RE: SOURCE

Final report of the project

Sustainable management of plastic waste from hospitals

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Preface

This project has been performed within the strategic research program RE:Source, with funding from the Swedish Energy Agency and participating partners. We would like to send a warm thank to all participants for their dedication and commitment during the project. Without their contributions the success of this project would not have been possible.

The big interest the project received nationally and in other Nordic countries shows the importance of the area, and we are looking forward to following up and expand this work further as a national, Scandinavian and/or European project in the future.

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Sammanfattning

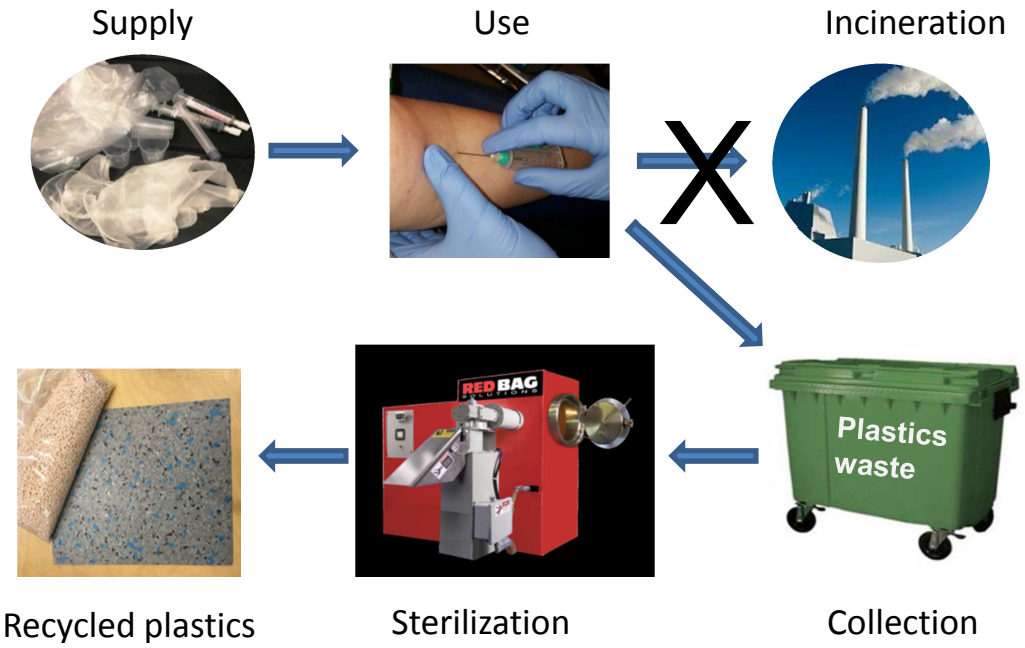
Sjukhus förbrukar stora mängder plast och volymerna fortsätter att stiga. Merparten av plasten används i engångsprodukter som plastsprutor, engångsförkläden, sterila förpackningar och liknande på grund av patientsäkerhet, lägre kostnad och bekvämlighet. Medicinskt avfall har historiskt lagts på deponier eller förbränts, men politiker och hälsovårdsorganisationer börjar efterfråga ett nytt tillvägagångssätt på sjukhus som minimerar avfall hela vägen från tillverkning till bortskaffande. I detta sammanhang nämns kraftigt ökad återvinning som en viktig del av en bredare insatts för att förbättra sjukvårdens hållbarhet och minska avfallet. Produkter inom vårdsektorn är ofta av hög kvalitet och gjorda av högkvalitativ plast, vilket gör dem ännu mer värdefulla för återvinning. Trots att det finns stor efterfrågan på högkvalitativt plastavfall så är en vanlig uppfattning att avfall som genereras på sjukhus är "smutsigt" och utgör en hälsorisk, vilket gör folk ovilliga att använda den.

Projektets mål var att öka återvinningsgraden för sjukhusplastavfall utan att öka personalens arbetsbörda och utan ökade risker för människor eller miljö. För att uppnå detta mål användes lämpliga förbehandlingsmetoder som kan avlägsna infektionsrisker från plastavfallsfraktionen; dels en hydrotermisk metod som levereras av RedBag Solutions (RBS) och dels en ozoneringsprocess som levereras av Ozonator. Huvudutmaningen var att ta reda på hur kvaliteten på plast från brännbart plastavfall påverkas av de olika förbehandlingsmetoderna, men utan att kompromissa med total avlägsning av potentiella infektionsrisker. Tre material för studien valdes noggrant ut i samförstånd med sjukhus och produkttillverkare: polyeten (PE) som används i förkläden, polypropen (PP) som används i medicinska koppar och sprutor och polyvinylklorid (PVC) som används i handskar. Efter förbehandling utvärderades materialen med avseende på färgförändring, stabiliseringsgrad och förändring av kemisk struktur. Den viktigaste slutsatsen från förbehandlingsstudierna var att förbehandlingsprocesserna inte medför några mätbara förändringar i de studerade materialen, utom vissa indikationer på en mindre förlust av mjukgörare i PVC-proverna.

Den förbehandlade plastens förmåga att fungera bra i industriella processer utvärderades i två storskaliga återvinningsförsök. PP-materialet användes på Bergo Flooring för tillverkning av golvplattor av 100% återvunnen PP medan PVC-materialet användes vid Tarkett för produktion av golv innehållande 20 viktprocent återvunnen PVC. Före tillverkningen förbehandlades materialen i en kommersiell storskalig RBS-utrustning i USA. Den huvudsakliga erfarenheten från försöken var att materialen är användbara och fungerar bra i tillverkningsprocessen, även om det finns utrymme för förbättringar som skulle öka användbarheten hos de återvunna materialen. En viktig sådan förbättring skulle vara att identifiera och hindra potentiell förorening av de förbehandlade materialen. En annan är att säkerställa en tillräcklig grad av stabilisering av materialen för att minimera nedbrytning under användning, förbehandlingar och återvinningsprocesser.

Slutligen utvärderades förbehandlingsteknikerna och efterföljande återvinning med avseende på miljömässiga, ekonomiska och sociala faktorer. Resultaten visar att förbehandling och återvinning är fördelaktigt ur ett klimatperspektiv, även med antagna materialförluster och antagen kvalitetsminskning av det återvunna materialet. Miljökrediteringen för återvunnet plastmaterial gavs endast hälften av de jungfruliga materialen. I de industriella återvinningsförsöken ersattes en betydande

del av det jungfruliga materialet med det återvunna materialet utan kvalitetsminskning, varför miljökrediten borde vara betydligt högre än 0,5. Det innebär att miljöfördelen med återvinning är ännu högre än den beräknade i LCAn.



Summary

Hospitals use large amounts of plastics which continue to rise. Most of the plastics are used as disposable items such as plastic syringes, single-use gowns, sterile packaging, etc. due to patient safety, lower cost and convenience. Medical wastes historically have been disposed of in landfills or incinerated. However, politicians and health organizations are beginning to call for a new approach at hospitals that minimizes waste from manufacturing to the disposal. In this context, significantly increased recycling is highlighted as important part of a broader effect to improve hospital sustainability and reduce waste. Products for the healthcare sector are often of high quality and made from high grade plastics, which makes them even more valuable for recycling. However, despite the fact that there is considerable demand for such high-quality plastic waste, the perception that waste generated in hospitals is "dirty" and constitutes a health risk makes people reluctant to use it.

The project goal was to increase recycling rates of hospital plastics waste without increasing workload of the staff and without increasing risks for people or the environment. To achieve this goal, suitable pre-treatment methods were used capable to remove infection risks from the plastic waste fraction viz. a hydrothermal method supplied by RedBag Solutions (RBS) and an ozonation process supplied by Ozonator. The main challenge was to find out how quality of plastics from combustible plastic waste fraction is affected by the different pre-treatment methods but without compromising the total removal of the potential infection risks. Three materials for the experimental study were carefully chosen in consensus with hospitals and product manufacturers: polyethylene (PE) used in aprons, polypropylene (PP) used in medicine cups and syringes and polyvinyl chloride (PVC) used in gloves. After pre-treatments, the materials were evaluated with respect to colour change, degree of stabilization and alteration of chemical structure. The main conclusion from the pre-treatment studies was that the pre-treatment processes do not cause any measurable changes in the materials studied except some indications of a minor plasticizer loss in the PVC samples.

Capability of pre-treated plastics to perform well in industrial processes was evaluated in two large-scale recycling trials. The PP material was used at Bergo Flooring for production of floor tiles made of 100 % recycled PP while the PVC material was used at Tarkett for production of flooring containing 20 w% of recycled PVC. Before manufacturing, the materials were pre-treated in commercial large-scale RBS equipment in USA. The main experience from the trials was that the materials are useful and perform well in the manufacturing process although there is room for improvements that would increase the usability of the recycled materials. One important objective would be to identify and hinder the potential contamination of the pre-treated materials. Another objective would be to ensure a sufficient degree of stabilization of the materials in order to minimize degradation during usage, pre-treatments and recycling processes.

Finally, the pre-treatment technologies and subsequent recycling were evaluated with respect to environmental, economic and social factors. The results show that pre-treatment and recycling is beneficial from a climate perspective, even with assumed material losses and assumed quality reduction of the recycled materials. The environmental credit for recycled plastic materials was given only half of the virgin materials. In the industrial recycling trials a significant part of the virgin materials was replaced by the recycled materials without quality reduction thus the

environmental credit should be significantly higher than 0,5. This means that the environmental benefit due to recycling is even higher than calculated by the LCA.

Introduction and background

Since society and industry have become more environmentally conscious, recycling has become a priority option for handling of plastics waste. Eighty percent of conventional plastics produced today are thermoplastics, which can be re-melted and, therefore, mechanically recycled, which provides an effective and resource efficient way of reusing the post-consumer plastics. Thus, there is a general ambition to improve waste management in all sectors of society, but in particular to increase material recycling, although reuse and waste prevention have also become increasingly focused as a result of the requirements of the EU waste directives.

