No. B 2269
November 2016

Options for increased low-risk recycling of building products

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Funded by: Miljöfonden, Sveriges Ingenjörer and the Foundation for IVL Swedish Environmental Research Institute
Report number B 2269
ISBN 978-91-88319-27-2
Edition Only available as PDF for individual printing

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This report has been reviewed and approved in accordance with IVL's audited and approved management system.

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Summary

Materials containing chemical substances with hazardous properties may, under certain conditions generate undesirable emissions of such chemicals during the use phase, as well as during recycling and other types of waste treatment. Since recycling of materials is a key element in the movement towards a circular economy it is crucial that the recycling is conducted in way that minimizes the risk associated with exposure to hazardous chemicals. Construction and demolition waste is a category of products where large volumes of waste are managed. In addition, new construction is very resource- and energy-intensive, which is why increased recycling is desirable from a waste, energy and resource perspective. Meanwhile many of the older building products which are now appearing as waste due to demolition and re-construction, contain potentially harmful substances such as various plasticizers, flame retardants, anti-corrosion and waterproofing additives, etc. Chemicals which have been phased-out from new materials may thus remain in the technosphere due to recycling of older materials. The EU target for recycling of construction and demolition waste is set to 70 percent by the year 2020 and development of reliable procedures for waste management, recycling and risk assessment for this product group are desirable.

The overall aim of this project was to investigate opportunities to increase the recycling of construction and demolition waste, without increasing the risk of negative effects on humans and wildlife due to recycling of undesirable hazardous chemicals. Based on current knowledge on recycling methods for construction goods and chemical contents we have specifically studied four building product categories: PVC floor, plaster waste, flat glass and EPS boards which were selected based on a set of selected criteria. Opportunities and obstacles for increased recycling were highlighted for each product category. Specific attention was also given to the demolition process, as it precedes recycling and reuse of any type of construction material. The following aspects were studied: recyclability with current methods, pre-treatment requirements to guarantee safe materials, the possibility to carry out risk assessments with regard to hazardous substances and use area as well as recyclability for other purposes than the products' original function. The study was mainly carried out through literature studies and interviews/visits with relevant actors.

Out of the four product categories the largest potential for climate savings was estimated to arise from increased recycling of EPS, a material group with low content of hazardous chemicals (in Sweden and depending on the production year). Although the environmental burdens for the other product groups are lower in comparison to that of EPS, increasing recycling for these products would still carry with it significant climate savings. For product groups where recycling techniques and infrastructure are already in place i.e. for plaster and glass, increasing recycling rates could be achieved with relatively little effort. Increased selective demolition and on-site sorting of construction and demolition waste is of great importance to enable an increase of the recycling of building products, and also to better control the occurrence and flow of chemicals throughout the product lifetime and through waste and recycling stages. This is especially true for building products that already have a functioning recycling process with no significant problems regarding hazardous substances e.g. plaster boards and flat glass. Through selective demolition, it is possible to increase recycling rates in a relatively short time. However, even though selective demolition is often a requirement from ordering clients in demolition purchasing involving actors within the public sector, follow-ups are rare and most likely selective demolition does not occur to sufficient extent. The main obstacle to increased selective demolition is the lack of incentive due to the high cost compared to incineration of mixed fractions since the value of the sorted material is not sufficient to compete with conventional treatment. Much larger volumes of waste are needed for the value to be sufficient in relation to transportation costs (true for e.g. plastic). Lack of space

for containers is also an obstacle. Therefore selective demolition is more common on larger demolition sites. Economic instruments need to be implemented to increase the application of selective demolition.

The results from the project showed that hazardous chemicals are not the main obstacle to increased recycling of building products, rather it has to do with costs and access to recycling facilities. Thus economic instruments and improved logistics and infrastructure may promote increased recycling.

Concerning chemicals, the lack of knowledge on chemical content can sometimes be an obstacle to recycling, especially as it limits the possibility to assign a value to the waste fraction. To avoid this knowledge gap in the future, the introduction of a logbook for building materials, as required in the certification system Miljöbyggnad, is a possibility which would facilitate recycling in the long term since it enables tracking of materials, products and their contents. In the short term, qualitative, relative risk assessments have to be conducted, comparing environmental impact of recycled versus virgin materials using existing knowledge on chemical content in the waste fractions, or "worst-case" scenarios, based on historical knowledge of chemical contents in building products. Knowledge of the chemical content is key factor here, and in the lack of reliable information or realistic "worst-case" assumptions, chemical analysis has to be conducted. There may, however, be cases where a certain chemical is entirely unwanted, for example if it is banned or phased out with reference to the precautionary principle. In these cases recycling of such products is basically not possible.

