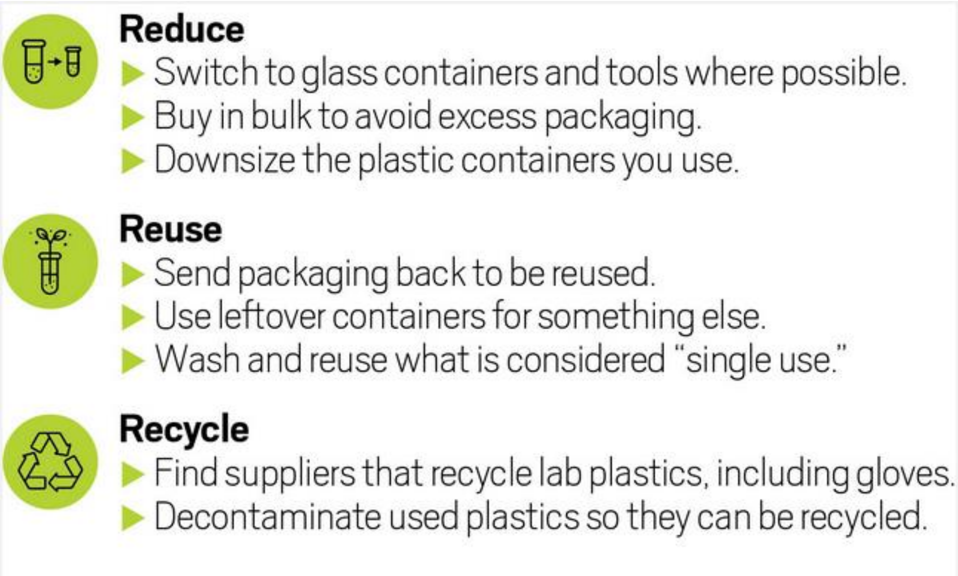

Figure 8. Measures to decrease plastic footprint in the laboratory (Chemical & Engineering news 2019).

In accordance with the EU Waste Directive, Finland has produced a new national waste plan until 2023. It includes national targets and measures for waste management and reduction of waste volume and harmfulness until 2030 (except for Åland, which makes its own plan). The target goal for waste management in Finland and for reducing the amount and harmfulness of waste by 2030 are diverse. First issue is that high-quality waste management should be a major part of a sustainable circular economy. Second issue is that the waste sector should have high-quality research and experimental activities and waste expertise at a high level. And lastly, the amount of waste must decrease from the current level while re-use and recycling have risen to a new level. (TEM 2019)

In directives 2008/98/EY Article 11 (2) is stated about re-use and recycling measures, the preparing for re-use and the recycling of waste materials such as at least plastic, metal, glass and paper originated from households and perhaps from other origins, as far as these waste streams are waste like from households. Recycling shall be increased to a minimum of overall 50 % by weight. This may include hospitals and other public originations considering clean package waste. In addition, Commission decision 2019/2010 requires the use of best available techniques (BAT) for waste incineration in accordance with Directive 2010/75. This includes plastic waste incineration.

2.4.1 Legislation of hazardous plastic waste

According to World Health Organization (WHO), the total amount of medical waste, about 85% of is categorized as general and nonhazardous, while about 15% is evaluated as harmful (WHO 2018). Many plastics may be chemically harmful in many aspects. They may be potentially toxic themselves or absorb other pollutants (Rochman et al. 2013). For example, transfer of additives in PVC from medical supplies can accumulate in the blood. In addition, PVC can be also carcinogenic. The Rochman et al.'s study (2013) states that the physical dangers of plastic debris are established, and the potential dangers of the chemicals are noteworthy. Suggested solution for this problem is to classify most harmful or mixed and therefore unrecyclable plastics as hazardous waste. Estimates say that significant share of plastic waste could be reduced if most risky plastics are categorized as hazardous and switched with reusable, safer materials. (Rochman et al. 2013). When hazardous substances are inputted into new products, the residues of them can leave behind into new products for long period of time. At the same time knowledge about hazardous substances have found often insufficient. (Fråne et al. 2015)

About the aspects presented above, juridical base should be clarified for cases when plastics are considered clean and when contaminated and not suitable for ordinary plastic recycling scheme. Coarse juridical framework of hazardous waste in context of Finland is presented below as follows.

The EU Waste Catalog (Commission Decision 2014/955 / EU) defines which wastes are considered as hazardous in the Community. In Finland, the list is implemented in Annex 4 of the Waste Decree (179/2012, amended 86/2015).

In Finnish waste act (646/201) which is subordinate in EU legislation mentioned above, hazardous waste is determined as "waste, which is flammable, explosive, infectious, otherwise hazardous to health, dangerous for the environment or any other similar property (hazardous property)."

PROPERTIES OF WASTE WHICH RENDER IT HAZARDOUS

H 1 'Explosive': substances and preparations which may explode under the effect of flame or which are more sensitive to shocks or friction than dinitrobenzene.

H 2 'Oxidizing': substances and preparations which exhibit highly exothermic reactions when in contact with other substances, particularly flammable substances.

H 3-A 'Highly flammable'

- liquid substances and preparations having a flash point below 21 °C (including extremely flammable liquids), or
- substances and preparations which may become hot and finally catch fire in contact with air at ambient temperature without any application of energy, or
- solid substances and preparations which may readily catch fire after brief contact with a source of ignition and which continue to burn or to be consumed after removal of the source of ignition, or
- gaseous substances and preparations which are flammable in air at normal pressure, or
- substances and preparations which, in contact with water or damp air, evolve highly flammable gases in dangerous quantities.

H 3-B 'Flammable': liquid substances and preparations having a flash point equal to or greater than 21 °C and less than or equal to 55 °C.

H 4 'Irritant': non-corrosive substances and preparations which, through immediate, prolonged or repeated contact with the skin or mucous membrane, can cause inflammation.

H 5 'Harmful': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may involve limited health risks.

H 6 'Toxic': substances and preparations (including very toxic substances and preparations) which, if they are inhaled or ingested or if they penetrate the skin, may involve serious, acute or chronic health risks and even death.

H 7 'Carcinogenic': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce cancer or increase its incidence.

H 8 'Corrosive': substances and preparations which may destroy living tissue on contact.

H 9 'Infectious': substances and preparations containing viable micro-organisms or their toxins which are known or reliably believed to cause disease in man or other living organisms.

H 10 'Toxic for reproduction': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce non-hereditary congenital malformations or increase their incidence.

H 11 'Mutagenic': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce hereditary genetic defects or increase their incidence.

H 12 Waste which releases toxic or very toxic gases in contact with water, air or an acid.

H 13 (1) 'Sensitizing': substances and preparations which, if they are inhaled or if they penetrate the skin, are capable of eliciting a reaction of hypersensitization such that on further exposure to the substance or preparation, characteristic adverse effects are produced.

H 14 'Ecotoxic': waste which presents or may present immediate or delayed risks for one or more sectors of the environment.

H 15 Waste capable by any means, after disposal, of yielding another substance, e.g. a leachate, which possesses any of the characteristics listed above.

Figure 9. Directive 2008/98/EY Annex 3.

In Waste Framework Directive 2008/98/EY (1) Article 3 (2) definiens a hazardous waste, which displays one or more of the hazardous properties listed in Directives Annex III H9 which are presented in **figure 9** above. Annex states the meaning of infectious, which means "substances and preparations containing viable micro-organisms or their toxins which are known or reliably believed to cause disease in man or other living organisms".

There are no EU-level criteria for infectivity, but according to Commission Regulation 1357/2014, the assessment is carried out in accordance with national legislation or guidelines. This had led into situation where is no binding legislation in Finland on the definition of infectivity. According to the interpretation guidelines prepared jointly by the Ministry of the Environment, the Ministry of Social Affairs and Health, the Ministry of Agriculture and Forestry, Valvira, the National Institute for Health and Welfare and Evira, infectious hazardous waste in Finland means: In Finland, infectious waste is waste that contains microbes belonging to the UN 2814 and UN 2900 categories of the Transport Regulations for Dangerous Goods, which includes 17 enlisted viruses in addition 32 others viruses when cultivated. Examples of these viruses are Ebolavirus and Monkeypox. However, Puumala virus is not included in UN 2814 Hanta virus's category. For a note, coronavirus is not included in this list. In addition, cultures of Escherichia coli (verotoxigenic), Mycobacterium tuberculosis and Shigella dysenteriae (type 1) for diagnostic purposes only are not considered infectious. Puncturing and incising waste contaminated with bodily fluids is not considered infectious in Finland if it is sorted and packaged correctly. (YM 2016, 58-60.)

In case of hazardous waste, Finnish Waste act (16 a §) indicates the obligation to package and label hazardous waste. It states that hazardous waste shall be packaged and labelled, and the necessary information on it must be provided at all stages of waste management. This facilitates monitoring of waste shipment from the place of origin to the recovery or disposal site as well as monitoring of the properties of the waste. As stated before, hazardous waste constructs as separated legal section. Because hospitals and their laboratories deal with these possibly dangerous characteristics, it should be clarified what actually separates "clean plastics" from "dirty" (contaminated which might include microbes) that prevents the use of usual recycling process.

Kalogiannidou et al. (2018) notes that 57 % of the total examined medical waste is classified as toxic because the plastic products have been in contact with formaldehyde such as formaldehyde canisters. In addition, the mixed hazardous waste fraction was about 26 % of the total medical waste. In addition, empty plastic containers are the dominant fraction of the infectious waste category. (Kalogiannidou et al. 2018)

3 PLASTIC WASTE MANAGEMENT IN HOSPITAL LABORATORIES

Two main types can be identified as medical waste. First type is called as general waste and second one is identified as special waste. Since general waste is not defined or regulated as hazardous or potentially dangerous waste, it does not necessarily require special treatment, disposal and handling, which sometimes identified as non-regulated medical waste (NRMW). The main reasons to develop recycling methods for medical plastic waste are numerous. For instance, plastic waste amount in medical waste is shown to be greater than in municipal solid waste (MSW). What comes to hospitals plastic wastes costs, they are remarkable. Biggest numbers come from transportation costs to disposal facilities. Overall, costs for disposal and treatment of RMW (regulated medical waste) are higher than NRMW or MSW. (Lee et al. 2004)

In Finland, there is little research carried out considering hospital waste management. Despite this, investigations and investments are done across Finnish hospital districts. For instance, at Kuopio University Hospital (KYS) combustible waste is collected by a conveyor system installed on the properties. After this, the energy fraction is sorted into waste shafts and transported to crushing process and further incineration to the Leppävirta waste-to-energy plant. Garbage bags are color-coded to tell what waste to put into which bag. These different units, both hospital and waste management staff are the ones who really influence for high quality recycling. In KYS, about from 25 % to 50 %, more than a couple of hundred tons of waste can be recovered through material recycling or direct reuse. According to Statistics Finland's waste statistics, about 41 per cent of all municipal waste generated by Finns ends up being recovered through recycling. (SVT 2021) One obstacle to more efficient waste recovery may be, for example, long transport distances to treatment plants. Separate collection of plastic waste has started in some hospitals. The problem, however, is that a large proportion of hospital plastic waste are not in valid for reprocessing facilities. According to *Jukka Collan* from KYS, healthcare packaging plastics are not suitable to producer-responsible recycling through Rinki Oy and therefore funds cannot be gained from them. Only consumer plastics are eligible, as Rinki derives income from them through packaging producers. In other words, collecting and therefore recycling healthcare plastic packages are not economically viable in Finland at this moment. Healthcare plastics also have their own hygiene challenges, so using them for energy is seen as the best way to utilize them. Single-use disposable plastic equipment is often used as backup to provide enough equipment sets for all occasions, for example in emergency rooms. In large hospitals, a bottleneck can be the capacity for equipment maintenance, as cleaning and disinfecting surgical instrument sets also requires manual work. (YLE 2019)

Tampere University Hospital (TAYS) has developed a “dirt classification” for plastic waste, which makes sorting easier. It is estimated that the plastic waste from the TAYS and other hospitals such as Hämeenlinna, Helsinki and Kuopio could together produce plastic waste to replace 1300 tons of new raw plastic annually. (YLE 2008)

Private healthcare operator Terveystalo has investigated the production of plastic waste in their operating rooms. Terveystalo has 260 offices in Finland and 17 hospital units. Experimental collections were executed by using collection containers and teaching and encouraging staff to implement waste sorting by its quality. It was discovered that one operation room becomes about a large bag of plastic a day. Packaging design plays a big role in recycling. Some suppliers come with packaging whose qualities are not exactly known. This is why waste management company Lassila &Tikanoja (L&T) has started analyzing these packaging, hoping that suppliers will take responsibility for the recyclability of materials. (L&T 2020)

In South Karelia Social and Health Care District (Eksote) only energy and dry waste collection is used. This means that plastic is not recycled. Plastic flushing syringes go to mixed waste, because plastic antibiotic bottles and infusion lines may contain drug residues and are considered therefore no recyclable. (Lappeenrannan uutiset 2018)

Promoting recyclability of commercial products is often found very challenging because of following factors: Recycling for raw materials is prohibited for certain hospital plastics, e.g. for plastics containing drugs or bacteria, as well as for certain persistent organic pollutants (POP-compounds) such as flame retardants. In general, hospital plastics are sometimes considered not to be recyclable at all. In recycling point of view, it should also be noted that external substances can diffuse into plastics during use, which can affect the properties of the plastics and thus their recyclability. This means that recycling plastics used in hospitals must take into account any drugs (e.g. hormonal, antimicrobial, cytotoxic, or radioactive) and organic compounds (viruses, bacteria, fungi) that may have diffused into the plastics to determine their recyclability. (Järvelä&Järvelä 2015) This means that foreign substances may also diffuse into plastic Falcon/centrifuge tubes, plastic containers for solid chemicals and plastic bottles/tubes used in laboratories. However, many clean plastic products such as pipette tip boxes and inserts with non-contaminated bottles for cell-culture media are not facing this problem at all because these are never in contact with bodily fluids or potentially hazardous substances.