Hospitals use large amounts of plastics every year as modern healthcare would be impossible without many of the plastic-based medical products. The global market for medical plastics is estimated to reach 18.3 billion pounds in 2022 from 13.6 billion pounds in 2017 by annual growth rate of 6.2% for 2017-2022 [1]. However, medical-grade plastics often are stigmatized in recycling leading to low recycling rates which is currently a common problem at hospitals worldwide. In Sweden, it was estimated that about 25.000 ton of plastic waste from 21 Swedish county councils is incinerated annually but only 500 ton is recycled [2]. Most of the materials are single use items that are disposed after one use, because it enables easy handling and the materials may not be suitable for disinfection and reuse. Among medical products there are disposable items such as gloves, protective aprons, medicine cups, syringes, nozzles, hoses, etc. Some of the consumed plastic products may be contaminated by different infectious microorganisms or dangerous substances such as pharmaceuticals, which in both cases restrict the recycling or reuse opportunities of the plastics. Due to the potential infection risks, recycle plants are unwilling to handle hospital waste, thus the plastics are currently often sent to combined heat and power plants (CHP) to be incinerated with energy recovery. Special waste fractions, including blood bags and other plastic products with direct patient and body fluid contact, are destroyed in special facilities. These fractions are not in focus for the current project. Many plastics are however materials that, if correctly used and recycled, are durable and can be recycled several times. Products developed for the healthcare sector are often of high quality and made from high grade plastics, which makes them even more valuable for recycling. Health care plastics lend themselves to numerous markets. For instance, high quality polypropylene (PP) is always in demand with compounders because of its relatively high value and universal applications for blending and pelletizing.

In order to achieve the goal to significantly increase plastics recycling it is necessary to develop suitable technologies capable of handling this type of waste. The challenges that hospitals are facing are how to successfully increase recycling rates taking into consideration the safety, economy, regulatory, resources and infrastructure issues that come with it. The volume of plastics waste from healthcare is huge and the ability to recycle these materials would significantly reduce the environmental impact while preserving the value of these highly useful materials. This project is based on a pre-study financed by Vinnova during 2013 [2], where the current waste treatment and the amount of different polymers in hospitals were studied. Several studies [3][4][5] have shown that mechanical recycling of plastics is much more sustainable than energy recovery through incineration (for example only 25% of the energy is required when producing plastic from recycled material compared to when the virgin feedstock is used), thus mechanical recycling is

environmentally beneficial compared to energy recovery. Some of the conclusions from the pre-study were that in order to increase plastic recycling from hospitals, new techniques for sterilization of waste are needed. The technology for automated sorting must also be improved so that the hospital staff doesn´t need to spend much time on sorting waste in too many fractions. To facilitate this, good communication and close collaboration between manufacturers, users and recyclers is needed, to minimize the number of different materials used in healthcare products. The communication part was one of the most challenging issues in this project and therefore it was given a special attention during the whole project time. The knowledge about plastics and their potential for recycling varied between different partners and also between different hospital and counties. Thus exchange of knowledge about plastics, bioplastics, biodegradable plastics and recycling was an important step in the project.

The current project is based on the idea that it is possible to significantly increase recycling rates of hospital plastics waste without increasing the workload of the staff or disrupt the hospitals´ daily work and without increasing health risks for people or risks for environment. To achieve this goal, it is necessary to use suitable pre-treatment methods that can remove potential infection risks from the plastic waste fraction without compromising the quality of the materials. After pre-treatment plastics can be handled and recycled without health risks related to the handling of waste. The main research question in this project was to find out how the quality of the plastics from the combustible plastic waste fraction is affected by the pre-treatment using different methods but without compromising the total removal of the potential infection risks. Two different pre-treatment methods were studied viz. ozonation and hydrothermal treatment. This type of hospital waste management is already used in other parts of the world such as the United States and Asia, while it is still at the planning stage in Europe where England and Holland are ahead of Sweden in planning. In countries using these methods however, the treated residual waste goes to landfills or incineration (with or without energy recovery). The innovative part of this project is that we intend to customize the pre-treatment methods not only to make the waste harmless but also recyclable. In addition, the hospitals will also be able to process other valuable materials with the same methods, such as stainless steel, which can subsequently be utilized with significant economic gains as a result.

One key aspect to increase recycling of plastics is how the regions interpret what is contaminated plastic waste. The central regional support function called “vårdhygien” (healthcare hygiene) plays an important role in this interpretation, guiding the hospitals in their county/region on what is contaminated and how to handle different products in different situations. This makes it difficult to implement stringent and clear instructions to the staff on how to handle plastic waste. Clear and continuous information is a key factor to implement successful handling of plastic waste. Also, the attitudes to recycling of plastics from hospitals are still very different between the hospitals staff and other actors in the value chain, especially recycling companies.

Plastic recycling is also associated with a number of environmental, social and economic issues. The use of different solutions, especially the pre-treatment methods was evaluated and compared with existing practices from an environmental and resource point of view. The social aspects were investigated in relation to what the

use of the proposed solutions entails and what the consequences are for the staff in the hospitals, for example with regard to acceptance, commitment and approach. The economic aspects were discussed taking into consideration the purchase of equipment, costs associated with the use of equipment for county councils and alternative costs and revenues in the form of waste management and waste fractions changing. However, it was not possible to make generic cost estimations due to the very different prerequisites in the different regions and hospitals.

Finally, the important part of the project was communication and exchange of knowledge and experience between different participants. A strong partnership and open communication between hospitals, recyclers and product manufacturers is a key. While a single hospital may not generate a profitable volume of material for a recycler many hospitals interested in working together can provide sufficient volumes to make recycling economically viable. It is also important to correct some common misconception about health care plastics e.g. that all plastics from hospitals are inherently dangerous as a result of contact with biohazardous materials, drugs and other unsafe materials. Swedish hospitals are committed to training their staffs on proper sorting and separation and are very open to recyclers that are willing to provide feedback and open dialogue to make health care plastic recycling a reality.

Implementation - project structure and methodology

Project organisation and management

The project was carried out in close collaboration between researchers, health care personal, plastic product manufacturers, manufacturers of sterilization equipment and the plastic industry. The steering group was appointed to ensure good coordination, communication and exploitation of the results and included the project manager, WP leaders and one environmental coordinator (different person depending on the work load) from hospital has worked with the necessary decision needed for the project direction.

The management of the project have been challenging due to several reasons. At the beginning of the project, the large variations in organization size, regional variations on waste management and how plastic waste is handled at the different partner organizations (hospitals) required a great deal of discussions and time in order to reach a common view and agreement regarding what products, methods and boundaries to apply in the different investigations in the project. Once this was resolved there was a significant improvement in project communication, interest and engagement from all partners throughout the remaining project time. Unfortunately, one of the partner hospitals, Södersjukhuset (SÖS), left the project during the first year due to lack of resources (time). The project was also affected by unplanned loss and temporary absence of key competences in the project group over long periods (e.g. change of job, sick-leave and paternity leave) which ultimately required us to prolong the project time.

The project activities have been organised in six different work packages (WP). RISE has coordinated the project together with representatives from the participating partners. Regular meetings have been organised to follow up on project progression and discuss the path forward. These activities make up the content of WP1. WP2 assessed the technical aspects of the pre-treatment methods and the degree of sterilization that can be achieved after treatment. The aim was that all treated materials should be regarded as risk free and can be handled in the ordinary recycling chain. In WP3 the resulting effects of pre-treatment on the material properties was evaluated. The important information was if the materials retain an acceptable quality after pre-treatment and if it is possible to sort different materials in clean fractions. In WP4, the large-scale trials were initially scheduled to be performed in Sweden and/or UK. However, due to that neither of the required equipment were available in Europe at the time for the trials, the trials were rescheduled to be performed at the companies US sites. This change required large adjustments regarding sourcing of products to be tested in order to minimize the additional time and costs for material shipments. Although a new plan for performing the large-scale trials were set in action, only one of the companies (Red Bag) were able to deliver pre-treated materials within the timeframe of the project. The pre-treated materials were used in industrial processes and new products were manufactured. Processability and material/product quality was evaluated. The purpose of WP5 was to evaluate the environmental, economic and social consequences of the proposed pre-treatment solutions from a system perspective. Finally, WP6 involved external communication and dissemination of the results and organization of seminars.

Product selection

The idea for a future implementation of a new waste handling system for hospitals is increased plastic recycling with a minimal work load for the hospital staff. Increased sorting is therefore not a desired path, instead the aim is that all plastic waste can be thrown in the same container, sterilised by pre-treatment and then automatically sorted and handled risk-free by the recycling industry. Automated sorting and separation of different plastics however present challenges that are not the focus of this project. To limit the project to only sterilisation treatments and recyclability, a few specific products were selected and used separately as clean fractions.

The products were carefully chosen in collaboration with hospitals and product manufacturers, taking several factors into account. There must be a large enough volume of the product for it to be economically interesting to recycle. The product must be manufactured from a polymer that is suitable for recycling. There must be a demand for recycled material on the market.

The hospitals provided data on purchase volumes of different products. Although the actual volume differed largely between counties of different size, the same products generally came up in top of the charts everywhere. The decision landed on the following products:

- Aprons made from polyethylene (PE)
- Medicine cups and syringes made from polypropylene (PP)
- Gloves made from polyvinyl chloride (PVC)

Most counties prefer nitrile gloves instead of vinyl, but the choice fell on vinyl gloves since nitrile rubber is not a material suitable for mechanical recycling.

These products were delivered (by product manufacturer) or bought new and throughout the project all experiments were performed on new, unused products to minimize effects from possible contaminations. No actual recycling of used products was tested.