There is an inherent conflict between the goal of achieving a circular economy and closed production cycles and to obtain a 'non-toxic environment' through the phase-out of hazardous substances, and there is need for a deeper analysis and discussion on the consequences of recycling of materials containing hazardous substances and its implications on risk, exposure and human health. We have suggested a road map that may be applied to assess the risk of potential uses of a waste fraction containing potentially problematic substances. Independent of which method that is used, some knowledge or estimate of the chemical content in the waste fraction is required.

The main conclusions to be drawn from the current study are:

- Out of the four studied products, increasing the recycling of EPS insulation materials has the highest potential in terms of climate savings. Most EPS is still incorporated in existing buildings, thus there is a great possibility in preparing infrastructure for recycling of EPS insulation in Sweden although problems related to cost-effective transport of such bulky material needs to be solved. In Sweden, the majority of EPS insulation does not contain hazardous flame retardants also making this building product eligible for increased recycling from a risk perspective. It is however important to consider that EPS produced before 2005 may contain HBCD and Deca-BDE if produced before 2002.
- The main obstacles to increase recycling of construction products appear to be associated with lack of incentives due to high costs of selective demolition and on-site fine sorting compared to conventional waste treatment methods. Economic instruments such as e.g. higher tax on land-filling or incineration or subsidies on using recycled material in goods could help in promoting selective demolition.
- Hazard assessment tools such as GreenScreen are not suitable to evaluate environmental impact of chemicals in recycled building products, since they do not consider exposure and risk. To obtain a circular economy and evaluate pros and cons with re-cycling of construction products, a life-cycle risk perspective needs to be taken on chemicals in materials.

- To assess the potential risk associated with chemicals in recycled materials, some knowledge or estimate of the chemical content is required. If reliable information on material content is lacking, chemical analysis should be promoted.
- Low exposure applications could be a suitable alternative for materials containing phase-out chemicals, e.g. PVC floor installation waste in bottom-layers of floors or in outdoor applications, (e.g. traffic signs, traffic calming products and road cones). Recycling of phase-out substances can be motivated if environmental benefits are high (e.g. positive effects on climate and resource depletion) end the perceived toxic impact is low. Furthermore, recycling of phase-out substances usually implies lower concentration than in the primary product and thus potential risks will gradually decrease.

Sammanfattning

Material som innehåller kemiska ämnen med farliga egenskaper kan under vissa omständigheter generera oönskade utsläpp av sådana kemikalier under användningsfasen samt vid återvinning och andra typer av avfallsbehandling. Eftersom återvinning av material är en central del i utvecklingen mot en cirkulär ekonomi är det viktigt att återvinningen sker på ett sätt som minimerar riskerna med exponering för farliga kemikalier. Bygg- och rivningsavfall är en produktkategori där stora volymer avfall hanteras. Dessutom är nybyggnation mycket resurs- och energikrävande, varför ökad återvinning är önskvärt ur avfalls-, energi- och resursperspektiv. Samtidigt innehåller många av de äldre byggprodukter som nu producerar avfall på grund av rivning och ombyggnad potentiellt skadliga ämnen såsom olika mjukgörare, flamskyddsmedel, korrosionsskydd, tätskikt, etc. Därför kan kemikalier som har fasats ut från nya material finnas kvar i teknosfären på grund av återvinning av äldre material. EU:s mål för återvinning av bygg- och rivningsavfall är satt till 70 procent fram till år 2020. För att uppnå detta mål utan att öka risken för negativa effekter på hälsa och miljö behövs tillförlitliga system för avfallshantering, återvinning och riskbedömning.

Det övergripande syftet med föreliggande projekt var att undersöka möjligheterna till ökad återvinning av bygg- och rivningsavfall, utan att öka risken för negativa effekter på människor och djur på grund av återvinning av oönskade farliga kemikalier. Baserat på existerande kunskap om återvinningsmetoder för byggvaror och kemiskt innehåll har vi studerat fyra byggvarukategorier: PVC-golv, gips, planglas och EPS- plattor som valdes ut baserat på ett antal kriterier. Möjligheter och hinder för ökad återvinning belystes för varje produktkategori. Särskild uppmärksamhet gavs också till rivningsprocessen, eftersom denna föregår återanvändning och återvinning av alla typer av konstruktionsmaterial. Följande aspekter studerades: återvinning med nuvarande metoder, behov av förbehandling för att garantera säkra material, möjligheten att genomföra riskbedömningar när det gäller farliga ämnen samt återvinning för andra ändamål än produkternas ursprungliga funktion. Studien har huvudsakligen genomförts genom litteraturstudier och intervjuer med/besök hos relevanta aktörer.