3.1 Composition of healthcare waste

To gain further insight into plastic in European healthcare, HCWH Europe waste audition gathered waste over a 48-hour period within hospitals participating in the project in Europe. Project participants were encouraged to prioritize auditing waste generated in the neonatal wards because of the patient's vulnerability to the health impacts of plastic. Of the 1,330kg of waste audited 47.67% was plastic. The analyzed waste included general, sanitary/offensive, and plastic recycling waste streams as presented in **table 5** below. (HCWH Europe 2021.18.)

Table 5. Number of total recycled plastics in hospital environment. (HCWH Europe 2021, 19.)

HOSPITAL	AUDITED WARDS	WASTE STREAM	TOTAL WASTE (KG)	PLASTIC WASTE (%)
Hospital 1	Orthopaedic, Neurosurgery, neurology, spine and video telemetry	General waste	148.4	34.3%
		Sanitary/offensive waste	96.9	68.9%
		Recycling waste	21.8	47.0%
Hospital 2	General, maternity, Neonatal, Neonatal ICU	General waste	66.3	9.8%
		Sanitary/offensive waste	341.2	49.4%
		Recycling waste	10	65.6%
Hospital 3	Neonatal, Gastroenterology	General waste	68.9	60.0%
		Recycling waste	7.4	83.0%
Hospital 4	Intermediate care wards	General waste	155.6	14.0%
		Sanitary/offensive waste	237	83.0%
		Recycling waste	14.6	19.0%
Hospital 5	Neonatal ICU, Ophthalmology	General waste	57.38	18.5%
		Sanitary/offensive waste	87.43	48.0%
		Recycling waste	17.34	26.3%

Including all piloted hospitals, the plastic recycling waste streams represented a comparatively low proportion of the total waste, proposing that very small share of the total healthcare plastics is sent for recycling. A key challenge of the audits was identifying the plastic types, because labelling is not always available on products. This absence of information meant that many items were classified as “unknown” or “mixed materials”. (HCWH Europe 2021, 19.)

Disposable wipes were in use in big amounts in hospitals across Europe. While the waste audits revealed that unused disposable disinfecting wipes were being discarded away. Most disposable wipes were made of plastic of different kinds, generally polypropylene or polyester. This can be put down to the fact that wipes are prone to drying out, and multiple wipes may be removed when only one is needed. (HCWH Europe 2021, 22.) Plastic types commonly found in healthcare are presented in **appendix I.**

However, numbers of plastic wastes vary. For instance, Alwabr et al.’s study (2016) determines the generation rate, quantity and the physical composition of medical waste generated in hospitals of Sana'a city, Yemen as stated in **figure 10** below. Study carried out on four governmental hospitals where the composition of hospital wastes generation was studied. Purposive sampling was used in the selection of the hospitals, which included (Al-Thawra, Al-Kuwait, Republic, and Military). Results presented that the daily waste generated was on average 5615 kg/day where approximately 74 % was classified as a general (non-hazardous) waste. While 26 % of the total waste were hazardous (pathological, infectious and chemical wastes). The total waste generation was on average 3 kg/patient/day, and 2.5 kg/bed/day.

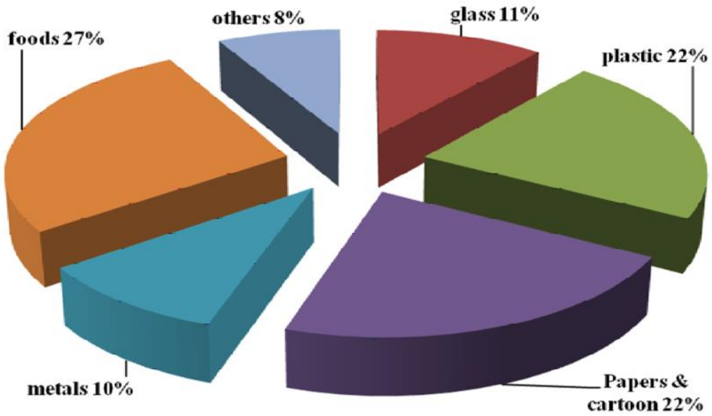

Figure 10. The percentage rate of the composition of the general waste in the hospitals. (Alwabr et al. 2016).

Furthermore, the composition of healthcare waste is researched in few studies. In **figure 11** below is presented the composition and its differences between public and private hospitals. The chart shows that there are no differences between these two.

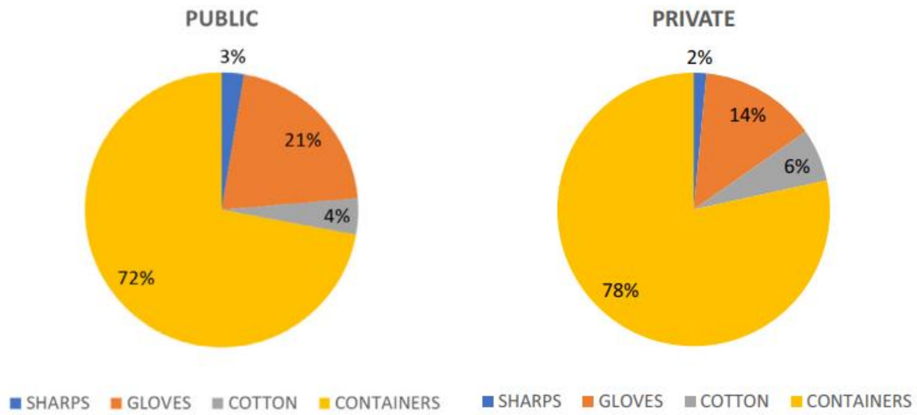

Figure 11. Distribution of sub-components of infectious waste in the private and public HISTOLBs (% of the infectious waste). (Kalogiannidou et al. 2018)

But what is the distribution of different product types? HCWH Europe have performed collaborated study between different European hospitals.

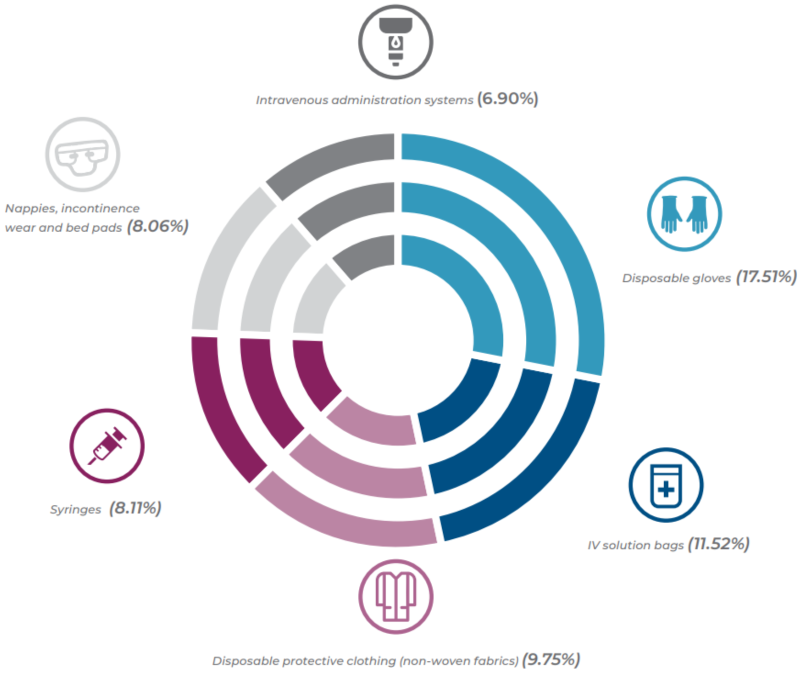

Figure 12. Distribution of most used plastic product types. (HCWH Europe 2021, 8.)

Study shows that only six product categories accounted for over 60% of the total plastic used annually in hospital conditions as presented in **figure 12** above.

Procurement data can in many situations identify what plastic types are used. Procurement data in the UK from one healthcare provider illustrate the plastic types used for the products following:

l HDPE – Tubing connectors

l PE – Mostly plastic bags, almost all aprons and part of gowns

l PVC – Catheters, shoe covers, tubing sets

l PP – Sharps containers, patient wipes and kidney dishes, disposable bowls and gallipots

Waste that contains infective pathogens is defined as infectious healthcare waste that can pose a risk for contagion and illness. It includes materials contaminated with body fluid and blood, laboratory cultures, human excreta and microbiological samples. PPE, like gloves, goggles, long-sleeved gowns, masks and face shields are also considered infectious waste.

These waste streams have increased by a remarkable amount during the COVID-19 pandemic. Thus, a challenge can be pointed what comes to managing this waste type during the pandemic. (Das et al. 2021, 3.)

Non-infectious nor hazardous healthcare waste forms proximately 90% of the waste generated by a hospital organization which includes for example used plastic water bottles, office paper, magazines, newspapers, food waste, and food packaging are considered non-hazardous healthcare solid waste. (Das et al. 2021, 3.) The remaining 10% comprises of infectious waste and is generated in all the wards, intensive care units, operation theatres, blood banks and laboratories. Specially from lastly mentioned, most of plastic waste were contaminated, which included for example tips, Petri dishes, pipettes, test tubes (both plastic and glass), and slides. (Shah 2012)

Overall, the plastic waste composition in hospital waste can be included as a major waste stream, despite remarkable differences between related composition studies. This may be resulted by different calculation methods and study scopes in different studies. Research data from various sources has confirmed that it is not an uncommon that it is normal to have a statistical difference among individual laboratories and hospitals of the same type. (Kalogiannidou et al 2018.)

3.2 Hospital laboratory waste management methods

Major of the studies considers waste composition in operation rooms or plastic waste composition and utilization generally in hospitals (Potera 2012). However, more specific studies have emerged in recent years.

The study from the University of Exeter estimated that life scientists alone create approximately 2 % of the plastic waste produced worldwide, which means 5.5 million tons. One volunteer awareness campaign result showed that on average, the scientists who took part produced 300–400 g plastic waste in one day, which equates to 70–100 kg per year. However, changes towards sustainable laboratory operations actions need to occur on many levels, both producer, institution and employer levels to optimize material use. (chemistryworld 2020)

The major sources of hospital plastic wastes seem to be from laboratories, but also from operating rooms. Plastic generated by laboratories are not normally considered as recyclable plastic and therefore plastic waste are treated as hazardous waste. (Lee et al. 2002)

In United Kingdom, commonly used laboratory consumables such as centrifuge tubes are made of PP, while flasks and culture dishes are usually made of LDPE, PS and HDPE are most commonly used in lids. What comes to further details about materials, most usual method is to look for them from manufacturers own website. It has been noted that lids must take special care because they often contain a rubber or ring made from paper. An acceptability for each plastic product should be checked with recycling company to clarify their tolerances. (TheBiologist 2021)

There is a possibility that laboratory's waste contractor may not have the capability to deal with laboratory plastics which are decontaminated. This may be cause of several reasons, such as lack of space, absence of possibilities to collect such waste or lack of funding. Thus, there is requirement to have accessibility to specialist recycling company what should be able to manage plastics recycling for a bearable cost. As and practical example, in Genever Lab at the University of York’s Department of Biology, separate out all types of plastics they produce. They also bag them separately to make it more economically affordable for their provider of recycling services. (TheBiologist 2021) Genever lab follows four guidelines in their recycling program where the first one is to “Buy better” **(see figure 8)**. Because it is difficult to recycle efficiently mixed plastic materials, to counter this problem may be a reviewing the common plastic products which the laboratory is currently purchasing. Also, important aspect is to look, what kind of plastic type they are made of. One suggested tool is to make a spreadsheet settled with color coding for each plastic type. Where possible, decreasing the number of deliveries is one other way to stay in count that how many different plastics there are, when there are fewer active parties. For example, Genever Laboratory (Lab) used a 100 ml tube previously that had an HDPE lid and a PP body. This basically meant that an additional trash canister was required to collect these lids specially. Also, Genever Lab’s considered the use of plastic tubes were its price. Deliveries of the tubes strengthened those with other consumables. New tubes what Lab purchased had lids made of LDPE. These tubes are the same type of plastic that is in all the other lids they already use. This makes Labs recycling process easier and less effort to execute. (TheBiologist 2021)

Second guideline is to use less, where Lab planned their experiments as competent as possible, but normally they only reflect how the experiments are set up most easily what they carry out. The problem was that Lab did not look how many consumables they possibly use. For example, a small vessel was most usual type to imply tests. Because there are normally only a few samples and therefore only part of a multiwell plate have to be used. This leaves eventually empty wells into plates. It was found that purchasing of correct size of multiwell plates were the best a solution. Therefore, it was preferred to switch to smaller sized plates. In addition, switching to multiplexing assays or running several experiments on one plate was found as another solution. However, the most environmentally friendly choice consumable material found to be glass. If glass product was an option for purchase and suitable in both decontamination and cleaning aspect, changing to glass was found a reasonable solution. (TheBiologist 2021)

Third guideline considerers plastics decontamination requirements. If decontamination procedure is used, there must be a setup of monitored and robust decontamination procedure line to ensure that contaminated waste does not end up into the disposal cycle untreated. Genever laboratory have developed and tested a decontamination guideline and incorporated it into their training for students and new staff. Recycling cycle may also include a 24-hour saturation in a highly effective disinfectant, followed by a rinse and placed into the suitable waste containers based on plastic type. Laboratory waste can be handled by waste management team. (TheBiologist 2021)