Experimental methods

The scope of the experimental part of the project was to evaluate to recyclability of the selected plastic products after being subjected to a sterilization process as pre-treatment method for recycling. Sterilization is done to ensure that no hazardous substances such as bacteria or pharmaceuticals are passed on to expose personnel working in the recycling chain to danger. However, such sterilization methods may also result in degradation of the polymers to an extent where they cannot be used again. Therefore, it is important to analyse the material properties after sterilization treatment.

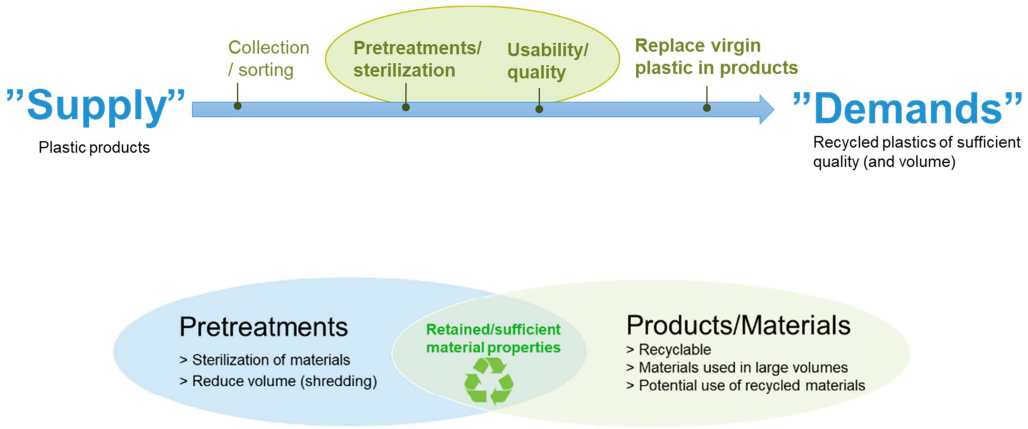


Figure 1. Schematic overview (upper figure) of the different steps of the project, starting at a plastic supply (products) and ending with new products containing the recycling plastic materials. The lower figure illustrates the balance between the pre-treatment methods and the retained quality of plastic products/materials suitable for recycling (e.g. existing secondary market (demand) and sufficient volumes).

The project partners RedBag Solutions (RBS) and Ozonator provide commercial equipment for waste sterilization based on two different techniques. RBS works with a hydrothermal sterilisation process, which means that the material is exposed to heat and water/steam under pressure and shredding in the same 30 minutes long process. Ozonator on the other hand uses ozonation, which means that high concentration of ozone is used to sterilize the material. Both processes were evaluated in this project.

In the first part of the project, lab-scale exposure trials were conducted where the selected products were exposed to similar conditions as in the commercial large-scale sterilization methods in order to find out the effect of the exposure conditions on materials quality. If the processes induced noticeable properties deterioration of the selected plastics, adjustments of the sterilization processes should be optimized in order to achieve both sterilization (primary objective of the processes) but also minimize deterioration of the materials quality in order to enable mechanical recycling of the pre-treated plastics into high quality products.

Hydrothermal treatment

Based on the information regarding sterilization conditions (time, temperature and pressure profiles) supplied by RBS, a few different lab-scale setups were tested in order to find the best approach for achieving comparable conditions.

The initial trials included using a steam autoclave as well as a hydrothermal treatment by using a microwave oven and monitor the time and temperature profiles of the individual processes. It was concluded that the microwave approach was able to best match the time and temperature profile due to the much more rapid heating and cooling ability and therefore provided a better ability to simulate the large-scale conditions.

Besides the processing conditions, different set-ups for exposing the selected products were tested and evaluated in order to ensure uniform exposure to heat and humidity for all material surfaces.

Ozonation

Because the ozonation process requires high ozone levels, Ozonator provided a contact at the Royal Institute of Technology (KTH, Stockholm) with the ability to perform the lab-scale ozonation trials according to the required conditions. The lab-scale simulations were therefore performed by KTH using a custom-made exposure chamber able to provide the necessary conditions.

Unfortunately, only a minor part of the prepared samples sent to KTH was subjected to ozonation. Therefore, the total amount of ozonated material from each product was a limiting factor for subsequent analyses.

Evaluation of pre-treated/sterilized material

The pre-treatment methods, hydrothermal and ozonation have been compared in two different aspects:

a) The technical aspects which included:

- capacity adjustment
- cutting size depending on the type and kind of plastics
- the next waste treatment step
- the effect on plastic materials and their recyclability

Based on manufactures declarations, both pre-treatment methods have similar possibility for capacity adjustment. The cutting size of the plastics from hydrothermal method could be adjusted if needed for the next step i.e. sorting. Because there were no results from large scale ozonation, it is not possible to discuss the cutting size or shape of shredded plastics. The effects of both methods on plastics quality for recycling have been evaluated extensively later in the lab-scale trials for both methods and after large scale hydro-thermal pre-treatment.

b) The evaluations of sterilization degree - comparison of sterilization has been done based on the documentation from the producers of the pre-treatment methods.

The purpose of the lab-scale trials was to evaluate possible deteriorating effects from the pre-treatment/sterilization conditions on the material in the selected products. The purpose of the large-scale trials was to evaluate recyclability and quality of materials for manufacturing of new products which are not single use/short life products. It means that we have studied not only recyclability in general but also recyclability to the products which have higher “material quality factor” than 0,5 (this means that when 1 kg is recycled, the credit is more than 0,5 kg of virgin material), because the products manufactured were not a downcycling, for more information please see the IVL report [6].

Depending on the plastic type, various evaluation methods have been used. As three of the products were produced of polyolefin plastics (Aprons (PE), syringes and medicine cups (PP)), these products were evaluated based on changes in chemistry (e.g. oxidation by FTIR) and potential loss/consumption of stabilizing additives (OIT by DSC).

As the chemistry and additives used in the vinyl gloves (PVC) is significantly different from the polyolefins, these materials were evaluated based on discoloration

(indication of PVC-degradation), changes in chemistry (by FTIR) as well as potential loss of plasticizer (using liquid extractions and GC-MS).

For a more detailed description of the analytical methods used, please see appendix 1.

Environmental, economic and social aspects

The environmental, economic and social consequences of the proposed pre-treatment solutions were also analysed from a system perspective. We assessed the possibility to pre-treat visibly clean plastic flows to enable increased acceptance and recycling of the materials. Here follows the methodology description of the work in WP5. The complete report from WP5 can be found in IVL report [6].

The method Life Cycle Assessment (LCA) has been used for assessment of environmental impact. The two different pre-treatment methods were studied, Ozonation and Hydrothermal, illustrated as scenario 1 in below Figure 2. Scenario 2 represents the conventional energy recovery of plastic waste. Both scenarios start at the collection of plastics at the hospitals. One kilogram of collected plastic acts as the functional unit in the comparison i.e. the reference unit for that environmental results are related to. The composition of the plastics collected by hospitals is assumed to be 20 % of each material: LDPE (Low Density Polyethylene), HDPE (High Density Polyethylene), PP (Polypropylene), PVC (Polyvinyl chloride) and others. Others are divided in PET (Polyethylene terephthalate) and PS (Polystyrene), in equal amounts. This assumption is based on the hypothesis that was used in the earlier work about plastic fractions at Swedish hospitals [7].

- When materials are energy recovered or recycled, they replace other energy and material production. In the model calculations, this benefit is modelled for: Energy recovery: Credits for the same amount of energy that is generated in the energy recovery process.
- Recycling: The quality of the plastic pellet material is assumed to be lower for recycled material compared to virgin material. The benefit of recycling 1 kg material is therefore lower than 1 kg of virgin raw material. This is referred to a material quality factor, which is assumed to be 0.5.

The plastic waste is assumed to be collected in big bags when transported between the processes. The environmental impact from these containers is however neglected and it is assumed that they are reused several times (likely future scenario).

It is assumed that there is no transport between the near infrared spectroscopy (NIR) sorting and the density separation.