Av de fyra produktkategorierna uppskattades den största potentialen för klimatbesparingar härröra från ökad återvinning av EPS, en materialgrupp med lågt innehåll av farliga kemikalier. Fastän de andra produktgrupperna har lägre klimatbördor i jämförelse med EPS kan viktiga klimatbesparingar uppnås från att öka återvinningen av även dessa avfallsslag. För produktgrupper där återvinningsteknik och infrastruktur redan finns tillgängligt t.ex. för gips och glas, skulle en ökad återvinning kunna uppnås med relativt lite åtgärder.

Ökad selektiv rivning och lokal finsortering av bygg- och rivningsavfall är av stor betydelse för att möjliggöra en ökning av återvinningen av byggprodukter, och även för att bättre kontrollera förekomsten och flödet av kemikalier under hela produktens livslängd och genom olika avfalls- och återvinningssteg. Detta är särskilt sant för de byggprodukter som redan har en fungerande återvinningsprocess utan några betydande problem när det gäller farliga ämnen, t.ex. för gipsplattor och planglas. Genom selektiv rivning är det möjligt att öka återvinningsgraden på relativt kort tid. Men även om selektiv rivning ofta är ett krav från kunder, inklusive från aktörer inom den offentliga sektorn, är uppföljningar sällsynta och den selektiva rivning som utförs sker sannolikt inte tillräckligt noggrant, delvis beroende på hur konstruktionerna ser ut och att fullständig separation av olika fraktioner inte alltid är möjlig. Förutom dessa tekniska aspekter är det huvudsakliga hindret för ökad selektiv rivning bristen på incitament på grund av den höga kostnaden jämfört med t.ex. förbränning av blandade fraktioner. Värdet av det sorterade materialet

räcker inte för att konkurrera med konventionell behandling och mycket större volymer av avfall behövs för att värdet ska vara tillräckligt stort i förhållande till transportkostnaderna (gäller t ex plast och kartong). Ett annat vanligt hinder, speciellt på mindre rivningsplatser, är brist på utrymme för behållare. Därför är selektiv rivning vanligare på större rivningsplatser. Ekonomiska styrmedel måste införas för att öka tillämpningen av selektiv rivning.

Resultaten från projektet visar att farliga kemikalier inte är det viktigaste hindret för ökad återvinning av byggprodukter, utan det har att göra med kostnader och tillgång till återvinningsanläggningar. Således kan ekonomiska styrmedel och förbättrad logistik och infrastruktur främja ökad återvinning.

När det gäller kemikalier, kan bristen på kunskap om kemikalieinnehållet ibland vara ett hinder för återvinning, särskilt som det begränsar möjligheten att monetärt värdera avfallsfraktionen. I dessa fall, är det faro- och riskbedömning som krävs, vilket kan vara särskilt utmanande när det kemiska innehållet i avfallsfraktionen är okänt. För att undvika denna kunskapslucka i framtiden, skulle ett införande av en loggbok för byggmaterial, likt det som krävs i certifieringssystemet Miljöbyggnad, vara en möjlighet som skulle underlätta återvinning på lång sikt eftersom det möjliggör spårning av material, produkter och deras innehåll. På kort sikt måste kvalitativa relativa riskbedömningar genomföras, i syfte att jämföra miljöeffekter mellan återvunna och jungfruliga material med hjälp av befintlig kunskap om kemikalieinnehållet i avfallsfraktioner, eller utifrån "worst-case" scenarier, baserat på historisk kunskap om kemikalieinnehåll i byggprodukter. Här är det viktigt att skilja mellan fara och risk. Det faktum att en kemikalie anses "farlig" innebär inte nödvändigtvis att den kommer att orsaka några skador på människor eller djur, därför är det viktigt att beakta återvinnings- och användningsmönster när man bedömer riskerna med exponering för kemikalier från återvunna produkter, och det är viktigt att tänka på var en viss kemikalie sannolikt kommer att emitteras. Det kan dock finnas fall där en viss kemikalie är helt oönskad, till exempel om den är förbjuden baserat på politiska beslut. I dessa fall är återvinning av sådana produkter i princip inte möjlig.

Det finns en inneboende konflikt mellan målet att uppnå en cirkulär ekonomi och slutna produktionscykler och målet att uppnå en "giftfri miljö" genom utfasning av farliga ämnen, och det finns behov av en djupare analys och diskussion om konsekvenserna av återvinning av material som innehåller farliga ämnen och dess konsekvenser för exponering, risk och människors hälsa. Vi har föreslagit ett tillvägagångssätt som kan användas för att bedöma relativa miljörisker för en avfallsfraktion som innehåller problematiska ämnen för olika användningsområden. Oavsett vilken metod som används krävs någon kunskap eller uppskattning av det kemiska innehållet i avfallsfraktionen.