Fourth guideline considers about resistance for changes, because initial reactions are likely to be mixed what comes to improve recycling. In Genever lab’s case, researchers can easily work weekly over 40 hours and the basic cognition is that recycling will take up more time than it normally does. (TheBiologist 2021)

Last issue to overcome is the communication. Because in university management has many parties involved, it makes difficult to carry out efficient communication. By introducing easily understandable plans may reduce staffs concerns about the new recycling scheme and promote more openness which increases trustworthiness towards new recycling practices. One tool to help in this issue may be the introduce of easy-to-follow workflows and build adequate commitment for staff. It has found that the staff tend to follow new practices when those are set up. Also, tendency with budget frames or co-work with existing companies of waste management could also influence change progresses. (TheBiologist 2021)

Another real-life example originates from The Basic and Clinical Neuroscience team at the Denmark Hill Campus in Kings College London, where staff carried out research in the main laboratory of the polymer codes for the daily plastic products used in tissue culture. The study found that much of plastics could be recyclable after a thorough rinsing. After finding this research, the study team created easily understandable posters to profile the lab plastics which could be recycled. In addition, communications were improved to make the new waste streams familiar to staff via departmental circulars and noticed boards. In addition, specific bins were placed to perform plastic waste collection. The goal was to make the process as a clear as possible. (KingsCollegeLondon 2021)

Listing of recyclable plastics with lab examples for Lambeth Council is presented in **table 6** below. (KingsCollegeLondon 2021)

Table 6. Examples of plastic types related to laboratory products. (KingsCollegeLondon 2021)

Polymer types recycled by Lambeth	Polymer code	Example from lab
Polyethylene (PET or PETE)	1	Bottles used in tissue culture (TC) that contain media, other media supplements and reagents used for standard TC procedures (e.g. passaging)
High Density Polyethylene (HDPE)	2	Containers for non-toxic chemicals and laboratory reagents, typically powders
Polypropylene (PP)	5	Micro centrifuge tubes

At School of Life Sciences in University of Dundee's Central Technical Services in Scotland collects the plastic recycling waste from dedicated colored waste bins for each waste type in specific pick-up points. They were able to collect and recycle contamination free and dry, colored, clean, dry and millable plastic. Amounts of waste were monitored separately by each plastic type. To carry out these procedures efficiently, an SOP (Standard Operating Procedures) were designed. (Dundee 2020)

3.3 Experiences of economic viability of hospitals plastic recycling

What has already discussed above, Finnish hospitals rely on areal recycling systems, so they do not treat their wastes any further than collecting and pre-sorting. This means that hospitals recycling system in Finnish environment must be comprised as part of municipal or national operator network. Thus, to find most economically best solutions it should look also outside of hospital organization as already before passingly subjected.

To maximize the value at plastic recycling field at institutional scale, it requires wide scale changes. These changes are often associated with supply-chains, infrastructure, investments, societal aspects, political will and key industries financial viability. At an institutional level, Fletcher et al.'s study (2021) has presented new processes in waste generation cycle, including new training and procurement practices. (Fletcher et al. 2021) For example, there have been found an alternative study scope for more reusing and reduction of plastic material. For instance, while reusing items in a laboratory context, it may have obvious limitations, particularly in relation to cross-infection and contamination. Some concerns regarding infection risk have been accused to be not evidenced, leaving a veritable potential for increased plastic reuse. Where reusing items has considered in many cases impossible, limiting production of waste could be avoided instead. For example, by wrapping sterilized instruments in a single plastic layer wrap instead of a double layer. Other possibility could be to encourage the operating staff to open plastic instrument packs only when those are needed instead of opening packages by pre-emptively. (Fletcher et al. 2021)

Small volumes of collected recyclable plastic waste may challenge cost-effective recycling. This also may lead in a situation where recyclable plastic waste ends up into incineration when companies and other parties do not see recycling reasonable and not pay the effort to start recycling. Kleinhans et al. (2021) studied that according to companies' statements, they do not necessarily know that there are collection systems available for each waste/plastic type. Companies also believe that the waste amounts they produce are not significant and therefore they do not recycle their waste. (Kleinhans et al. 2021.) When discussed about sustainability, this may be the reason why laboratory product producers include so much packaging material compared to their laboratory item size they hold. Because producers are not fully aware of their recycling possibilities of their products. In comparison, transport and collection is often done by private operators instead of being organized by the local municipalities such as L&T in Finland.

Adequate plastic waste gaining volumes and the process are in key role for cost-effective recycling. In context of Finland, the creation of a Nordic level co-operation recycling platform which helps to gain better required plastic waste volumes requires however stakeholder involvement. By gaining coalition parties from across the plastic waste value chain could bring additional value in this stakeholder coalition, including other parties such as production industry, designers, recyclers and processers, waste management companies, consumer representatives and public sectors (national/regional/local). (Fråne et al. 2015)

As presented in **figure 13** below, the business model of medical waste recycling can be mainly divided into three parts: waste classification, waste generation and temporary waste storage:

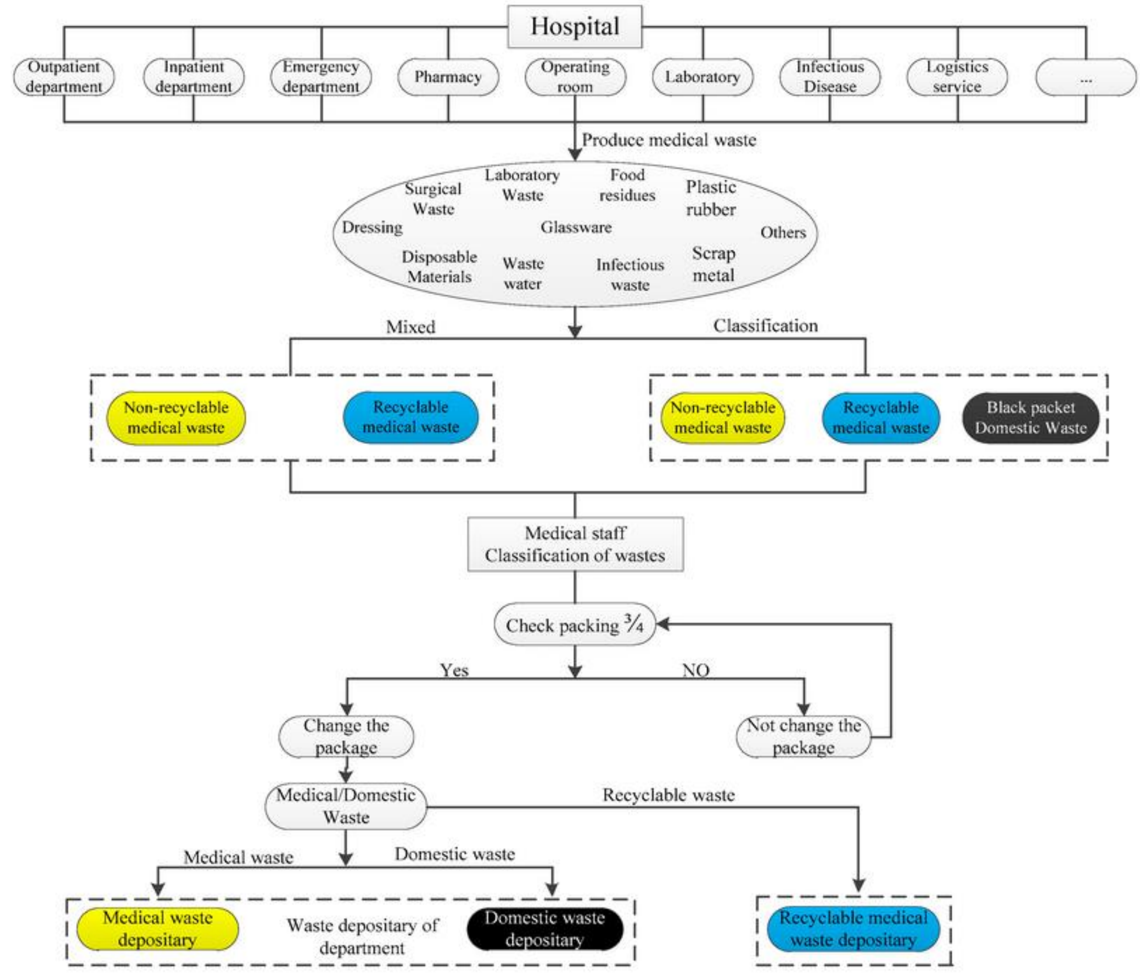

Figure 13. Medical waste recycling business model. (Liu&Zhong 2018)

According to Liu&Zhong (2018), no matter what kind of recycling scenario or how plastics streams are separated and then recycled, it was always cheaper compared to domestic waste incineration when recycling cost were comparer to waste disposal fees. (Liu&Zhong 2018)

Liu&Zhong (2018) determined that the medical waste classification may reduce the non-recyclable medical waste and at the same time increase the amounts medical waste, which can be recyclable. This means that there could be possibility to reduce disposal cost, increase income, reduce impact on the environment, and increase the resources recyclability. In addition, clear and straightforward implementation of the recycling and classification standards for medical waste have seen to have impact to decrease the output of nonrecyclable medical waste. In addition, it has noted to have an impact to improve the utilization rate of recyclable medical waste. Also, it could solve the problematics what comes to waste classification, such as high disposal costs, low recovery rate and reducing disease risk of transmission and environmental pollution as presented before. (Liu&Zhong 2018)

Another example study about recycling costs were conducted in private hospital in Ohio, United States. The project set up single-stream recycling considering non-hazardous waste, where the results showed a remarkable financial benefit towards recycling. In recycling method, they used the single-stream method was found as a low-effort practice for personnel because there was no collecting and segregation. Also, no additional manpower was required for recyclables. (Riedel 2011)

What comes to plastic waste related costs set by EU, two types of tariffs have been implemented since 2019. First one was meant for convectional plastics and a second one tariff was meant recyclable plastics. This tariff is also lower compared to tariff dedicated to convectional plastics. Despite this, these tariffs differentiation has shown to phase out for mixed plastic waste. A slowdown to "*design-for-recycling"* has noted to be the newest taxation measure announced for nonrecycled plastics, which covers whole EU. The European Commission has proposed a taxation of 0.80 euros/kg of plastic waste when being incinerated. Despite the issues of plastics and the downcycling of plastic waste have been estimated to intensify in the future, as it is related more closely to the goals of EU's waste separation and not for real recycling measures. Therefore, this tax has found to be only counterproductive measure. (Gradus 2020, 12) This cost may increase the pressure to rise waste disposal cost and therefore increase plastic recycling infrastructure to be built, despite its problematics already discussed before.

As a conclusion, recycling laboratory plastics can be seen the most economically sufficient solution compared to incineration as a mixed waste. What recycling method and technology is the best depends on many factors, which depends on what management method, legislation and disposal methods are currently available in waste procurer organization.

4 TYKS LABORATORY PLASTIC WASTE DATA ANALYSIS

In 2019, Turku University Hospital (TYKS) treated 230 000 patients in its eight separate hospital campuses. (VSSHP Annual report 2021). Waste management in TYKS follows Finnish waste legislation and authority hierarchy of management in collaboration with municipal waste operator L&T and local waste management authority, Lounais-Suomen Jätehuolto Oy (LSJH). (LSJH 2017)

According to L&T, TYKS plastic recycling procedures are constantly under further development. In addition, L&T has recognized that guidelines and instructions for waste producers should be updated more often to keep up better in L&T's technological abilities currently available. Because whole recycle chain from waste collection to utilization procedures in L&T facilities have to be to gain suitable for raw material and for recycling method currently available. (Eeva Lammi e-mail, 7.12.2021)

4.1 TYKS plastic recycling guidelines

L&T is currently responsible for the utilization of hospital waste from TYKS. L&T has set recycling guidelines for each plastic type as follows. The customer is responsible for the costs from transport and collection to the L&T terminal, but plastic material recycling itself is free of charge. According to L&T, sensible driving amount for recycling process is proximately 5 tons of plastic material. However, a remarkable factor is that the receiver of waste materials ensures the waste quality requirements currently in force. This means that the quality requirements may change quite rapid schedule (Eeva Lammi e-mail. 7.12.2021).

TYKS waste management guide supports the employees to sort and collect waste properly. According to the waste guide, a department or unit must be aware of the type of waste produced in its facilities and provide the necessary information on the waste to the next waste handler. The waste is instructed to be marked clearly enough either with a sign on the collection container or with the waste bag color code. The color coding of the waste bag also indicates the quality of the waste. For instance, the black garbage bag contains combustible waste, and a clear transparent bag is for film plastic. Packaging should be done in a way that the waste remains inside the bag without damaging it. To prevent tearing, the waste is packed loosely, and the air is removed as accurately as possible before closing the sack. The bag is tightly closed with a cable tie or thread so that it does not open in further processing. The waste shaft/elevator between the floors is used to collect combustible waste directly into the waste compactor. Any larger bag may cause a jam and should not be used. The bag must not contain heavy liquid waste that is gravitational and might break down and mess the clamp. The transport of such waste is managed separately. The suitability of the waste collection equipment belonging to the property (suitability, condition, signs, cleanliness) is taken care of by the service provider, currently L&T in TYKS case. (Jäteohje 2018)

Currently used waste sorting guideline (Jäteohje 2018) is according to L&T, outdated. In **figure 14** below is presented L&T's current recycling possibilities what comes to healthcare waste. (Eeva Lammi e-mail. 7.12.2021). Despite this, this thesis issues current recycling methods in practice at TYKS.