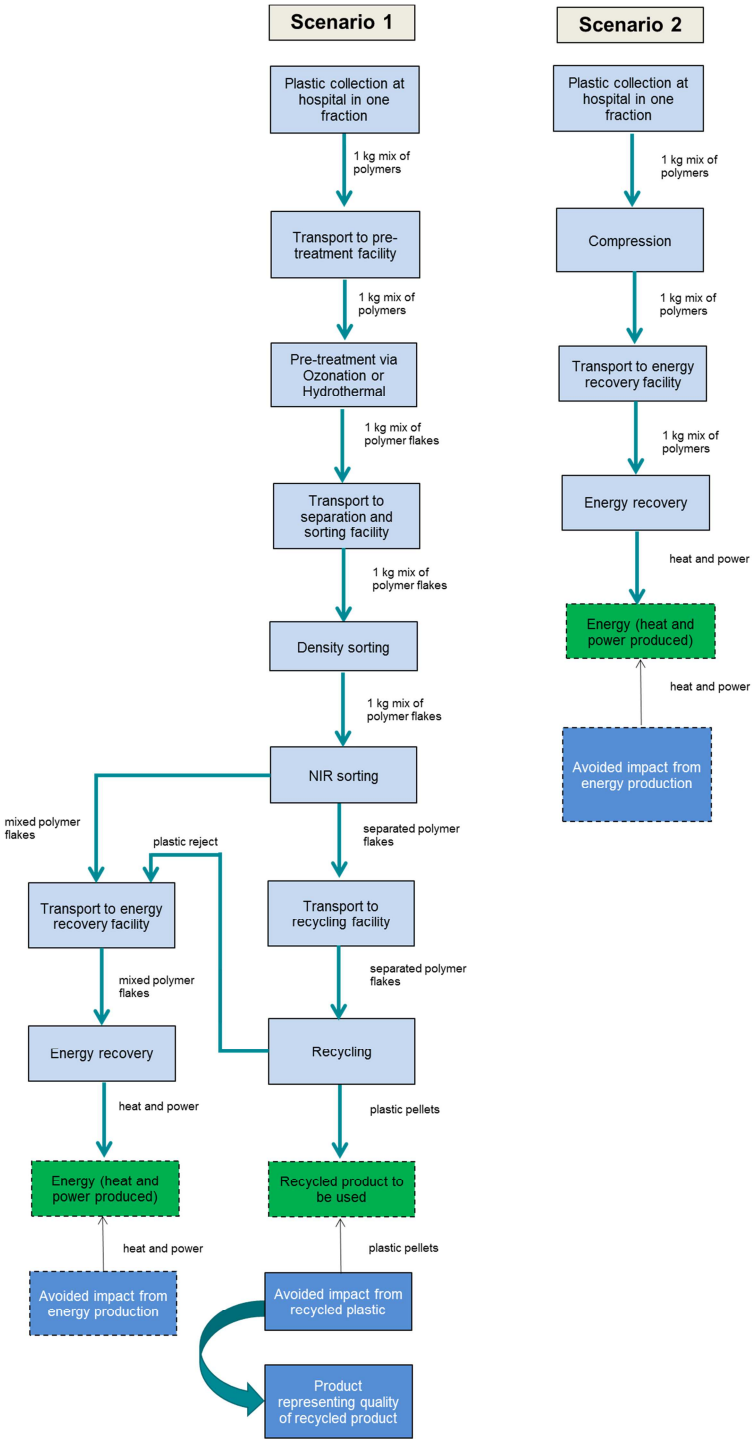


Figure 2 – Overview of the studied system

In the above 2, the scenarios can be seen:

- Scenario 1a – Recycling, pre-treatment by Ozonation
- Scenario 1b – Recycling, pre-treatment by Hydrothermal
- Scenario 2 – Energy recovery

The environmental assessment evaluates the new solutions, especially pre-treatment methods and compares with existing waste handling practices using Life cycle

assessment (LCA). In this LCA environmental impact categories listed in table 1 have been selected.

Table1 – Environmental impact categories assessed in the study, result is per 1 kg collected plastic.

Impact category	Unit	Method
Global warming potential (Climate change)	kg CO2 equivalents	CML 2001 – Jan. 2016
Eutrophication potential (EP)	g PO4 equivalents	CML 2001 – Jan. 2016
Acidification potential (AP)	g SO2 equivalents	CML 2001 – Jan. 2016
Photochemical ozone creation potential (POCP)	g Ethene equivalents	CML 2001 – Jan. 2016

The energy use is also assessed based on the use of energy resources in table 2.

Table 2 – Energy use assessed in the study result is per 1 kg collected plastic.

Inventory category	Unit	Method
Total energy resources	MJ, lower heating value	Modeled result
Renewable energy resources	MJ, lower heating value	Modeled result
Non-renewable energy resources	MJ, lower heating value	Modeled result

The economic assessment focuses on the Swedish hospitals‘ perspectives. It is a qualitative assessment based on interviews with the three of five hospitals represented in the study and cost data from different actors in the value chain. A qualitative economic assessment investigates aspects associated with the purchase of equipment, costs associated with use of equipment for county councils and alternative costs and revenues connected to waste management and recycling. The work also includes qualitative assessment of what consequences the use of new pre-treatment solutions would bring for the hospital staff in terms of work load, acceptance and attitudes.

The economic and social assessments are mainly based on interviews with representatives from three counties/regions participating in the project: Stockholms Läns Landsting (hereinafter SLL), Region Jönköpings län (RJ) and Region Jämtland Härjedalen (RJH). The interviews were focused around the work environment, staff attitudes and practical handling of plastic waste in the hospitals and other healthcare institutions. The interview questions can be found in in the IVL-report [6].

It should be emphasized that this is a theoretical system where processes are chosen based on what a system for pre-treatment could look like in the future, where different sorting and treatment processes are available today etc.

Results and discussion

Lab scale trials simulating the hydrothermal process

The visual inspection of the samples after hydrothermal treatment showed no major indications (e.g. colour changes) that the tested materials had been degraded. The high temperature applied in the process made the Apron samples to crease due to the low melting temperature of the PE, as shown in figure 3.

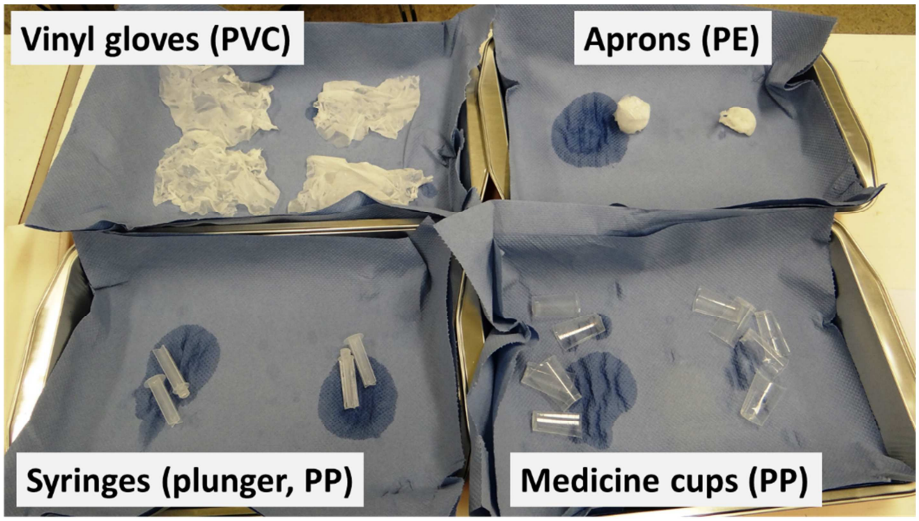


Figure 3. Visual appearance of the pre-treated products after lab-scale hydrothermal treatments.

Comparative analyses of as-received and pre-treated (hydrothermal) PE material (from Aprons) and PP material (from syringes and medicine cups) were performed in order to investigate possible degradation of the materials or loss of stabilizer. The stabilization levels were evaluated by measuring the oxidation induction time (OIT, based on the standard ISO 11357-6) using differential scanning calorimetry (DSC). In order to investigate possible degradation and change in chemical structure in the materials, Fourier Transform Infrared spectroscopy (FT-IR) were applied.

The OIT-analyses of the PE-materials were performed on melt pressed sheets from as-received and pre-treated products (Aprons), due to observed creasing of the thin film when melted. The OIT was measured at 180°C as a low degree of stabilization was expected due to the short service life of the product. The results showed rather short OIT, confirming a low level of stabilization, but did not indicate any further reduction in OIT from the pre-treatment. Furthermore, the FTIR analysis did not reveal any signs of degradation (i.e. oxidation) from the hydrothermal treatment.

The analyses of the PP-materials (syringes and medicine cups) showed no sign of degradation or stabilizer loss. The OIT (performed at 190°C) indicated a low degree of stabilization but no significant differences could be detected between as-received and pre-treated materials The FTIR did not reveal any noticeable changes between the materials.

Comparative analyses of the PVC material (from vinyl gloves) presented no visible change of colour (discoloration) in the pre-treated products. There were however a few small slots through the thin film after pre-treatment, potentially induced by changes in material composition and/or rearrangement of polymer molecules when

the material was exposed to the higher temperature during pre-treatment. The FTIR did not reveal any noticeable changes in chemistry or indications of degradation. However, there were indications of plasticizer loss (about 20%) in the pre-treated sample, as measured by solvent extractions followed by gas chromatography coupled to a mass spectrometer (GC-MS). The potential loss of plasticizer does not significantly affect the quality of the recycled PVC-material as the material composition can/will be adjusted by the end-user in order to obtain the required property profile for the end-use application. Furthermore, the noticed slots in the film will not impair recycling as the material will be re-melted in the recycling process.

Lab scale trials simulating the ozonation process

The visual inspection of the samples after ozone treatment showed no major indications (e.g. colour changes) that the tested materials had been degraded.

The PE and PP materials were tested by the same procedures as for the hydrothermal treated samples but with some modifications due to the limited amount of pre-treated material.

The FTIR-analyses at the material surface of the PE aprons showed minor peaks in the carbonyl region, indicating that some oxidation may have occurred during the ozonation process. As both the un-treated and pre-treated PP-products revealed minor peaks in the carbonyl region, it was difficult to evaluate whether oxidation may have occurred.

However, additional analysis of the bulk (cross section) of a pre-treated PP-syringe, showed no carbonyl peaks, hence indicating that the functional groups (from oxidation or other source) giving rise to the observed peaks were limited to the surface of the samples (Figure 4).

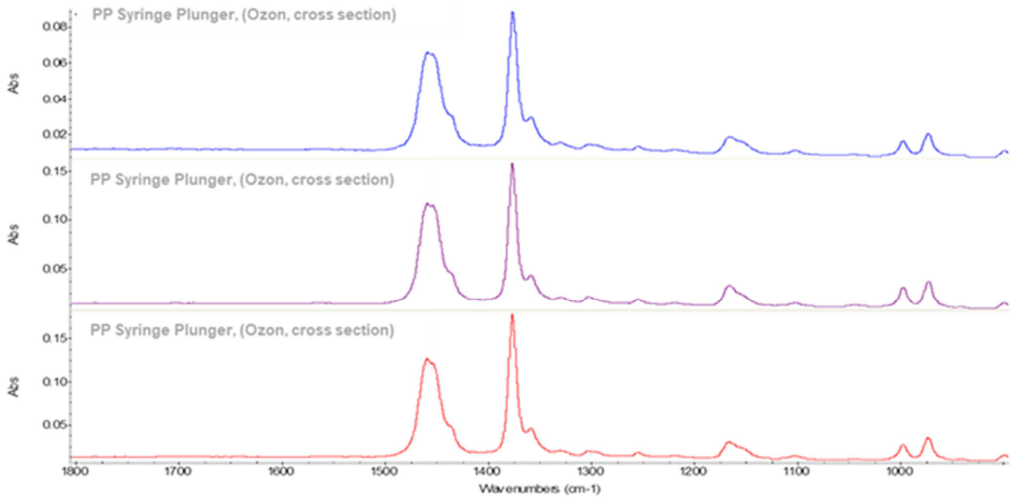


Figure 4. FTIR-spectra from the bulk of the ozone treated syringes revealing no indication of oxidation in the material bulk.

The OIT-measurements were only performed on the PP-syringe and indicated no decrease in the level of stabilization as compared to an un-treated sample.

The visual inspection of the pre-treated vinyl gloves showed no indications of degradation (discoloration) and there were no noticeable chemical changes observed by FTIR.

Due to the limited sample volumes of the pre-treated products, it was not possible to further investigate whether the performed ozone pre-treatment have affected the material quality and recyclability of the materials. This was to be further investigated in the large-scale recycling trials in the project.

Mechanical recycling and quality evaluations

The large-scale recycling trials were focused on two of the material flows: PP for testing at Bergo Flooring, and PVC for testing at Tarkett.

The large-scale pre-treatments of the products were initially planned to be conducted using full scale sterilization equipment provided by RBS and Ozonator, located in Europe. However, due to limited availability of these equipment in Europe, these tests were rescheduled to be performed at the companies US-sites.

The companies were instructed to order 30 kg each of selected medicine cups (PP) and vinyl gloves (PVC) from US-based suppliers and perform sterilization using their commercially available large-scale equipment. The selection of products for the large-scale trials was based on end-user demands and limited by the project budget. Both processes include an in-process shredding step to ensure complete sterilization of the material, producing small flakes that were to be used for subsequent characterization of required material properties (by RISE) before being forwarded to large-scale recycling trials at Bergo Flooring AB (PP fraction) and Tarkett AB (PVC fraction).

Unfortunately, Ozonator was not able to perform the large-scale pre-treatments using their equipment within the timeframe of the project. Therefore, the project is not able to draw any conclusions regarding the recyclability of PP or PVC using the Ozonator process.

The products that were pre-treated by RBS were sent to RISE for subsequent characterization and further preparations for the recycling trials at Bergo Flooring AB and Tarkett AB. However, when receiving the pre-treated samples it was deduced that the pre-treatment had been performed on another brand of PP medicine cups as well as vinyl gloves. This called for additional characterization of the as received products in order to obtain reference values for comparison.

Characterization of hydrothermally pre-treated products from RBS

The materials received after the large-scale treatment were in the form of shredded plastic flakes. The flakes from the shredded PP medicine cups displayed a slight brownish discoloration that was even more pronounced after remelting the material as shown in figure 5.

Figure 5. Comparison of visual appearance of un-treated medicine cup and remelted bars (left) with flakes and remelted bars after hydrothermal treatment (RBS)

Although the noticeable discolorations, the subsequent analyses (FTIR and OIT) showed no indications of material degradation, hence suggesting that the discoloration could be due to sample contamination from the pre-treatment process. Further melting experiment, and more sensitive chemical analyses, were therefore conducted in order to confirm and identify the origin of the contaminant. Solvent extraction followed by chromatography did not reveal any plausible explanation to the discoloration. However, X-Ray fluorescence (XRF) analysis showed very low content of iron and chlorine (0,04 weight % each) in the RBS treated PP (measured on produced floor tile), that was not detected in the untreated medicine cups. The potential presence of iron oxides could contribute to the brownish discoloration of the processed materials.

Due to the irregular shape and size of the obtained PP-flakes the material was once more extruded and regranulated into uniform pellets suitable for processing to flooring tiles by Bergo Flooring. The melt flow index of the regranulated material (figure 6) was measured to 5,9 g/10 min (2,16 kg, 230°C, ρ = 0,739 g/ccm) which is slightly higher ($\approx$ 7 %) as compared to the initial value (new product).

Figure 6. Regranulated pellets made from received flakes from the RBS process.

The reason for the slightly higher MFI could be either as a result from the potential contaminant that caused the discoloration, and/or due to a minor reduction in molecular weight due to degradation. However, no indication of oxidative degradation was detected by FTIR. The need for a regranulation step could potentially be avoided by optimizing the shredding in the pre-treatment process in order to obtain flakes of smaller and more uniform size distribution. However, it is important to bear in mind that excluding the regranulation step may reduce the homogeneity of the recyclate if the processed plastic fraction contains products made from varying material qualities (e.g. MFI) and therefore reduces the possibility of quality control (e.g. by spot checks) prior to use.

The processed vinyl gloves (PVC) were tested by FTIR, for potential detection of new functional groups, as well as GC-MS to investigate potential loss of plasticizers. The FTIR did not reveal any noticeable changes in the processed material as compared to the unprocessed materials. The GC-MS did indicate a potential minor loss of plasticizer (< 10%), however the changes were less than the estimated measurement uncertainty of the analyses and therefore not confirmed.

Recycling trials

The pre-treated (and regranulated) PP-material was sent to Bergo Flooring to be tested in one of their floor tile products. The products that were produced and tested were fully (100%) based on the pre-treated and recycled PP-material in order to evaluate the usability of this material in their products (Figure 7). No additional stabilizer was added during processing.

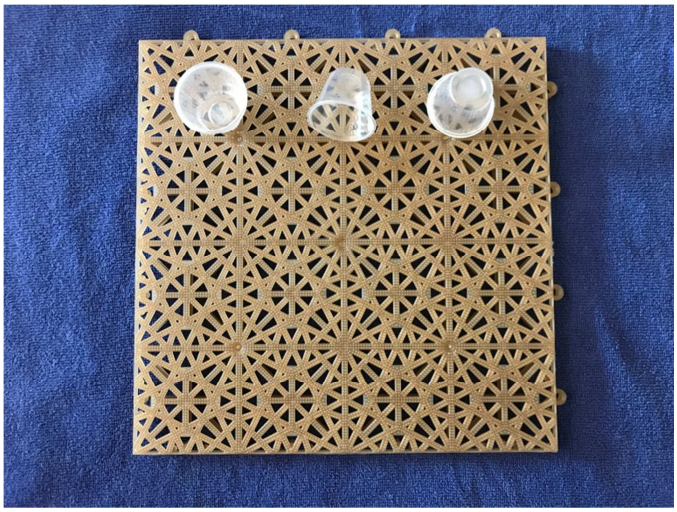


Figure 7. Produced flooring tile fully based on the pre-treated (RBS process) and recycled material from PP medicine cups.

The initial product evaluation of the produced tiles was performed by Bergo Flooring with the following conclusions:

1. The material discoloration is not acceptable as it restricts the usage of this material to a limited number of floor tile colours.
2. Mechanical tests (including bending angle and impact strength) performed 24 h after production showed that the products greatly exceeded the requirements (!).
3. Test performed 14 days after production showed that the tiles still passed the requirements regarding impact strength but failed the bending angle test.

One possibility that were discussed is that the material has been degraded during the multiple processing steps (regranulation and production) as no additional stabilizers had been added during either of these processes.

Subsequent FTIR analyses of the floor tiles did, however, not give any indications that the material had been degraded (oxidized) by the multiple processing steps (figure 8).

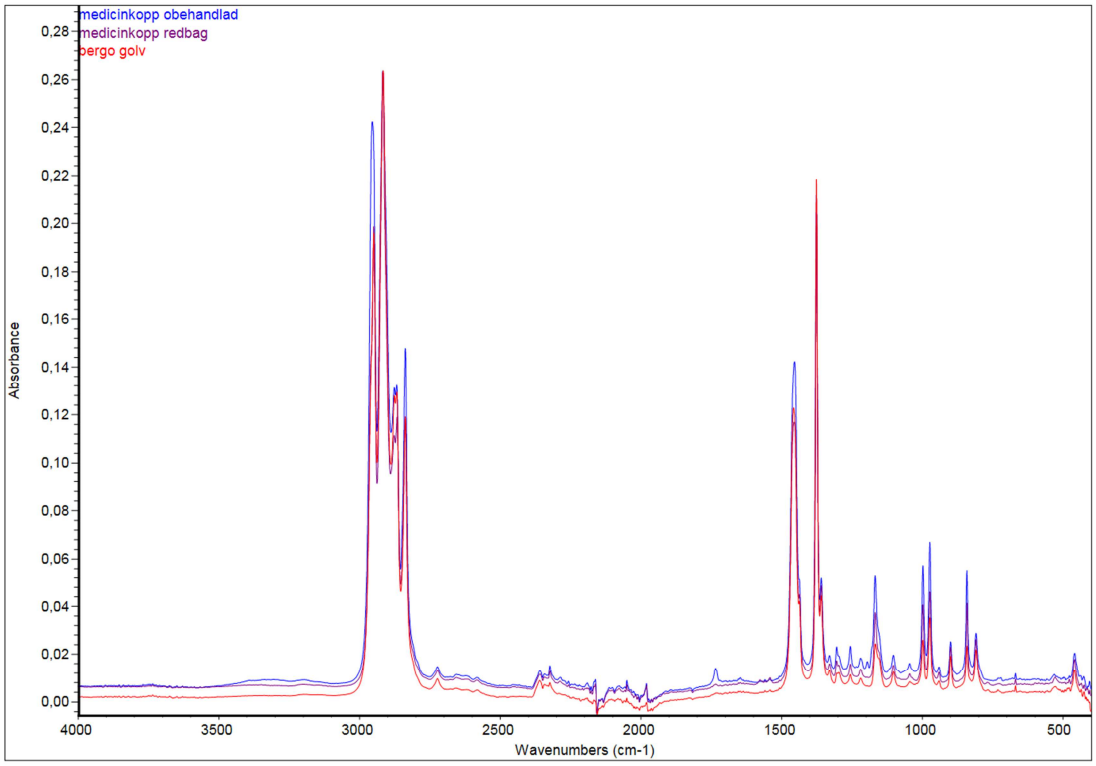


Figure 8: FTIR curves of untreated medicine cup (blue), RBS treated medicine cup (purple) and Bergo flooring made from RBS treated medicine cups (red).