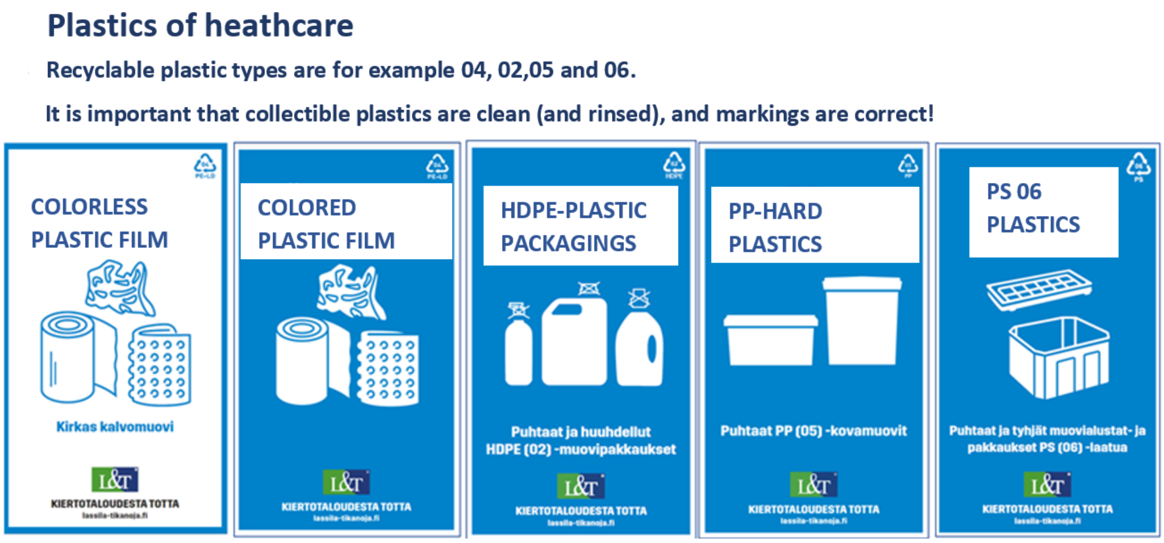

Figure 14. L&T's recyclable plastic qualities in healthcare. (Eeva Lammi e-mail. 7.12.2021), (© L&T Ympäristöpalvelut Oy).

At this moment, each employee in TYKS sorts the waste generated in workstation into the containers and facilities provided. The unit or department have a place reserved for this purpose in each floor. There is an expert in each unit for responsible for waste management to advise and guideline. Occupational safety in waste management is ensured for example with the right packaging choices and careful packaging and labeling of the waste. The occupational safety of personnel transporting waste is ensured by suitable work clothes and protective gloves. Waste management is a collaboration between all parties, so user representatives attend a waste management planning meeting 3-4 times a year or as needed. The meeting is convened by a representative of the property owner. The compartments collect hazardous waste in a designated container in the compartment or unit. Other hazardous wastes are instructed in a separate instruction. There is also a separate instruction on the delivery of hazardous waste. A separate plastic collection rack can be purchased for collection, but plastic can also be collected directly in a transparent PE-plastic bag. The waste bags are delivered to the baler. (Jäteohje 2018) In **figure 15** below is presented the instruction label for consumer plastics which includes for example shampoo bottles, plastic bags and food packaging's. For more specialized plastic products have separate instructions.

Figure 15. Instruction label for clean consumer plastics recycling in TYKS. (TiedoteTYKS 10.12.2020)

Furthermore, in **figure 16** below is presented the TYKS collection and logistics chain for Special healthcare waste, plastic film and combustible mixed waste (polttokelpoinen jäte). (Jäteohje 2018)

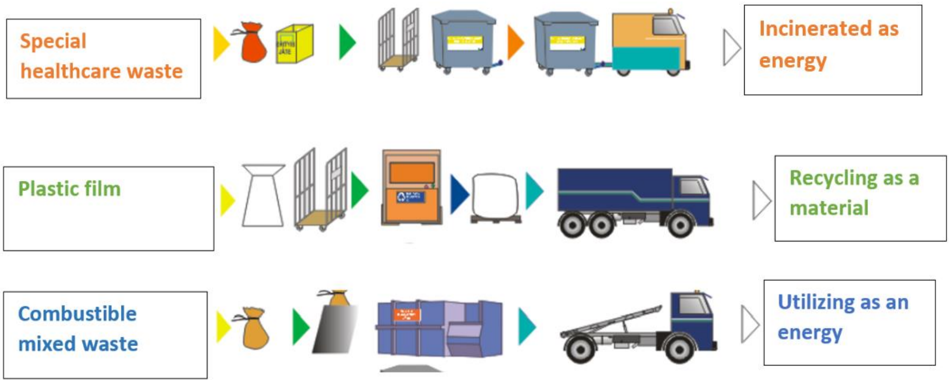

Figure 16. Collection and logistics chains for different plastic waste in case of TYKS. (Jäteohje 2018)

In TYKS, for every plastic type have separate recycling instruction for laboratory staff as follows in next chapters.

4.1.1 Plastic type (04), clear film, PE - LD

Only clear film plastic or bottles of the same material (04) are suitable for recycling cycle, not colored. Also, plastic quality must be same as in clear packaging. Care products are not accepted. Mixed product type qualities are shown in **figure 17** below. The plastic bag is placed in the roller cage. Sorted plastic by unsuitable matter will have to be disposed of as combustible waste, in which case the material that would be suitable for recycling, will be incinerated. The labels of products may remain, unless they can be easily removed. (VSSHP 2021)

Figure 17. Care product mixed incorrectly in film plastic pointed by red arrows. (© L&T Ympäristöpalvelut Oy).

Packaging plastic is collected separately at sites where a lot of packaging is unpacked and thus packaging plastic waste is generated. Examples of (04) plastic is presented in **figure 18** below. The collection is suitable for (04)-marked clear and colored polyethylene plastic (04 PE-LD), such as:

• Empty plastic packaging and wrappers

• Stretch and shrink film plastics

• Flame retardant film and hoods

• Bubble wrap

• Empty inner bags

Figure 18. Examples of (04) plastics. (© L&T Ympäristöpalvelut Oy).

4.1.2 Plastic type (02) PE - HD

In TYKS, PE - HD (02) bottles are recycled without caps. Example of (02) bottle and canister are shown in **figure 19** below. Collection in a clear plastic bag with markings on the bag with the mark 02 PEHD. Transport to the L&T terminal costs, but material is free of charge. In TYKS Chirurgical hospital recycling if 02- plastic packages has been started at 2021.

Figure 19. PE - HD (02) are mostly bottles or canisters, they should be washed clean to be suited for recycle. They should not include residues of dangerous substances or food. (© L&T Ympäristöpalvelut Oy).

4.1.3 Plastic type (05), PP

PP plastics (05) of different colors are all collectible. Collection is performed in clear plastic bags (collection bag material PE or PP bag). Marking on the bag with marker (05) PP. Sacks, sack racks and transports to the L&T terminal are charged, but the material processing is free of charge. The **figure 20** below shows polypropylene pieces that are suitable for recycling. However, metal-containing tape or film coated packages are not accepted for recycling.

Figure 20. Pipette tip boxes of made from (PP), they must be empty and clean to be able to be recycled. (© L&T Ympäristöpalvelut Oy).

4.1.4 Plastic type (06), PS

PS 06 plastics, for example boxes for surgical tool sets as shown in **figure 21** below must be empty and clean. Collection of plastics is done in the trolley.

Figure 21. Pipette tip boxes of made from (PP) (© L&T Ympäristöpalvelut Oy).

4.1.5 Combustible waste

Combustible waste refers to non-recyclable miscellaneous municipal waste that is mainly used for energy. Recyclable waste such as film plastic as well as special health care waste and hazardous waste must be removed from combustible waste share. Waste containing labels with personal information are collected separately as security material. Combustible waste is eventually dropped in a black plastic bag into a waste pit or transported directly to the dedicated waste compactor. Combustible plastic waste is then incinerated at a municipal waste incineration plant. The energy generated by combustion is utilized in heat and electricity production. (Jäteohje 2018)

Combustion plastic wastes in TYKS is a main utilization procedure if recycling is not arranged. Most common combustible plastic waste types are (Jäteohje 2018):

• Disposable tableware, disposable bowls, disposable protective jackets and caps

• Gloves such as latex, nitrile rubber and vinyl gloves

• Packaging and protective plastic, plastic bags and sacks (> pure PE, suitable for film plastic)

• Disposable textiles (any washable textile disposal is taken care of by the laundry)

• Empty hand wash and hand sanitizer packs

• Disposable care supplies and care kits

• Polystyrene and other plastics

• Empty plastic canisters, buckets, plastic boxes, plastic medicine jars and empty needleless syringes

For special waste and hazardous waste, separate instructions are prepared. Special waste management is organized in the same way as for non-hazardous waste, but special waste is collected in separate secured containers. Contained plastic waste is collected in the department. The service provider, who picks up this waste, also brings an exchange waste container.

The sorting, packaging and marking of other special waste types are done in the laboratory/hospital department. There may be an intermediate collection point for waste in the department/unit, but there are rooms for collection containers on maintenance floor. Special medical waste containing personal information is handled as special waste.

In TYKS, hazardous waste means waste that may present any special hazard or harm to health or the environment for its chemical or other properties. It is important for safe waste transport and handling that all hazardous properties of the waste are marked. Most of the collection of hazardous waste belongs to the department or unit, so they have their own waste instructions for this kind of special waste. (Jäteohje 2018)

4.1.6 Costs of each plastic waste type

Each waste type has different management cost depending on its qualities and recyclability. Pure package waste is recyclable and free of costs, while hazardous or special waste require a separate logistic chain and a specific combustion process with higher costs (**table 7** below).

Table 7. TYKS waste disposal costs in 2021. Cost of hazardous waste disposal is an estimation because eg. package size affects the price. (Kari Kandelberg, personal information 19.11.2021).

TYKS waste disposal costs in 2021 by waste type		
Waste type	**Price (EUR/ton)**	**Waste management/ disposal company**
Packaging/ film plastic	0	L&T Oyj
Combustible waste	160	Lounais-Suomen Jätehuolto Oy
Combustible waste with sensitive personal information	1040	Fortum Oyj
Sharp waste	310	L&T Oyj
Hazardous waste	700	Fortum Oyj

5 METHODS

The method section describes a chosen research method supported by the literature background as presented before. In this thesis, quantitative research with qualitative elements was determined as the research method. Because traditional quantitative composition methods were not suitable, applied quantitative method was developed for this thesis.

Traditionally mixed waste composition studies are based on a method, in which the composition is figured out by sampling the properties of waste in bulk. This means that certain amount of mixed waste is weighted, poured on a sampling table, separated and then analyzed by the waste type and amount. (Kivo 2017; European Commission 2004) However, this method used for various hospital plastic waste will pose hazards for the investigator, if applied to hospital plastic waste. Regardless, similar principles as mixed waste composition study can be used by turning it the other way around and auditing the plastics that enter to the material flow. This thesis analysis is performed by using consuming data of purchased plastic laboratory products. Because it is reasonable to believe that weighing the incoming plastics will provide similar results as weighing the plastics in the waste collection.

Case-analysis were performed in main TYKS laboratories situated in Medisiina D building and in T-hospital in Turku.

The study method in laboratory small plastics were carried out as follows:

First, laboratory staff was asked to identify and collect all product codes which are used in the procuring of plastic items in their laboratories, as well as all the ordering data by procurement department for all laboratory units in TYKS for the year 2020. In addition, the pharmacy unit provided data about hand sanitizer packages and other alcohol products used in laboratories. Most significant plastic products were identified by order volume. Each laboratory unit was asked to name a contact person for this project to assist in further data collection, with special emphasis for recycling potential.

After that, general plastic waste audit was performed, focusing on six main laboratory units to identify plastic waste types, their sorting and disposal from the unit. These units and their specialty functions were:

Clinical microbiology (identification of microbes and antibiotic resistance)

Haematology (blood cell and coagulation analyses)

Special chemistry (immunochemistry, chromatography, etc)

Pathology (histopathology, cytopathology, autopsy services)

Genomics (cytogenetic and molecular genetic analyses)

Sample logistics unit (for samples sent in from other healthcare facilities)

Emergency laboratory (sampling and analyzing 24/7)

Other, smaller laboratory units were excluded from the thesis data analysis, as they did not name a contact person or were situated in other towns.

Most important plastic waste types including packaging and transport materials were identified in co-operation with these six units, and on following visits, material weight data was also collected. A follow-up period of two weeks was organized to collect volume data of non-procured plastic items, e.g., polystyrene transport boxes. Plastic recycling/disposal methods were identified to gain better understanding of the whole plastic product life cycle in laboratory. The researcher visited the laboratory units under strict staff surveillance because laboratories hold classified personal information and are not open for public.

The majority of consumed plastic types were recorded in Microsoft Excel-program and were supplemented by procurement data. By combining these numbers, the realistic numerical value of consumed laboratory products in each laboratory could be estimated accurately enough for the goals of this thesis. Additionally, laboratories' small plastics weight data was also obtained from open online sources in addition by weighting the plastic items personally. Afterwards, weight values were added to calculate the volume of most significant plastic materials and multiplied to give approximate annual values. This was done separately for each laboratory unit in the thesis but also for all units together. Emergency laboratory operates every day and other laboratories from Monday to Friday which was taken in account in calculations.

It is notable that not all of TYKS laboratory units participated the thesis, but some plastic product quantities, e.g., disinfection products, were calculated for all of the laboratory units, 26 altogether. The plastic waste from disinfection and alcohol-based articles per laboratory was collected by weighing empty packages using a kitchen scale, similarly as the weighing laboratory small plastics. Item types, which were purchased less than 10 pieces, were excluded from calculations due their insignificant nature for the thesis results. The article weights were multiplied to gain annual volume for each product. In addition, wipe packages were weighted both empty and full. Some of the plastic canisters came directly from supplier as refilling containers and had their own rotation. These were not included in the analyses.

5.1 Data analysis

The TYKS staff names where consumption numbers are gained are anonymized. All analyses were made using simple Excel calculations and graphics. The calculations followed Global Green and Healthy Hospitals- network's official waste assessment guidelines (GGHH) as much as possible.

6 RESULTS

Two methods, analysis of laboratory procurement data and field research in selected laboratories, were used to investigate main trends, composition and quantities of laboratory plastic waste.

Most common laboratory plastic types were pipettes and their heads, pipette head boxes, culture and fixative bottles, polystyrene and clear plastic wrapping, cylindric bottles, solution bags, reagent and solvent canisters and packaging plastics of all kinds. It was possible to identify plastic material by its label for most of the plastic items, but in some items the label was lacking (e.g., single use pipettes, cups, tubes and packaging materials. (Laboratory plastics audit 16.9.2021) Pasteur pipettes, used in large quantities, were most likely made of polyethene despite the label of type was not present in the product itself. (Auxilab 2021)

The quantities of disinfection products, alcohols and wipe packages are presented in **figure 22** below. Part of wipes may be contaminated after use. Other shares of disinfection plastic waste are uncontaminated after rinse. All small sized, under 5-liter disinfection bottles were made from (02) PE-HD, their amount being 739 kg. Of this, 450 kg were ethanol bottles, and the rest were disinfection solutions for hands, surfaces and instruments.

All in all, most consumed plastic bottles were hand and surface disinfectant bottles (500 ml) and 500 ml ethanol bottles of different percentage. However, the most consumed item of all compared to mass were disinfectant wipes of different brands.

Wipe packages shells of all sorts weighted **528 kg** in total when empty. Of these, **188 kg** (35,6%) contained foil film (ApoWipe Ethanol 80%). However, when wipe packs were full, the weight was **6075 kg**. Heavy weight can be explained by the wipes moist content, of which the towels itself are mostly polyester (60 %) and viscose (40 %), and the rest is volatile solvent. Other liquids may be absorbed into wipes if those are contacted into them. Wipes form the majority of disinfection plastic waste, but not all of it is plastic. Summary of calculations data is presented in **appendix II**.

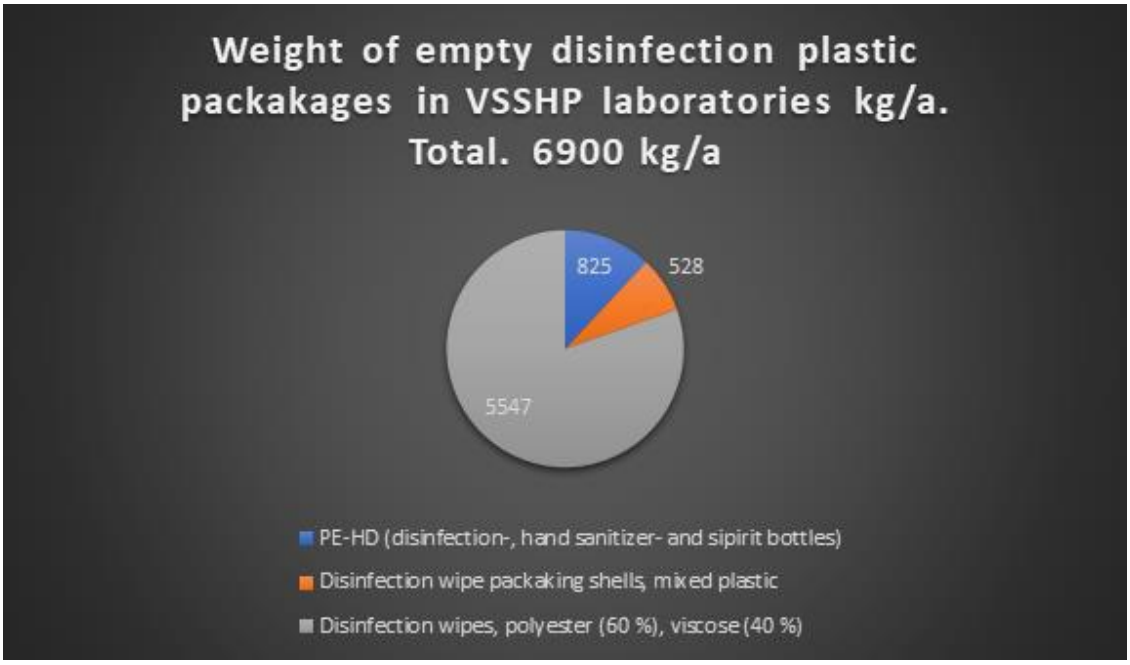

Figure 22. Weight of empty disinfection plastic packages in VSSHP laboratories /kg/a.

In **table 8 below** is presented the results of laboratory small plastics. Because of missing labels, plastic type identification is lacking some of cases. In emergency laboratory, the number of used pipettes and tubes were estimated by the numbers of empty package shells, which were estimated to be 2 tons/a. This number includes only the weight of empty pipettes and tubes.

Contaminated plastics consist mostly of laboratory small plastics, such as test tubes, pipettes, racks etc. Clean plastics were mostly pipette head shells and other packaging material. Formaldehyde canisters were identified as hazardous waste. Polystyrene was generally used as packaging material in all laboratories, but no estimations nor calculations could not be done in all laboratories because of small quantities used.

Table 8. Summary of laboratory small plastic analysis. Specifically presented plastic types, polystyrene (PS) and polypropylene (PP) are uncontaminated/clean. Hazardous plastics are plastic canisters have been on contact with formaldehyde and therefore unrecyclable. * Top laboratory plastic waste types and their amount is weighted/estimated by laboratory staff. Total all plastics by estimations (kg) are evaluated by using calculations and then rounded to the nearest tenth.

Plastic waste in a year (kg)	Clinical micro-biology *	Pathology	Emergency laboratory*	Special chemistry	Genomics	Hema-tology	Total by plastic type (kg)
Total all plastics (measured)*	**303**	**7670**	**2020**	**82**	**1027**	**16**	**11 118**
Total all clean plastics	225	-	520	23	159	-	**927**
Total polypropylene (PP)	162	-	-	-	43	-	**205**
Total polystyrene (PS)	78	24	-	-	303	5	**410**
Contaminated small plastics	-	7090	-	-	-	-	**7090**
Contaminated canisters	-	556	-	-	-	-	**556**
Total contaminated	-	-	1510	59	440	11	**2020**
Clean (PP) share	-	-	-	-	116	-	
Total all plastics by estimations (kg)	**300**	**7700**	**3900**	**80**	**1050**	**20**	**13 050**

As presented in table above, weight of all small laboratory plastics from participating six laboratories were 11 ton/a, where 1 ton/a were clean/uncontaminated, and 2 ton/a were contaminated on some level. When estimations were considered, the weight of total plastic waste rises into 13 ton/a. Empty slots in the table (-) indicate that specific data was not found in this specific laboratory (could not be estimated or there was no consumption at all). Pathology, genomic and emergency laboratories consumed more plastic materials than other compared units.

Contaminated plastics were contaminated biologically or chemically but not considered infective. All canisters (5000 ml, PE-HD) were contaminated or not currently collected for recycling. Most canisters had contained ethanol except for in pathology laboratory, where canisters were contaminated by other substances such as isopropanol, xylene and formaldehyde. Last mentioned was second most used chemical in pathology (after ethanol), where

909 canisters (165 kg of plastics) were consumed in one year. Formaldehyde was the only hazardous chemical presented in the whole thesis. Canisters and bottles from other laboratories had contained ethanol, which has not considered as a harmful contaminant if the canister is empty. Their consumption is calculated in **figure 22**.

The difference between calculated (observed) and evaluated values was that evaluated values included the estimations of realistic plastic consumption that was not possible assess during the field research period. For example, test tubes in analyzers were not able to be weighted, and estimation on tube consumption was based on empty tube trays collected. Also, a significant share of laboratory small plastic was not actually weighed as they had personal information tags and were biologically contaminated.

7 DISCUSSION

This thesis showed that more than 13 tons of plastic waste is produced annually in 6 selected university hospital laboratory units. In addition, almost 7 tons of disinfectant packages were used in VSSHP in total. Literature review showed that most of hospitals contaminated plastic waste come from laboratories. Disinfectant canisters were made from PE-HD, but largest share were viscose-plastic wipes and solvents, and the packaging shells were mostly mixed plastics or included foil lining. Because number of used wipes were relatively high compared to other analyzed waste streams, further research for recyclability of disinfection wipes for replacing and reduce their use is suggested. In addition, some of the wipes will contaminate in a way that they are no longer recyclable by current recycling methods and are ended up utilized as energy. (Kiilto 2021) Most of the recyclable laboratory small plastics were made from (PS).

Laboratory personnel in TYKS found to be innovative and motivated to develop ways to collect more plastics for recycling. In literature there exist partly contradictory views, as increase in workload was identified as the worrying factor. Despite this, TYKS laboratories positive attitude towards recycling could be seen as an attribute about the attitudes in Finnish laboratory organizations. Therefore, additional workload for recycling to staff cannot be seen as a problem.

Studies of laboratory plastic recycling were found to be still developing but the most important issues are already recognized, such as the majority of laboratory plastic waste are found to be contaminated in some level and require at least rinsing to be able for recycle. Also, statistical differences could be found from literature review, but it has noted to be a normal phenomenon in waste quality and quantity research in same kind of laboratory operations. Last mentioned inaccuracies may be the result of different practices in different organizations.

There is a consensus that recycling of plastics is profitable based on literature review and case thesis, no matter what technology used. Recycling is economically viable and do not cause more harmful workload for staff if performed correctly. The single-stream method of recycling is found to be easy for staff because there are no segregation and collecting recyclables required no additional manpower. (Riedel 2011) In case of TYKS, the data analysis demonstrates that environmental benefits and cost savings attributes towards even higher recycling rate. At this moment, costs of recycling plastic film in TYKS is free, compared to other waste costs such as combustible waste so increasing recycling potential can be seen economic option. According to L&T increasing the recycling rate of uncontaminated plastic packages at TYKS is possible in significant scale. This rate could increase even higher if rinsing of plastic containers is performed. However, this requires co-work with other waste management parties such as L&T to be achieved. Because recycling procedures, guidelines and recycling infrastructure must be established at TYKS, before performing further recycling of laboratory plastic waste is possible.

However, L&T performs recycling by separating plastic fractions by plastic type. Despite single stream method is found to be suitable in some cases, in case of TYKS source separation method is not considered as uncomfortable. As conclusion, L&T's current method to perform plastic recycling offered to TYKS does not generally estimated cause harmful extra workload for laboratory staff. However, single-stream recycling method would be the best solution for contaminated or hazardous plastic packages and containers, because this waste fraction is not currently recyclable with other clean nor rinsed plastic waste.

Due to the high volume in plastic product pieces, washing them before recycling holds a remarkable recycling potential increase in case of TYKS. This washing procedure can be included as a part of pre-sorting methodology, as part of recycling cycle. Washing of plastic packages and containers can be carried out in laboratories themselves according to L&T's current guidelines. TYKS positive attitude towards recycling supports this view.

According to TYKS laboratory staff, laboratory plastic products come from different sources, such as directly from the producer, hospital pharmacy and the logistics center. Therefore, clarifying the sourcing of the incoming plastic product flows for more controllable and could be easier to track. Therefore, this could be one option to have better control of plastic waste produced.

Referenced to data analysis, notable share of analyzed plastic waste had to have hazardous properties, such as used tubes can be contaminated by blood, because laboratory products are often used to collect and transport human samples and chemicals for analyses. Hazardous wastes are mandatory to be utilized by incineration based on Finnish legislation. Therefore, all laboratory plastic items and canisters cannot be currently recycled due to safety reasons.

According to data analysis, formaldehyde plastic canisters are remarkable waste share in pathology laboratory where it was found to be unrecyclable in all conditions due to formaldehyde's hazardous nature. According to formaldehydes safety data sheet paragraph 13.1, ccontaminated package must be disposed of as unused product as stated in directive 2008/98/EY and national legislation. Formaldehyde causes cancer and is harmful to aquatic life and it have to be disposed in a way that it considers these issues (Käyttöturvallisuustiedote 2020). Therefore, formaldehyde packages cannot be recycled as other packages because they cannot be rinsed, and current legislation prevents recycling. Therefore, possibilities of changing the formaldehyde canisters would be considered in a reusable form where they are reusable many times without disposing empty canisters when they are empty. Secondary solution would be that these empty canisters are utilized in pyrolysis. Furthermore, both literature and data analysis suggest for changing current recycling methods towards pyrolysis method in case of contaminated or toxic laboratory plastic waste. This may require further research. In pyrolysis technology, only a fraction of recycled plastic material can bring back as a new plastic raw material, making plastic little use more sustainable in laboratory field, where plastic use is difficult to replace among its significant use. Thereby, most of the hazardous plastic waste can be recycled as raw material in small level when pyrolysis is used, in technical side of view. Hence, recycling possibilities of laboratory plastics in Finland can be seen in bottleneck situation, where waste management operators are compelled to stay current recycling technologies while waiting the update of legislation to cower the recyclability of toxic and hazardous plastics.

In case of TYKS, source separation of hazardous plastic waste would not be required, and contamination is not an obstacle for recycling. This method would include the plastic fractions which would not be recycled in any other way. Therefore, improvements in recycling technologies and legislation are suggested to improve recyclability of these plastic waste fractions. As an example, pyrolysis can be seen one potential option to utilize hazardous plastic waste better in the future. But this change in recycling practices requires co-work with other waste management parties such as L&T.