As seen in figure 8, there is a minor peak in the carbonyl region (at ≈ 1700 cm^{-1}) in the unprocessed medicine cup (blue curve). This peak is not visible in either the pre-treated products (purple curve) or the final product (red curve) hence giving no indication that the material have been degraded by oxidation to a larger extent.

OIT analysis of the samples revealed a very short time to oxidation (e.g. very low stabilizer content) but no significant differences between the samples (figure 9)

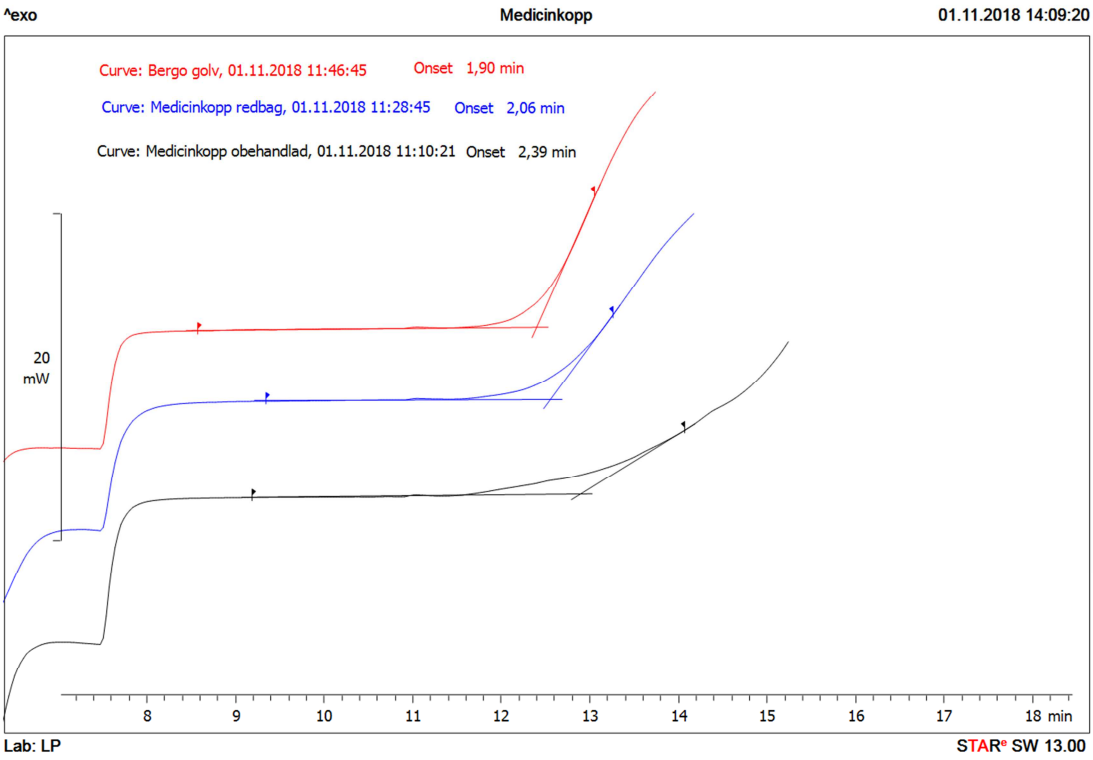


Figure 9: OIT curves of untreated medicine cup (black), RBS treated medicine cup (blue) and Bergo flooring made from RBS treated medicine cups (red).

Although there were no indications that the material has been degraded during the multiple processing steps, it is however possible that the stabilizer has been consumed enabling a rapid autooxidation in the final product, potentially catalysed by the detected iron in the material. It is well known that degradation of PP commences very fast once the stabilizer has been consumed. By increasing the level of stabilization in the original materials/products and/or adding new stabilizer in the recycling process could minimize the potential degradation in the recycling process and prolong the service life of the produced products.

The recyclability of the pre-treated PVC material (used in flake form) was tested by Tarkett AB. Due to the creamy colour of the gloves that were pre-treated (containing fillers) the material was compounded to produce a material with an off-white accent. The content of recycled PVC in the compound (bag in figure 10) was 20 %w. The compound was then used in the production of a multicoloured flooring (figure 10).

Figure 10. The produced compound (in bag) containing 20 % of pre-treated and recycled PVC from vinyl gloves and a produced floor sample partly based on the compound.

The evaluations by Tarkett concluded that:

1. The material is usable!
2. There were some black spots among the received flakes (contaminants).
3. The creamy colour of the gloves used in this study reduces its usability in new products. If the recycled vinyl gloves were to be uncoloured/unfilled (e.g. natural colour of vinyl gloves) the recycled material would be of even higher usability.

Environmental aspects

The results for the environmental impact categories and energy uses from the LCA study are presented in below Table 3 and displayed per 1 kg collected plastic material. It is important to remember when studying the results in table 3 that the manufacturing of the plastic is excluded from the modelled system. The category global warming potential is presented in a bar chart in Figure 11 below.

Table 3 – Aggregated results for environmental impact categories and energy uses selected in the study, result is per 1 kg collected plastic.

Impact category	Scenario 1a –Recycling (Ozonation)	Scenario 1b – Recycling (Hydrothermal)	Scenario 2 – Energy recovery	Unit
Global warming potential (Climate change)	0.53	0.55	2.8	kg CO2 equivalents
Eutrophication potential (EP)	-0.07	-0.06	-0.19	g PO4 equivalents
Acidification potential (AP)	-0.52	-0.48	-0.54	g SO2 equivalents
Photochemical ozone creation potential (POCP)	-0.23	-0.22	-0.17	g Ethylene equivalents
Total energy resources	-23	-20	-17	MJ, lower heating value
Renewable energy resources	-0.74	0.27	-11	MJ, lower heating value
Non-renewable energy resources	-22	-21	-6.3	MJ, lower heating value

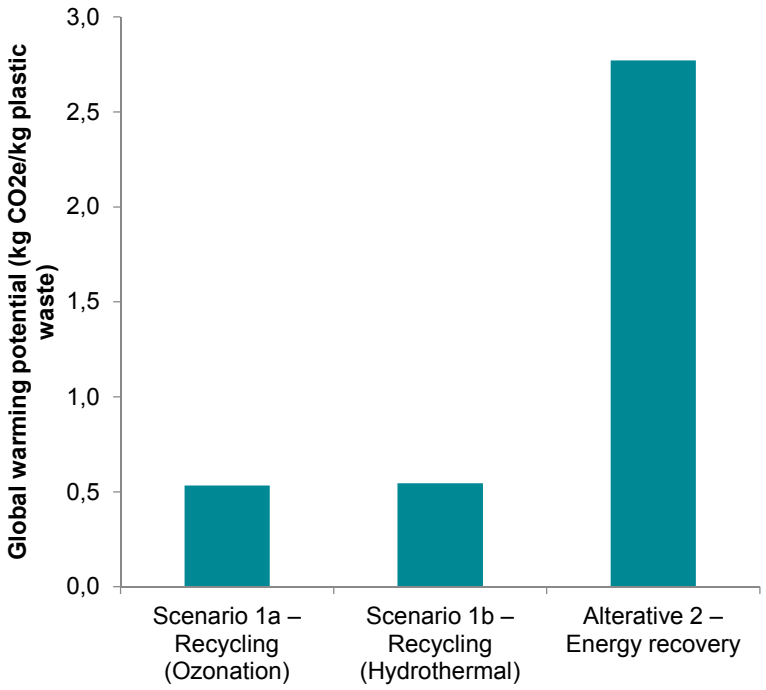


Figure 11 – Global warming potential for the different scenarios.

Plastic production is mainly fossil based and has a large environmental impact that is not included in the results of this study. This is the reason why results have negative numbers for most of the impact categories, indicating a net benefit rather than an impact. For the three categories *Acidification potential*, *Photochemical ozone creation potential* and *Total energy resources* similar results can be seen for the scenarios. The last one is however the sum of the two bottom categories *Renewable energy resources*, *Non-renewable energy resources*. The negative figure is larger for scenario 1a and 1b for the category *Non-renewable energy resources*. This is due to that fossil energy is replaced for the avoided production of energy and plastic material. In scenario 2, the energy produced is instead replaced with more renewable energy. The two remaining categories are *Global warming potential* and *Eutrophication potential*. The difference for the *Global warming* category is thoroughly described in the in IVL report [6]. The *Eutrophication potential* gives a larger environmental benefit for scenario 2. In this case it is due to the benefit of replacing Swedish district heat, which is produced partly from biomass as energy source giving a major contribution to the *Eutrophication potential*. In summary, the system expansion has a large impact on the results in terms of which processes for energy and heat production that are used for modelling replaced production.

Economic assessment

The economic assessment focuses on the Swedish hospital's perspectives. It is a qualitative assessment based on interviews with the three of the five hospitals represented in the study and cost data from different actors in the value chain. Each region has their specific arrangement for waste handling for hospitals and other facilities with service providers, sometimes through the facility owner/landlord. The terms and costs for the services are set through public procurement contracts and renegotiated regularly. In some cases, the hospitals have different service providers for different fractions, and the total number of waste fractions can be up to 40. Costs for waste handling therefor vary between regions and hospitals, depending on the design and volume of their contracts, the transport distances in the area, the local fee for incineration of waste and other factors such as current material prices.

Some Swedish counties/regions do not sort plastics separately, while others sort up to three different fractions of plastics. All three hospitals participating in this study have some kind of separate sorting of plastics. Two of them also have compression of soft plastics on site to save space and facilitate transportation. Today, a large amount of used plastics is not sorted separately but sent to energy recovery with other combustible waste.

Cost components

The different costs related to pre-treatment, recycling and energy recovery are borne by different actors in the value chain. One of the largest costs in the pre-treatment and recycling scenarios is the investment in the different pre-treatment machines for ozonation or hydrothermal treatment. The investment could either be taken by the hospitals themselves or by a recycling company. The cost of investment has not been shared by the pre-treatment representatives in the project, but interviews point to that it would be a substantial cost even for a large hospital. For smaller hospitals, it would not be a feasible investment. If a hospital would invest in pre-treatment, an additional employee might also be required to operate the machine, which would mean

additional staff cost. It may however be possible that existing staff could handle the pre-treatment.

Other costs include transportation of the material to Germany or to energy recovery, sorting and recycling costs and fees for energy recovery. These costs would likely be borne by the waste management companies and reflected in the costs for waste handling of the plastic fractions. The ownership of the material normally shifts to the waste management company at the pickup from the hospital [8].

The main conclusion when discussing costs is that it is impossible to present a cost structure that applies to the generic scenarios studied in the project. Most costs depend on the local conditions and setups between actors in the value chain. The actors contacted are cautious to give examples even of transport costs without knowing more about the exact quality and amount of material [8]. Costs for sorting and recycling have been equally difficult to find for a theoretic case like the one in the study. It is in fact highly uncertain if the pre-treated material can actually be separated into different plastic types after being shredded and mixed in the pre-treatment machine. German sorting company Tomra offers test sorting of plastics in its demonstration facility. The first day is then free of charge, second day is 7500 Euro and third day 1500 Euro, and this could be a possible test to determine if it is possible to separate mixed shredded fractions with NIR/VIS technology [9]. Other ways of separation are also possible, such as sink/float.

The examples of revenues from recycling companies are also not applicable to the case of mixed fractions, since they represent clean and fully separated flows of specific polymer types, like pure transparent LDPE or shredded rigid PP. Another important factor for recycling companies is the access to sufficiently large volumes that are stable over time [10].

Fees for energy recovery vary by region and are normally included in the price that hospitals/regions pay the waste management companies. However, the fee for destructing contagious wastes is sometimes borne directly by hospitals [11]. This cost can be 15000 SEK per ton, compared to other fractions that can cost 600 SEK per ton (combustible waste from industry [12]) and yet others that are cost neutral [13]. One possible option from an economic perspective could therefore be that the hospitals pre-treat contagious waste streams so they can be sent to energy recovery rather than destruction. This would drastically lower the costs for the hospitals in the cases where they pay for destruction themselves.

Many waste management companies are also sceptical regarding if plastic streams from hospitals should be recycled at all, due to the potential contamination and infection risk.

Possible setups

There are basically two setups for the pre-treatment case; one where the investment in machinery is taken by hospitals and one where a waste management company buys the machine and offers pre-treatment as part of their service. If the waste is classified as contagious, the second option may involve more expensive storage and transport.

A third setup is, as discussed above, to pre-treat contagious waste at the hospitals and send it for regular energy recovery. This would not replace any primary plastic

material through recycling but could reduce the need for other energy sources and reduce cost for the hospitals.

To evaluate the business case requires investigations along the entire value chain, and it is doubtful if hospitals would see this as a key priority. As one of the interviewed representatives put it: “Waste management is not our core business”.

Social assessment

The assessment of social factors is a qualitative analysis based on interviews with three project partners representing regional hospitals and healthcare in the project. The interviews were focused around the work environment, staff attitudes and practical handling of plastic waste in the hospitals and other healthcare institutions. The aim of the interviews was to identify challenges and key factors for successful sorting in hospitals, and to investigate the attitudes towards implementation of new pre-treatment methods.

Current success factors and challenges

The regions have different prerequisites for plastic sorting, like the size of the region and hospitals, transport distances, storage space and budgets. Each region also has separate contract setup for waste handling, and a different level of dialogue with the local waste management companies. These are some of the reasons why sorting and handling of plastic waste is done in different ways today.

One key aspect to increase sorting of plastics for recycling is how the regions interpret what is contaminated plastic waste. The central regional support function called “vårdhygien” (healthcare hygiene) plays an important role in this interpretation, guiding the hospitals in their county/region on what is contaminated and how to handle different products in different situations. Some of the interviewed region representatives feel that the advice from vårdhygien differs depending on which person you ask. This makes it difficult to implement stringent and clear instructions to the staff on how to handle plastic waste. Clear and continuous information is a key factor to implement successful sorting.

It is important to inform and educate the staff on a regular basis, to refresh the knowledge and provide feedback on why sorting is performed and how the material is treated. This is a challenge in large hospitals, with thousands of employees and sometimes high staff turnover. The hospitals have similar setups for staff education with selected representatives being responsible for information and communication to all employees. The information is shared through regular meetings, letters and signs in the work place. The performance improves when representatives have chosen the task to inform colleagues themselves rather than having been assigned the task by management [11].

The infrastructure for sorting, such as well-designed sorting furniture, also improves sorting performance and increases collected volumes. It is helpful if the facility owner provides good furniture as part of the service, so that hospital staff doesn’t have to organize this. When new hospitals are designed it is important to provide adequate space for sorting in many areas of the departments.

The level of transparency and the procurement contract setup between regions and waste management companies also plays an important role in how plastic sorting is carried out. With close cooperation, solutions can be found for specific fractions or

products based on local conditions. In Jönköping, the separation of clear soft plastics provides an extra income for the region. They have also identified clean aprons as a separate fraction that is now sent to recycling. Having one waste management company for all fractions enables a deeper cooperation and a better dialogue, as opposed to having several different companies. This was expressed both by Jönköping and SLL, who have switched from 5 and 3 companies in the past to one service provider for all fractions.

The hospital in Östersund has different colours of collection bags for different waste fractions. This simplifies sorting for the staff and increases the quality of collected fractions [14]. Internal quality checks are also important to have good sorting results.

There is a limit for how many fractions the staff is willing and able to sort. In SLL, the staff is very content with sorting all plastics in one fraction. The other two regions sort up to 3 fractions, but the number also differs between hospitals in each region. All three regions state very clearly that sorting per plastic type is not a viable option, since there are too many material types and it would be too time consuming and complicated for the staff.

Reducing the amount of different materials that are sourced and using criteria to enable recycling are two possible goals for procurement in hospitals, but knowledge and resources are often lacking. There is a lack of guidance on these subjects, for example from the procurement agency. A procurement network between regions could also help to transfer knowledge, exchange success stories and produce standardised guidelines for the benefit of both hospitals and product manufacturers.

Introduction of a new waste system in one of SLLs hospitals has proven to be a challenge. Both sorting volumes and quality have decreased when a waste suction system was introduced [11]. This highlights the importance of routines and continuous information, and the fact that it takes time to implement a stable and successful practice. Table below summarises the identified success factors and challenges in hospitals relating to plastic waste sorting.

Table 4: Summary of current success factors and challenges related to plastic sorting.

Success factors
Good dialogue with waste management company
One waste management company for all fractions
Clear and continuous information and feedback
Dedicated staff representatives
Internal quality control
Different colours of collection bags for different fractions
Good sorting infrastructure provided and designed in dialogue with the staff to fulfil needs
Few plastic fractions (maximum 2-3)

Challenges
Limited space for sorting and storage in existing buildings
Unclear advice from vårdhygien regarding contaminated plastics
Introductions of new systems and practices
Large number of employees and staff turnover
Inadequate space designed for sorting in new hospitals
High stress levels make it difficult to prioritise sorting
Lack of criteria for procurement

Attitudes to pre-treatment

The staff in the three interviewed regions has an overall positive attitude to sorting plastics, and sorting practice has been implemented for a long time in all three regions. The staff is very engaged and often eager to sort out more plastics to recycling within their current system setup.

The attitudes to pre-treatment differ between the three interviewed representatives, where SLL has a slightly more positive view. The main reason for this is that a pre-treatment system would work well together with the new suction system at the hospital Nya Karolinska, at least in theory. However, initial dialogue with the manufacturer suggests that the investment cost would be too high. For the older hospital in Huddinge, pre-treatment would not fit well with the current sorting practice [11].

For Jönköping and Jämtland/Härjedalen, it is not feasible to invest in pre-treatment due to smaller volumes and constrained budgets.

Two of three regions, SLL and Jämtland/Härjedalen, foresee additional staff needs in connection to pre-treatment, while Jönköping believes that tasks could be shifted among existing staff since pre-treatment could replace current baling practice.

A short list of the different opinions from hospital representatives in the project regarding pre-treatment is presented below:

- Investment in machinery is too expensive!
- Extra staff would be required for operation, extra information and new work tasks.
- Sorting would be too complicated if more fractions were introduced, but...
- ... if all plastics were collected in one fraction it would instead mean a simplification.
- re-treatment could potentially replace current baling practice, which takes a lot of time.
- There is really no need for pre-treatment if only clean fractions are collected.

Discussion

LCA results and methodology

The overall result from the LCA is that plastic recycling is positive from a climate perspective. This is true even with the large losses of material assumed for the case. In LCA studies, the system boundaries and dataset selection are important factors influencing the results. In this study the system boundary has been drawn at the hospitals collection, which means that the environmental impact from primary plastic production is not included. This should be kept in mind when interpreting the results. System expansion has been used to illustrate the gains of replacing material production and energy production by recycling and energy recovery. A dominance analysis shows that the datasets dominating the results are the energy mixes in Sweden and Germany. When calculating replaced energy production, average or marginal data can be chosen.