However, most of contaminated plastics in terminological aspect should not be seen as harmful, e.g., clean and empty ethanol bottles and canisters, when they are rinsed. As ethanol, it is used as solvent and in cleaning, and the packages itself seldom contaminate with blood, excretions or other chemicals. In fact, laboratory staff may safely use them in collecting contaminated small items, instead of commercial collection canisters when washed. In addition, reusing of large reagent canisters and such, are commonly found to have secondary use application as collecting/storing purposes in TYKS laboratories.

As discussed above, the baseline for efficient recycling methods goes by the terms of current recycling and utilization technology currently available, which varies by the country and region. Fråne et al. has identified 3 main conditions that need to be improved to increase recycling of plastic waste from MSW (Municipal Solid Waste) sources in the Nordic countries were pure laboratory plastic waste includes. Firstly, plastic waste source separation needs to be improved further. Secondly, sorting of plastic waste needs to be effective, flexible, and generate secondary plastic raw material that meets the market demands. And finally, markets for secondary plastic raw material needs to exist and absorb the collected and sorted plastic materials to enable for recycling process into new products to replace virgin plastics. (Fråne et al. 2015)

Despite the problematics in recycle technology implementations, only a fraction of all plastic waste in TYKS are currently recycled. However, relatively large uncontaminated plastic fractions, especially polystyrene boxes and plastic casings form packaging materials can be seen easiest plastic waste fraction to add in recycling program with most little changes in recycling process overall. According to data analysis, polystyrene can be seen a remarkable share of unrecycled, uncontaminated plastic waste fraction in TYKS. Therefore, changing the polystyrene for recyclable contribute material made from popcorn (T&T 2021) would be a future solution to reduce polystyrene plastic waste in TYKS.

There were some limitations in this study. Firstly, data analysis did not comparable with literature revives data analysis 100 % because there was no same kind of coverage of plastic items as in data analysis. For instance, disinfection wipes were not researched any equivalent study. A clear equivalence factor was that plastic containers own a large share of total laboratory plastic waste. This presumption was clarified in case data analysis. Second presumption which was clarified was that there is a remarkable recycling potential in laboratory plastic waste.

Secondly, although procurement data could accurately tell what items are annually ordered in each laboratory, this data does not contain information about item materials, packages or their weight. The items must be investigated in laboratory units to identify their material and weight and to observe products that are not procured, eg. arrive in transport of samples etc. A conventional kitchen scale itself could be seen enough accurate to weigh plastic items, but some items were not able to be weighed at all and their volumes were estimated by other means. This leads into situation where volume data between the laboratories may not comparable. Lastly, the amount of packaging materials, especially polystyrene boxes vary weekly, and the volume of packaging materials should be monitored for longer periods or included in the original procurement data in future equivalent studies to gain more reliable data.

For the purposes or this thesis, it was not possible or necessary to aim for 100% accuracy in determining all plastic waste streams in these medical laboratories, but to identify major plastic volumes. Our method is supported by the waste assessment guideline of Global Green and Healthy Hospitals (GGHH) –network in which TYKS is a dedicated member since 2021.

As discussed before, there are no 100 % suitable recycling procedures for laboratory plastics in Finland due the problematics of collecting the waste and processing all shares of contaminated plastic waste. The reasons for this vary, but based on data analysis, complex and demanding procedures are required because plastic waste may include personal information markings which therefore require further design to build safe and reliable recycling chain. This requires most likely additional workload compared to conventional plastic waste recycling operation design. When tight schedules are taken into account in hospital environment, designing and implementing new recycling infrastructure and educating new procedures for staff in this kind of environment requires most likely longer timetables and additional workload. This may be the reason why TYKS recycling procedures are lacking behind.

Case analysis showed that significant amount of clean package materials is currently technically suitable for recycling such as pipette head casings, wipe packages and trays in TYKS and therefore in Finland. However, due the lack of collecting of laboratory plastic waste reaching full potential of plastic recycling is not currently reality.

Consequently, further development of current methodologies and designing the whole recycling cycle of more flexible, dynamic, more scalable can be seen as a great interest. The literature review identified that current most promising techniques are the combination of mechanical and thermo-chemical methods for contaminated laboratory plastics. However, also recycling the plastic packages with producer and user are already currently in use. This declines the production plastic waste rate so introducing and expanding this scheme to include other plastic canisters and packages would be one efficient method to reduce laboratory plastic waste.

In addition, generation of laboratory plastic waste do not consider having reducing potential in the future, without compromising the quality and economic efficiency of the laboratory work, as a large proportion of laboratory equipment is based on plastic packaging and containers as an integral part of the equipment, which is a manufacturer-specific matter. Therefore, the overall recycling of plastic waste should be improved as a whole in hospital laboratories, as the quality of plastic waste cannot be changed or reduced.

Hence the current limitations of TYKS recycling methods, it is constantly improving it processes in recycling. TYKS is recently gained a membership in a Global Green and Healthy Hospitals (GGHH) –network, which is under a global organization, Health Care Without Harm, that sets up specificized policy framework and policy. Basically, this network requires a set up for waste management committee as presented in **figure 23** below and allocate a dedicated budget for waste management and training. Also baselines for oversee, audition and education developing requires for safe waste handling and operations and dedicated strategic planning procedures are included for network members. In addition, the network sets the baseline of conducting the waste audits and monitoring of waste volumes and costs. (GGHH Waste Guidance)

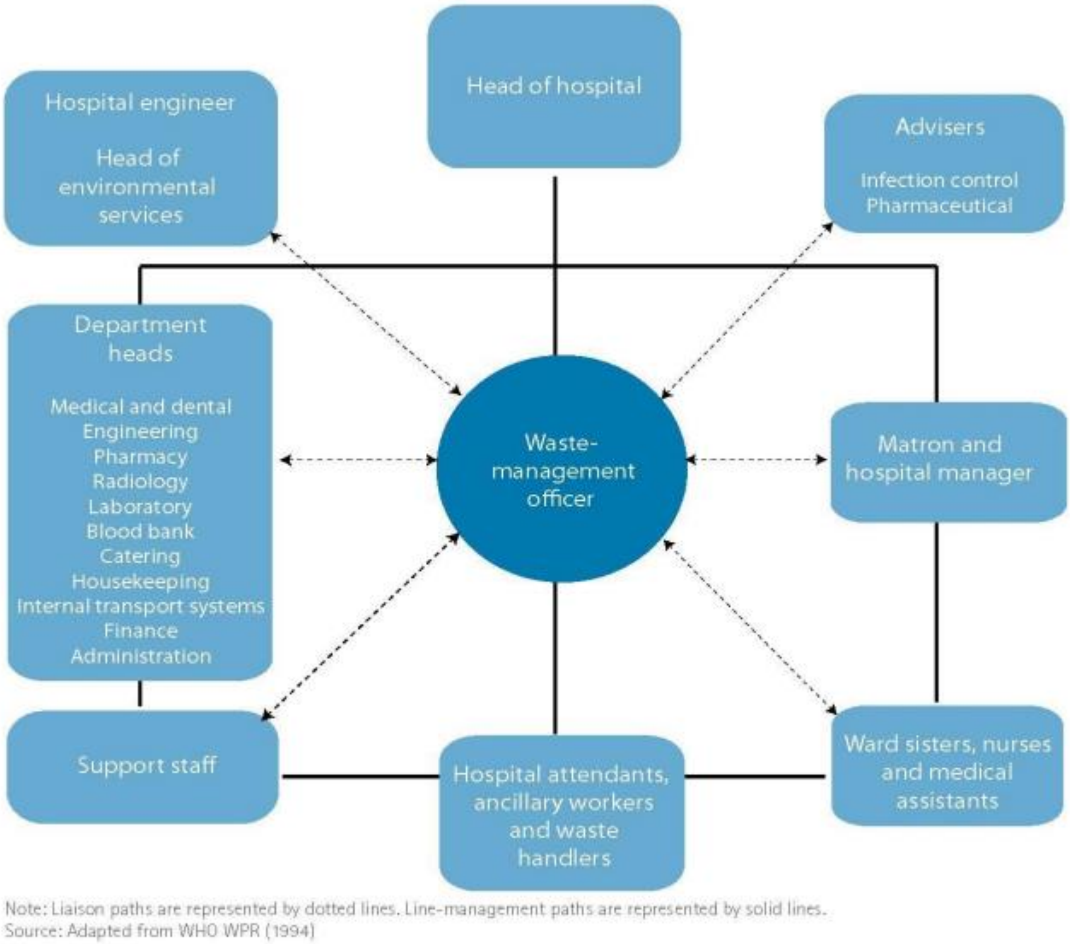

Figure 23. Organization guideline table of a waste management committee (GGHH Waste Guidance)

Guidelines are as follows:

1. Gathering data, benchmarking factors such as average occupants annually.

2. Performing a comprehensive audit for medical waste streams by determining weight and volume for hazardous and non-hazardous waste stream (suggested both monthly and annual amounts). Determine potential value of recyclables.

3. Analyze data and set goals for improvement goals considering waste reduction, elimination of certain wastes, increasing proportion of recyclables and prop gaining the information stated in step 3.

4. Communicate the results.

As discussed above, laboratory plastics in hospital environment could be improved in many ways. For instance, one way is to establish coherent and constantly updating recycling infrastructure with hospital laboratories and waste management companies such as L&T by using current recycling technologies. Other way is to participate to improve the recycling procedures in hazardous plastic waste like formaldehyde canisters and mixed materials such as disinfection wipes for future recycling solutions. Laboratory plastics show increasing recycling potential in both non-contaminated and contaminated plastic waste streams. By using combination of different recycling technologies such as mechanical and chemical recycling like pyrolysis, major part of hospital laboratory plastic could be recycled even higher rate. However, this will have an affect into feedstock for incineration plants for energy usage but while most of the plastics are originated from fossil-based materials increasing recycling potential can be seen as more sustainable option. In addition, health care and laboratory industry are not seen to move away from major single-use plastic products in their operations, hence increasing recycling potential can be seen reasonable option. Possibilities of increasing laboratory plastic recycling could overall rise material and economic efficiency in laboratory operations, which will play a determining role in providing safe and sustainable laboratory operations also in the future.

This thesis found these practiced procedures partly outdated and therefore suggest reform in recycling methods at TYKS. This thesis also suggests changing the currently used package material such as polyurethane and disinfection wipes into biodegradable option as an alternative to reduce total plastic waste production, within streamlining the laboratory plastic consumption. However, this thesis showed that potential of replacing laboratory plastic materials for other materials such as glass or biobased materials are limited due to high quality and hygiene standards. Hence, largest potential relies from reducing plastic consumption, increasing recycling rate and replacing package materials for more sustainable materials. Also, by extending plastic packages and canisters service life by circulating them withing producers and consuming laboratories were found as one alternative solution which is already in use at TYKS in small lever in some products. This thesis suggests for further research to develop current hospital recycling procedures to collect clean plastic casings and other clean package products such as polystyrene boxes to make their collection possible and therefore improve their possibilities to improving their recyclability. Other suggestion for further research is to develop further plastic waste pyrolysis plant suitable for Finnish conditions to enable both mixed contaminated and uncontaminated laboratory plastic waste among other medical plastic waste to improve recycling efficiency in hospital scheme. Also further research is suggested to determine volumes for nitrile gloves and other high volume single use plastic products to gain better understanding their recycling possibilities at TYKS.

As a conclusion, the results reported in this thesis data analysis are coherent with the results discussed in the literature and were able to answer the research questions. TYKS recycling guidelines can be seen in line with EU's recycling targets to circular economy after the implementation of updates this thesis has suggested and what TYKS has already started to implement. Additionally, this thesis benefits to the general research by providing first-hand information on awareness and practical application of laboratory plastic recycling and data analysis techniques by environmental organizations and private companies. This thesis could be a premise for further in-depth overall development for hospital laboratory plastic recycling scheme.

8 CONCLUSIONS

This thesis aimed to identify the laboratory plastic recycling potential by measuring and estimating produced waste plastic types and amount associated with current recycle possibilities and traditional approaches. In addition to learn about innovative techniques for its qualification applied in practice by TYKS/VSSHP laboratories, it encourages to response to the growing interest in increasing more sustainable operations what comes to plastic material usage in hospital environment. It was also essential to determine in which plastic waste streams are currently possible recycle by today's practices and which requires new approaches and technologies. The conclusions of this thesis are drawn upon literature review and the results of the quantitative data analysis. The information for data analysis were obtained by purchase data and plastic weight analysis. Also, TYKS laboratory branches have supported and confirmed the small plastics data analysis and the literature review described.

Literature review showed that laboratory plastic waste has not been researched much, in Finnish perspective even less. Despite this, unified perspective could be formed in hospital laboratory plastic recycling, which shoved, that plastic canisters are major laboratory plastic waste source and laboratory plastic waste has the highest contamination rate compared to other hospital functions. In addition, hospital laboratories recycling has found to be a complex process because of technical, legal and managemental reasons, which tend to cause inefficiencies in plastic recycling rate. Most of laboratory plastics are able to be recycled by using current recycling methods in Finland and it is economically profitable for all hospitals. Case analysis confirmed these views.

Furthermore, case analysis showed that significant part of the laboratory plastic waste are uncontaminated such as pipette head casings and different packaging material. In addition, when bottles and canisters are rinsed such as disinfection-, and ethanol bottles and canisters, they are considered as recyclable. Largest share of laboratory plastic waste were disinfection wipes and their shells, which are made commonly from pulp and plastic. This makes recycling of them difficult by using current technologies. Therefore, new recycling technologies such as pyrolysis is suggested for further research. Following, still noteworthy part of all laboratory waste are irrevocably contaminated and therefore unsuitable for recycling by current plastic recycling methods. Therefore, it is technically challenging to recycle hazardous plastics as raw material, such as hazardous formaldehyde canisters and used tubes contaminated by biological material.

However, most of laboratory plastics are not currently recycled, excluding clear plastic film, due to current recycling procedures in TYKS. According to the case data analysis, gained data and results will not necessarily be repeatable due the various limitations. However, the outline of waste fractions from studied hospital laboratory fractions can be embraced essentially as same as from other laboratories with same operations where same laboratory procedures are carried out. In addition, most noticeable limitation was lacking's in accuracy and repeatability plastic waste streams because those vary weekly. Also tracking laboratory plastic types and packaging weights cannot be tracked efferently because it was not surveilled any way currently. However, the amounts of different laboratory operations can be tracked more easily where comparing total plastic waste amounts with these operations are more feasible.

Case analysis showed that largest recyclable laboratory plastic shares were PE-HD and PS. However, remarkable part of all plastic waste were mixed plastics such as disinfection wipes and their packages. Both literature review and data analysis showed that plastic waste must be uncontaminated and cannot contain personal information to be able to be recyclable when using current recycling methods available for TYKS. Therefore, at this moment proximately half of the laboratory plastic waste could be recycled when rinsing of disinfection canisters are performed. The potential recycling rate found to vary quite significantly, depended on the laboratory. This rate may rise if irrevocably contaminated plastic waste shares could be recycled.

This thesis suggested following measures to increase TYKS laboratory plastics recycle rate. Firstly, deep the co-work with current waste utilization company L&T to keep up with current plastic recycling technical possibilities and update the recycling infrastructures at TYKS and train new recycling guidelines to staff. Secondly, form constantly updating waste management infrastructure in TYKS and inform their plastic waste properties to waste utilization company and other parties to implement new recycling procedures more dynamically and faster. Thirdly, to gain the data of produced plastic waste more efficiently. This may help TYKS to improve their waste management. At this moment plastic products come from various sources to laboratories and therefore the data currently available are fractured and difficult to collect, control and use. And finally, TYKS need to implement measures to decrease the number and amount of used plastic products to reduce the plastic waste production. For example, by switching disinfection wipes into other suitable disinfection method. Also, by building more canister-, and packaging material circulation infrastructures between the producer and consuming hospitals to reduce singe use plastic packaging waste.

REFERENCES

Alwabr, G. M., Al-Mikhlafi, A. S., Al-Hakimi, S. A., & Dughish, M. A., 2016. Determination of medical waste composition in hospitals of Sana'a city, Yemen. *Journal of Applied Science & Environmental Management*, *20*(2), 343–347. [Accessed 10 November 2021]. [Online]. Available at: https://doi.org/10.4314/jasem.v20i2.15

Aseweh Abor, Patience, and Anton Bouwer. "Medical Waste Management Practices in a Southern African Hospital., 2008." *International journal of health care quality assurance* 21.4 (2008): 356–364.

Antelava, Ana & Damilos, Spyridon & Hafeez, Sanaa & Manos, George & Al-Salem, Sultan & Sharma, Brajendra & Kohli, Kirtika & Constantinou, Achilleas., 2019. Plastic Solid Waste (PSW) in the Context of Life Cycle Assessment (LCA) and Sustainable Management. Environmental Management. [Accessed 10 November 2021]. [Online]. Available at: https://www.researchgate.net/publication/333951998_Plastic_Solid_Waste_PSW_in_the_Context_of_Life_Cycle_Assessment_LCA_and_Sustainable_Management

Al-Hanawi, M., Alsharqi, O., & Vaidya, K., 2020. Willingness to pay for improved public health care services in saudi arabia: A contingent valuation study among heads of saudi households. *Health Economics, Policy and Law, 15*(1), 72-93. [Accessed 10 November 2021]. [Online]. Available at: doi:http://dx.doi.org.ezproxy.cc.lut.fi/10.1017/S1744133118000191

Auxilab., 2021. Pasteur pipette. [Website]. [Accessed 11 November 2021]. Available at: https://www.auxilab.es/en/laboratory-equipment/pasteur-pipette-3-ml-500-pcs-/

Basel Action Network (BAN)., 2021. Dark clouds over the future of EU trash burning. [Website]. [Accessed 11 October 2021]. Available at: https://www.ban.org/news/2021/4/29/dark-clouds-over-the-future-of-eu-trash-burning

Chemistryworld., 2020. Seize the lab waste day. [Website]. [Accessed 19 November 2021]. Available at: https://www.chemistryworld.com/opinion/reducing-plastic-waste-in-the-lab/4011550.article#/

Chemical & Engineering news., 2019: Can laboratories move away from single-use plastic? [Website]. [Accessed 11 October 2021]. Available at: https://cen.acs.org/environment/sustainability/laboratories-move-away-single-use/97/i43

C&EN., 2019. Plastic has a problem; is chemical recycling the solution? [Website]. [Accessed 11 October 2021]. Available at: https://cen.acs.org/environment/recycling/Plastic-problem-chemical-recycling-solution/97/i39

Das, A. K., Islam, M. N., Billah, M. M., & Sarker, A., 2021. COVID-19 pandemic and healthcare solid waste management strategy – A mini-review. *The Science of the Total Environment*, *778*, 146220–146220. Accessed 11 October 2021. [Online]. Available at: https://doi.org/10.1016/j.scitotenv.2021.146220

Drzyzga, Oliver. Auxiliadora Prieto., 2019 Plastic waste management, a matter for the 'community'. Microb Biotechnol. 2019 Jan; 12(1): 66–68. Accessed 11 October 2021. [Online]. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6302740/

Directive 2008/98/EC of the European parliament and of the council of 19 November 2008 on waste and repealing certain Directives. [Accessed 27 June 2021]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098

European Commission., 2019. The European Green Deal. Brussels, 11.12.2019 COM(2019) 640 final. [Accessed 27 June 2021]. Available at: The European Green Deal. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

European bioplastics., 2021. What are the required circumstances for a compostable product to compost? [Accessed 27 June 2021]. Available at: https://www.european-bioplastics.org/faq-items/what-are-the-required-circumstances-for-a-compostable-product-to-compost/

European commission., 2004. Methodology for the Analysis of Solid Waste (SWA-Tool). [Accessed 16 October 2021]. Available at: https://www.wien.gv.at/meu/fdb/pdf/swa-tool-759-ma48.pdf

EUVL., 2013. Euroopan parlamentin ja neuvoston päätös No 1386/2013/EU vuoteen 2020 ulottuvasta yleisestä unionin ympäristöalan toimintaohjelmasta ”Hyvä elämä maapallon resurssien rajoissa”, EUVL L 354/171. [Accessed 27 June 2021]. Available at: https://eur-lex.europa.eu/legal-content/FI/TXT/HTML/?uri=CELEX:32013D1386&from=en

Fletcher, C., St. Clair, R., & Sharmina, M., 2021. A framework for assessing the circularity and technological maturity of plastic waste management strategies in hospitals. Journal of Cleaner Production, 306, 127169–. [Accessed 27 June 2021]. [Online]. Available at: https://doi.org/10.1016/j.jclepro.2021.127169

Fråne, A., Stenmarck, Å., Gíslason, S., Løkke, S., Castell-Rüdenhausen, M. zu, Raadal, H. L., & Wahlström, M., 2015. Future solutions for Nordic plastic recycling. Nordisk Ministerråd. https://doi.org/10.6027/TN2015-509. [Accessed 2 August 2021]. [online]. Available at: http://search.ebscohost.com.ezproxy.cc.lut.fi/login.aspx?direct=true&db=e000xww&AN=970202&site=ehost-live

Garcia, J. M., & Robertson, M. L., 2017. The future of plastics recycling. *Science, 358*(6365), 870-872. [Accessed 2 August 2021]. [online]. Available at: http://dx.doi.org.ezproxy.cc.lut.fi/10.1126/science.aaq0324

Goodship, Vannessa., 2010. *Management, Recycling and Reuse of Waste Composites.* Woodhead Publishing. [online]. [Accessed 2 August 2021]. Available at: https://app.knovel.com/hotlink/toc/id:kpMRRWC001/management-recycling/management-recycling

Gradus, R., 2020. Postcollection separation of plastic recycling and design-for-recycling as solutions to low cost-effectiveness and plastic debris. Sustainability (Basel, Switzerland), 12(20), 1–12. [Accessed 2 August 2021]. [online]. Available at: https://doi.org/10.3390/su12208415

HCWH Europe., 2021. Measuring and reducing plastics in the healthcare sector. [PDF-file]. [Accessed 4 November 2021]. Available at: https://noharm-europe.org/sites/default/files/documents-files/6886/2021-09-23_Measuring-and-reducing-plastics-in-the-healthcare-sector.pdf

Järvelä Pentti, Järvelä Pirkko., 2015: Teknisten muovien kierrätys ja uusiokäyttö. 2015. [PDF-file]. [Accessed 4 November 2021]. Available at: https://www.ym.fi/download/noname/%7BC3B5E587-A8C5-47FA-80EB-A034FBECAF99%7D/119332

Jäteohje 2018. Medisiina D jäteohje. E-mail from Leena Setälä. 21.9.2021.

Kandelberg, Kari. Personal information about the costs of hazardous waste disposal in TYKS. E-mail. 19.11.2021.

Kalogiannidou, Katerina. Eftychia Nikolakopoulou, Dimitrios Komilis., 2018. Generation and composition of waste from medical histopathology laboratories,Waste Management,Volume 79, 2018, Pages 435-442, ISSN 0956-053X. [Accessed 4 November 2021]. [Online]. Available at: https://www.sciencedirect.com/science/article/pii/S0956053X18305002

KleanIndustries., 2021. SPR Japan: World's Largest Waste-plastics-to-oil Recovery Plant (CHP Facility). [Accessed 10 November 2021]. [Online]. Available at: https://klean-industries.com/waste-processing-innovations/plastic-pyrolysis-recycling/spr-japan/

Kleinhans Kerstin, Ruben Demets, Jo Dewulf, Kim Ragaert and Steven De Meester., 2021. Non-household end-use plastics: the ‘forgotten’ plastics for the circular economy. [Accessed 2 August 2021]. [online] Available at: https://biblio.ugent.be/publication/8710264/file/8710266.pdf

Kuchibanda, Kizito, and Aloyce W Mayo., 2015. “Public Health Risks from Mismanagement of Healthcare Wastes in Shinyanga Municipality Health Facilities, Tanzania.” (2015).*TheScientificWorld* 2015 (2015): 981756–11.

Kivo., 2017. Opas sekajätteen koostumustutkimuksiin. Jätelaitosyhdistys. [Accessed 2 August 2021]. [online] Available at: http://www.kivo.fi/wp-con tent/uploads/Opas_sekajatteen_koostumustutkimuksiin_versio2.pdf

Kings College London., 2021. Recycling Laboratory Plastics. [Accessed 2 August 2021]. [online] Available at: https://www.kcl.ac.uk/aboutkings/strategy/sustainability/get-involved/staff/sustainability-champions/lab-champions/case-studies/recycling-laboratory-plastics

Kiilto., 2021. Disinfection towel. [Website]. [Accessed 11 November 2021]. Available at: https://www.kiilto.fi/tuote/easydes-peseva-pintadesinfektiopyyhe/#compositions

Kohvakka, Johanna, and Liisa Lehtinen., 2019. *Hyvä, paha muovi: vähennä viisaasti*. Helsinki: Minerva Kustannus Oy, 2019. Print.

Käyttöturvallisuustiedote., 2020, Formaldehydi 59244, IS-VET Oy. Päivitetty 14.1.2020. [PDF-file]. [Accessed 11 December 2021]. Available at: https://www.isvet.fi/ckeditor/plugins/fileman/Uploads/turvallisuustiedotteet/Formaldehydi.pdf

Lee, B.-K., Ellenbecker, M. J., & Moure-Eraso, R., 2004. Alternatives for treatment and disposal cost reduction of regulated medical wastes. *Waste Management (Elmsford)*, *24*(2), 143–151. [Accessed 11 November 2021]. [online]. Available at: https://doi.org/10.1016/j.wasman.2003.10.008

Lee, B.-K., Ellenbecker, M. J., & Moure-Eraso, R., 2002. Analyses of the recycling potential of medical plastic wastes. Waste Management (Elmsford), 22(5), 461–470. [Accessed 11 November 2021]. [online]. Available at: https://doi.org/10.1016/S0956-053X(02)00006-5

Setälä Leena. Personal information about TYKS plastic recycling. E-mail. 12.2.2021.

GGHH. Global Green and Healthy Hospitals, Waste Management Guidance document (not publicly available, personal information from Leena Setälä 12.2.2021.

Lammi Eeva. Personal information about L&T's recycling possibilities. E-mail. 7.12.2021.

Lappeenrannan uutiset., 2018. Muovijätteen määrä Eksoten sairaaloissa on valtava – kierrätystä ei ole järjestetty. [Website]. [Accessed 11 November 2021]. Available at: https://www.lappeenrannanuutiset.fi/paikalliset/1358605

Liu, Hao, and Zhong Yao., 2018. Research on Mixed and Classification Simulation Models of Medical Waste—A Case Study in Beijing, China. Sustainability (Basel, Switzerland), 10(11), 4226–. [Accessed 11 November 2021]. [online]. Available at: https://doi.org/10.3390/su10114226

L&T., 2020. Leikkaussalien muovit kiertoon Terveystalossa [Website] [Accessed 11 June 2021]. Available at: https://lassikko.lt.fi/leikkaussalien-muovit-kiertoon-terveystalossa

L&T., 2021. Muovin kierrätys. [Website]. [Accessed 8 November 2021]. Available at: https://tietopankki.lt.fi/muovimuuvi-kysymyksia-ja-vastauksia

LSJH., 2017. Jätehuoltopoliittinen ohjelma Lounais-Suomessa 2017 – 2022. [PDF-file]. [Accessed 11 October 2021]. Available at: https://www.lsjh.fi/wp-content/uploads/jatehuoltopoliittinen-ohjelma-2017-2022.pdf

Laboratory plastics detection round 16.9.2021. E-mail from Leena Setälä. 11.10.2021.