In the calculations the average energy mixes for the two countries, Sweden and Germany, are used. There are different energy mixes in the countries which have different environmental impacts, where the spread can be large e.g. between different regions or between different companies. The scope of this study is to provide an overview that corresponds to the energy conditions in the countries and not to demonstrate the environmental performance of different companies. As an example, it has not been investigated what energy mix a certain region has used, but average conditions for Swedish energy production have been adopted.

In cases where plastic is used in Sweden and then transported to Germany for recycling and energy recovery of rejected fractions, environmental impact becomes less than if the plastic is energy recovered or recycled in Sweden. This is because the energy being replaced (no need to be produced) has a greater environmental impact in Germany than in Sweden. This aspect should be taken into account when comparing the different scenarios as the average environmental performance of several of the included environmental impact categories are lower for Swedish energy production than for German energy production. Therefore, the chart in the sensitivity analysis should also be studied to get a complementary image.

System setup to enable recycling.

At the core of this study is the conflict between quality of pre-treated plastic fractions and the need to make sorting sufficiently simple for staff. The suggested setup to collect only one mixed plastic fraction is not optimal from a quality perspective, since the pre-treatment includes shredding of the material. The mixed shredded fraction could then be difficult to separate without putting in a lot of effort and cost. The separation technology investigated in this study is designed for larger sizes, such as complete products, or for removing impurities from clean and already separated fractions. Recyclers need clean fractions in their processes, and traceability through the value chain is important in order to resolve potential quality issues. This would be difficult for a mixed and shredded fraction. On the other hand, hospitals have limited capacity to sort out specific products or product types, due to time constraints and lack of physical space. Separate sorting and recycling of film fractions is

however performed successfully in some hospitals today, providing revenue to the hospitals. Especially clear film and foil fractions have a good market. There are Swedish actors who recycle these fractions today, reducing the need for costly transports. The reason we have chosen Germany for recycling is that the NIR sorting technology is not available in Sweden. This could change in the future. The German actors that we contacted in the study were very sceptical to handle any fractions from health care. The stigma around hospital waste is still strong, which indicates that recycling and sorting abroad could be difficult.

When presenting the short list of opinions from hospitals representatives regarding pre-treatment to the providers of pre-treatment equipment the following comments were obtained. RBE agrees with the opinions regarding the important simplicity in sorting all plastics in one fraction and the reduced needs for baling practices. However, according to RBE the investment cost is not too high and that there is only a minimum need for additional staff in order to operate their equipment. The different opinions between the hospital representatives and the providers of pre-treatment equipment highlight the need for further discussions regarding potential set-ups and procedures between hospitals, providers of pre-treatment equipment and recycling companies.

In terms of cost, the cost components for waste separation, recycling and energy recovery are usually not visible to the hospitals. There is maybe no need for complete transparency, but trust and dialogue within the value chain can enable solutions that minimises cost and increases recycling. Pre-treatment is probably too costly for most regions today, but may have potential for large regions in the future. This is however only true if it enables contaminated fractions to be recycled. In that case, pre-treatment would also mean substantial cost reductions for hospitals in terms of avoided destruction. As long as only “clean” fractions are sorted, the acceptance could instead be built on communication and trust in the value chain.

Conclusions and Future Work

This project has shown that there is a great potential for significant increase in recycling of thermoplastics from hospitals. It was demonstrated that recycling of PP (e.g. medicine cups) and PVC (e.g. vinyl gloves) that have been pre-treated by the RBS process could be used in commercial products without reduction of products quality. The high quality of the plastics used in these single-use healthcare products makes them attractive for recycling and usage in new durable products (e.g. flooring). Furthermore, LCA shows that plastic recycling is beneficial from the climate impact perspective. However, the environmental benefit caused by recycling is underestimated in this LCA as the quality of recycled plastics is assumed to be lower than the quality of virgin plastic pellets. The environmental credit for recycled plastic materials is given only half of the virgin materials. In the industrial recycling trials in this project a significant part of the virgin materials was replaced by the recycled materials without quality reduction thus the environmental credit should be significantly higher than 0,5 which is assumed in LCA calculation. This assumption is common when a material is intended to use for the same application.

There is of course still room for many improvements that would increase the usability of the recycled materials. One important objective would be to identify and hinder the potential contamination (discoloration) of the pre-treated materials. Another objective would be to ensure a sufficient degree of stabilization of the products/materials in order to minimize degradation during usage, pre-treatments and recycling processes. Additional stabilizer could also be added in the recycling process in order to ensure the required service life of the secondary products. Loss of plasticizer during pre-treatment has not affected the quality of the material and its recyclability. However the amount of additives such as plasticizer and stabilisers should be checked and adjusted if needed. When considering the environmental, economic and social aspects for enabling plastic recycling from hospital waste, there are some additional challenges to consider. First of all, since the shredding of materials is necessary in the pre-treatment processes, pre-treatment of mixed plastics must be preceded by development of sub-sequent suitable sorting and separation technology. Source separation into individual plastic types (by hospital staff) is not practically possible, since it is too difficult to see the difference between various plastic types and the staff work load would be too high. There is a delicate balance between work load for employees and separate sorting of different fractions, but there are also success stories where recycling of specific fractions bring revenue to hospitals. The motivation of employees is more of a driver than a challenge: the majority of hospital staff is positive to separate sorting of plastics! Key factors for successful sorting include well planned sorting infrastructure, sufficient storage space, good communication and internal quality control. From technical perspective, adapting of pre-treatment methods to amount of feeding material and to the next step of waste management especially sorting is a remaining challenge for the future research.

From an economical perspective, investment in pre-treatment equipment could be too costly for most hospitals at the moment, and the benefit will depend on the possibility to separate plastics in “clean” fractions.

From a market perspective, the size and quality of collected volumes are limiting factors to enable more recycling, since many recyclers need continuous access to stable material flows of homogenous quality. Increased recycling of specific

fractions could be achieved through local agreements with waste management companies and recyclers. A strategic network for procurement between regions would have potential to reduce the amount of plastic types and harmonise sustainability criteria for procurement between hospitals and regions. Polymer experts and expert in LCA could be a fundamental help in terms of comparable material and LCA results and procurement guidelines is also needed to support buyers.

Presentation of the results from the project has encouraged more counties and hospitals to further develop sustainable management of their plastic waste. It has also helped them to identify the needs that hospitals have concerning procurement routines for plastic products.

Comment(s)

Although the initial lab-scale trials using ozonation as pre-treatment did not indicate any severe degradation (oxidation) of the pre-treated products, further studies using larger sample volumes should be performed in order to evaluate the material quality and recyclability of plastic products subjected to ozone pre-treatment.

Publication list

Beside this report, the result of the work package 5 will be published as a separate report by IVL [6].

Project communication

The results of this project has been presented at five seminars and conferences: Project final seminar (open seminar) November 2018, Re:Source Result day 2018 and Environment Conference- MSO-konferens 2018 Jönköping in Sweden, at seminars “Keys to successful recycling of hospital waste” at Aarhus University Hospital in Denmark and EMPD conference (European Medical Polymer device) 2018. The project is also nominated for Innovyn Awards 2019.

References

[1] Andrew McWilliams (2018) Medical Plastics: Global Markets to 2022

[2] J.O.Sundqvist, A. Fråne (2014) Hållbar hantering av plastavfall från sjukvården. IVL report

[3] Pawel Gluszynski (2015) Healthcare waste in the EU - a short overview. Polish Zero Waste Association.

[4] Kari Sorola (2001) Reclamation of Plastic Waste generated in Hospitals. LIFE98 ENV/FIN/000577

[5] Andrew McWilliams (2018) BBC Research Report Overview: Medical Plastics Global Markets 2022

[6] J. Lindberg, H. Ljungkvist Nordin and A. Fråne (2019) Sustainability assessment of pre-treatment methods for plastic waste from hospitals in Sweden. IVL report C383

[7] A. Fråne and J.O. Sundqvist (2016) Återvinning av plast från Stockholms Läns Landstings sjukvårdsverksamhet. Uppdragsrapport.

[8] Personal communication with Stena Recycling

[9] Personal communication with Tomra, Germany.

[10] Personal communication with AXJO Plastics.

[11] Personal communication with Ewa Frank, SLL.

[12] Example from waste management company SYSAV: https://www.sysav.se/foretag/Priser/

[13] Personal communicaiton with Catarina Standroth, RJ.

[14] Personal communication with Åsa Paletun, RJH.

Appendix 1: Analytical methods

Fourier Transform Infrared spectroscopy (FTIR)

FTIR analysis can be used for identification of a polymeric material since characteristic absorption bands in the IR spectrum can be used to identify chemical bonds and functional groups present in the material. It is also possible to identify and quantify some specific functional groups that are formed as a result of a chemical degradation reaction such as e.g. oxidation. The surface of the different plastic products as received and pre-treated was analyzed using a Nicolet 6700 FT-IR instrument (Thermo Electron Corporation) equipped with a micro-ATR. Evaluations were performed by comparing the spectra from un-treated and pre-treated samples in order to detect new absorption bands corresponding to new functional groups in the materials.

Differential Scanning Calorimetry (DSC)

Measurements of oxidation induction time (OIT) by DSC are frequently used to estimate the level (or degree) of stabilization of polyolefins. The DSC analyses were performed on a Mettler DSC 1 instrument equipped with a gas controller and a sample robot. Small circular specimens were punched out from each sample and cut to circular plates in order to obtain the specified mass (5-10 mg) The temperature program was based on ISO standard 11357-6 and included heating the samples to 180°C (PE) or 190°C (PP) under inert (N_2) atmosphere. After reaching the selected temperature, the samples were exposed to oxygen (O_2) and the time until oxidation occurred (exothermal reading in DSC-curve) was recorded.