Mmereki, D., Baldwin, A., Li, B., & Liu, M., 2017. Healthcare waste management in Botswana: storage, collection, treatment and disposal system. Journal of Material Cycles and Waste Management, 19(1), 351–365. [Accessed 5 October 2021]. [Online]. Available at: https://doi.org/10.1007/s10163-015-0429-0

Muoviteollisuus ry., 2021. Muovit ovat monipuolinen materiaaliryhmä. [Website]. [Accessed 1 October 2021]. Available at: https://www.plastics.fi/fin/muovitieto/muovit/

Orion., 2020. Orionin lääke- ja itsehoitopakkausten lajitteluohje. [Website]. [Accessed 17 October 2021]. Available at: https://www.itsehoitoapteekki.fi/artikkelit/vastuullisuus/orionin-laake--ja-itsehoitopakkausten-lajitteluohje/

Palpa., 2021. Beverage container recycling briefly. [Website]. [Accessed 17 June 2021]. [online] Available at: https://www.palpa.fi/beverage-container-recycling/palpa-briefly/

Paraschiv, M., Kuncser, R., Tazerout, M., & Prisecaru, T., 2015. New energy value chain through pyrolysis of hospital plastic waste. *Applied Thermal Engineering*, *87*, 424–433. [Accessed 1 November 2021]. [Online]. Available at: https://doi.org/10.1016/j.applthermaleng.2015.04.070 I

Plasticseurope., 2015. Plastics – the Facts 2015, An analysis of European plastics production, demand and waste data. [PDF-file]. [Accessed 17 June 2021]. Available at: https://www.plasticseurope.org/application/files/3715/1689/8308/2015plastics_the_facts_14122015.pdf

Plastic Recycles Europe., 2021. Chemical recycling. [Website]. [Accessed 1 December 2021]. Available at: https://www.plasticsrecyclers.eu/chemical-recycling

Plastoposeeni., 2021. Muovien maailma. [Website]. [Accessed 1 December 2021]. Available at: https://ekokumppanit.fi/muoviopas/

Potera, C., 2012. Strategies for greener hospital operating rooms. Environmental Health Perspectives, 120(8), a306–a307. [Accessed 15 June 2021]. [online] Available at: https://doi.org/10.1289/ehp.120-a306a

Purohit, B. C., 2001. Book Reviews: A.V. Srinivasan (ed.), Managing a Modern Hospital, New Delhi: Response Books, 2000, 404 pp [Review of Book Reviews: A.V. Srinivasan (ed.), Managing a Modern Hospital, New Delhi: Response Books, 2000, 404 pp]. Journal of Entrepreneurship, 10(1), 94–96. Sage Publications. . [Accessed 15 June 2021]. [online] Available at: https://doi.org/10.1177/097135570101000106

Riedel, L. M., 2011. Environmental and financial impact of a hospital recycling program. AANA Journal, 79(4 Suppl), S8–14. Print.

Rochman, C. M., Browne, M. A., Halpern, B. S., Hentschel, B. T., Hoh, E., Karapanagioti, H. K., Rios-Mendoza, L. M., Takada, H., Teh, S., & Thompson, R. C., 2013. Classify plastic waste as hazardous. Nature (London), 494(7436), 169–171. [Accessed 15 June 2021]. [online] Available at: https://doi.org/10.1038/494169a

Rinkiin., 2021. Tuottajavastuu. [Website]. [Accessed 15 June 2021]. Available at: https://rinkiin.fi/yrityksille/tuottajavastuu/

Ragaert, Kim & Delva, Laurens & Van Geem, Kevin., 2017. Mechanical and chemical recycling of solid plastic waste. Waste Management. 69. [Accessed 5 November 2021]. [online] Available at: https://www.sciencedirect.com/science/article/abs/pii/S0956053X17305354

Shah. 2012. Charmi Shah. “Biomedical Waste Management: A Move Towards Green Environment.” *Asia pacific journal of management and entrepreneurship research* 1.3 (2012): 5–. Print.

Suomen ympäristö., 2018. Selvitys orgaanisen jätteen kaatopaikkakiellon vaikutuksista Julkaisusarjan nimi ja numero, Suomen ympäristö 3/2018. [PDF-file]. [Accessed 10 November 2021]. Available at: https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/160946/SY_03_3018_Orgaanisen_jatteen_kaatopaikkakielto.pdf

Suomen virallinen tilasto (SVT)., 2021: Jätetilasto ISSN=1798-3339. Helsinki: Tilastokeskus. [Website]. [Accessed 11 November 2021]. Available at: http://www.stat.fi/til/jate/index.html

University of Dundee, School of Life Sciences., 2020. Laboratory plastic recycling waste scheme introduced. [Website]. [Accessed 14 October 2021]. Available at: https://www.lifesci.dundee.ac.uk/news/2020/jan/28/laboratory-plastic-recycling-waste-scheme-introduced

Simón D., A.M. Borreguero, A. de Lucas, J.F. Rodríguez., 2018. Recycling of polyurethanes from laboratory to industry, a journey towards the sustainability,Waste Management,Volume 76, 2018,Pages 147-171. [Accessed 11 November 2021]. [Online]. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0956053X18301831

T&T, Tekniikka & Talous., 2021. Popcornista kehitettiin käsittämättömän täydellinen korvaaja styroxille – Tulenkestävää, eristää lämpöä kuin styrox mutta 2x lujempaa, 100 % biohajoavaa (kuvia). Website. [Accessed 30 December 2021]. Available at: https://www.tekniikkatalous.fi/uutiset/popcornista-kehitettiin-kasittamattoman-taydellinen-korvaaja-styroxille-tulenkestavaa-eristaa-lampoa-kuin-styrox-mutta-2x-lujempaa-100-biohajoavaa-kuvia/a165103a-9934-49e7-a1a8-6050b0f7f0ae

The Biologist., 2021. How to... reduce your lab's plastic waste. [Website]. [Accessed 11 November 2021]. Available at: https://thebiologist.rsb.org.uk/biologist-features/how-to-reduce-your-lab-s-plastic-waste

Tiedote 12.12.2020. TYKS. Muovinkierrätys lisää mahdollisuuksia. E-mail from Leena Setälä. 12.2.2021.

Työ- ja elinkeinoministeriön julkaisuja., 2019:64. Muovijätteen kemialliset hyödyntämisratkaisut ja -markkinat kiertotaloudessa. [PDF-file]. [Referred to 11 November 2021]. Available at: https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/161993/TEM_2019_64.pdf

Turku waste management., 2021. Turun Kaupunkiseudun jätehuoltomääräykset. [PDF-file]. [Referred to 11 June 2021]. Available at: https://www.turku.fi/sites/default/files/atoms/files/jatehuoltomaaraykset_yleinen_osa.pdf

United Nations., 2015, THE 17 GOALS | Sustainable Development [Website] [Referred to 11 August 2021]. Available at: https://sdgs.un.org/goals

Uusiouutiset., 2019 Pyrolyysi lisäisi muovin kierrätystä 27.9.2019. [website]. [Referred to 11 September 2021]. Available at: https://www.uusiouutiset.fi/pyrolyysi-lisaisi-muovin-kierratysta/

Uusiouutiset., 2013, Sairaalajäte tulee palamaan vantaalla. [PDF-file]. [Referred to 01 December 2021]. Available at: https://www.uusiouutiset.fi/UU8-13HUS.pdf

Uusitalo, Kaisa., 2017. Hyvä paha muovi. Teoksessa Työryhmä & Nikkanen, Hanna. Hyvän sään aikana. Mitä Suomi tekee, kun ilmasto muuttaa kaiken. Helsinki: Into Kustannus Oy. Print.

VSSHP., 2021.Infoa muovin lajittelusta. E-mail from Leena Setälä. 12.2.2021.

VSSHP Annual report., 2021. Erikoissairaanhoidon tunnuslukuja. [website]. [Accessed 1 December 2021] Available at: https://www.vsshp.fi/fi/sairaanhoitopiiri/talous-ja-toimintaluvut/erikoissairaanhoidon-tunnuslukuja/Sivut/default.aspx

VTT., 2019. Fast pyrolysis of industrial waste residues to liquid intermediates -experimental and conceptual study. Oasmaa Anja et al. 2019. [PDF-file]. [Accessed 11 September 2021]. Available at: https://cris.vtt.fi/ws/portalfiles/portal/52613662/WasteBusters_Final_report_VTT_R_512_19.pdf

VTT News., 2019. VTT to add new methods to the plastics recycling chain. 11.6.2019. [Website]. [Accessed 7 November 2021. Available at:

https://www.vttresearch.com/en/news-and-ideas/vtt-add-new-methods-plastics-recycling-chain

VTT info., 2021. Info about VTT. [Website]. [Accessed 7 November 2021]. Available at: https://www.vttresearch.com/fi/tietoa-meista/tietoa-vttsta

Vingwe, Edward, Edgar Towa, & Arne Remmen., 2020. Danish Plastic Mass Flows Analysis. *Sustainability (Basel, Switzerland)*, *12*(9639), 9639–.]. [Accessed 7 November 2021]. [Online]. Available at: https://doi.org/10.3390/su12229639

World Health Organization (WHO). Health-Care Waste. Fact Sheet., 2018. [Website]. [Accessed 11 October 2021]. Available at: http://www.who.int/mediacentre/factsheets/fs253/en/

WHO., 2020. Treatment and disposal technologies for healthcare waste. [PDF-file]. [Accessed 11 October 2021]. Available at: https://www.who.int/water_sanitation_health/medicalwaste/077to112.pdf.

World Economic Forum, Ellen MacArthur Foundation, and McKinsey & Company., 2016. The New Plastics Economy – Rethinking the future of plastics. [Accessed 7 October 2021]. [Online], Available at: http://www.ellenmacarthurfoundation.org/publications

Yle., 2019. Jätteiden hyötykäyttö sairaaloissa. [website]. [Accessed 7 October 2021]. Available at: https://yle.fi/uutiset/3-10591956

Yle., 2008. Muovin kierrätys sairaaloissa. [website]. [Accessed 11 October 2021]. Available at: https://yle.fi/uutiset/3-5114309

YLE uutiset., 2014. Fortumin uusi pyrolyysivoimala seisahtuu jo 15 asteen pakkasessa. 24.1.2014. [website]. [Accessed 11 October 2021]. Available at: https://yle.fi/uutiset/3-7046047

YM. 2016. YMPÄRISTÖN-SUOJELUYMPÄRISTÖHALLINNON OHJEITA 1:2016. [PFD-file]. [Accessed 11 October 2021]. Available at: https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/74873/OH_1_2016.pdf

Zand, A.D., Heir, A.V., 2021. Environmental impacts of new Coronavirus outbreak in Iran with an emphasis on waste management sector. *J Mater Cycles Waste Manag* 23, 240–247. [Accessed 8 October 2021]. [Online]. Available at: https://doi.org/10.1007/s10163-020-01123-1

Zhao, Peng & Xie, Jun & Gu, Fu & Sharmin, Nusrat & Hall, Philip & Fu, Jianzhong., 2018. Separation of mixed waste plastics via magnetic levitation. Waste Management. [Accessed 17 July 2021]. [online] Available at: https://www.researchgate.net/publication/323532539_Separation_of_mixed_waste_plastics_via_magnetic_levitation

<u>Plastic types commonly found in healthcare</u>. (HCWH Europe p.39. 2021)

Plastic types commonly found in healthcare[100]

RESIN CODE	PLASTIC TYPE	ABBREVIATION	COMMONLY USED IN
1	Polyethylene terephthalate (Polyester)	PET, PETE	Water/drinks bottles, textile fabrics.
2	High-density polyethylene	HDPE	Milk/yoghurt drink bottles, waste bags, IV fluid containers, syringe barrels.
3	Polyvinyl chloride	PVC	Blood bags, IV bags, tubing, catheters, respiratory masks, disposable gloves.
4	Low-density polyethylene	LDPE	Plastic bags, plastic films, other flexible packaging.
5	Polypropylene	PP	Syringes, sterilisation "blue" wrap, irrigation bottles, basins, cups and disposable items e.g. surgical masks, gowns, caps, shoe covers, drapes.
6	Polystyrene	PS	Plastic cutlery, yoghurt cups, fruit & vegetable trays, clear solid packaging, test tubes.
	Expanded polystyrene (Styrofoam)		Fast food packaging, packing "peanuts", insulation.
7	OTHER All plastics that do not fit in any of the above categories, common examples include:		
Polycarbonate[vi]		PC	Medical tubing, catheters, incubators, syringes, blood oxygenators, baby bottles.
Polyurethane		PUR	Sponges
Polyamide		PA	Tea bags
Nitrile rubbers			Disposable gloves, catheters.
Polylactide		PLA	Coffee cup lids, yoghurt pots.

Summary of data analysis calculations

VSSHP laboratories disinfection products and alcohol package consumption 2020	
total PE-HD bottles and bags (kg/a)	713
total wipe packs when empty, shells only (kg/a)	528
total wipe pags when full, no shells (kg/a)	5447

Weight per item (empty):

500 ml pump bottles, 58 g

500 ml bottles, 37 g or 40 g depending on brand

1000 ml bottles, 58 g

1000 ml bag, 53 g

5000 ml bottles, 172 g

100 ml bottle, 17 g to 19 g depending on brand

All above are PE-HD

Wipe packs: Wetwipe: 27 g empty and 141 full; Easydes: 4 g empty, 73 g full; ProWipes: 27 g empty, 142 g full; ApoWipe: 2 g empty, 7 g full.

Wipe packs are mixed plastics, depending on brand