De viktigaste slutsatserna som kan dras från den aktuella studien är:

- Av de fyra undersökta produkterna, har ökad återvinning av EPS-isolering den högsta potentialen när det gäller klimatbesparingar. De flesta EPS-plattorna är ännu inbyggda i befintliga byggnader, vilket innebär att det finns en stor möjlighet att förbereda infrastruktur för återvinning av EPS-isolering i Sverige. I Sverige innehåller majoriteten av EPS-skivorna heller inga farliga flamskyddsmedel vilket ur risksynpunkt också gör byggprodukten till en bra kandidat för ökad återvinning. Det är dock viktigt att beakta att EPS som tillverkats före 2005 kan innehålla HBCD och Deka-BDE när de produceras före 2002.
- De huvudsakliga hindren till ökad återvinning av byggprodukter verkar i samband med bristande incitament till följd av höga kostnader för selektiv rivning jämfört med konventionella rivningsprocesser. Ekonomiska styrmedel såsom t.ex. högre skatt på deponering eller

förbränning eller subventioner på att använda återvunnet material i varor kan bidra till att främja selektiv rivning.

- Farobedömningsverktyg såsom GreenScreen är inte lämpliga för att utvärdera miljöeffekter av kemikalier i återvunna byggprodukter, eftersom de inte beaktar exponering och risk. De är mer anpassade för användning i ett substitutionsarbete. För att sträva mot en cirkulär ekonomi och utvärdera för- och nackdelar med återvinning av byggprodukter krävs ett riskperspektiv med beaktande av hela livscykeln.
- För att bedöma potentiella risker med kemikalier från återvunnet material, krävs tillförlitlig kunskap om eller uppskattning av det kemiska innehållet. I avsaknad av sådan information bör kemisk analys utföras.
- Särskilda tillämpningar med låg exponering kan vara ett lämpligt alternativ för att möjliggöra återvinning av material som innehåller vissa utfasningsämnen, t.ex. återvinning av installationsspill av PVC-golv i bottenskikt av golv eller i utomhusapplikationer (t. ex. trafikskyltar, farthinder och vägkoner). Återvinning av utfasningsämnen kan motiveras om miljöfördelarna är höga (t ex positiva effekter på klimatet och resursförbrukning) samtidigt som risken för toxiska effekter är låg. Dessutom innebär återvinning av utfasningsämnen vanligtvis lägre koncentration i den återvunna produkten än i primärprodukten och därmed kommer potentiella risker successivt att minska.

Abbreviations

B&C	Building and construction
CFC	Chlorofluorocarbons
EPS	Expanded polystyrene
GBR	the Swedish Flooring Trade Association
LDPE	Low-density polyethylene
NPG	the Nordic Plastic Pipe Association
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinylchloride
rPVC	Recycled PVC
SVOC	Semi-Volatile Organic Compounds
VOC	Volatile Organic Compounds
XPS	Extruded polystyrene

1 Introduction

Materials containing chemical substances with hazardous properties may, under certain conditions give rise to undesirable emissions of such chemicals during the use phase, as well as during recycling and other types of waste treatment. The content of chemical substances is not always based on conscious choices, and chemicals which have been phased-out from new materials may remain in the technosphere due to recycling of older materials. Flame retardants have been found in low levels in plastics toys, and a presumed reason for this is the use of recycled flame retardant plastic in the manufacturing of toys (Ionas et al., 2014). There are also many recycled materials that do not find a market because the recycling industry cannot guarantee the material content to a sufficient level of detail. A circular economy requires materials to be used many times without value loss, which requires increased monitoring of hazardous substances. The knowledge of the impact and influence of hazardous substances on reuse and recycling is currently inadequate, especially concerning the extent and implication on exposure and human health of "wrong chemical in the wrong place" due to recycling into other products and recirculation of phased-out substances. Environmental chemical research has traditionally been focused on chemical presence and effects on the external environment, but as a consequence of reduced industrial emissions, the focus has shifted to the indoor environment, and to those goods that account for a significant part of the contribution to human exposure (Bekö et al., 2013) as well as to their influence on the presence of hazardous substances in the outdoor environment (Björklund et al., 2012). It has long been realized that hazardous substances may hinder the recovery of materials from the waste stream; however, this knowledge has not yet led to any significant changes in terms of product development or recycling habits. One reason for this apparent inaction is the complexity of the issue as it relates to technology and risk assessment as well as politics and market demand. For example, certain recycling and use may be considered acceptable from a risk perspective whereas the market has a different opinion, which may be harder to predict from an industrial perspective. With increased awareness throughout society about the importance of resource conservation and the need for increased recycling of used materials and products, there is need for a deeper analysis and discussion on the consequences of recycling of materials containing hazardous substances and its implications on risk, exposure and human health.

Building products is a category of products where large volumes of waste are managed. In addition, new construction is very resource- and energy-intensive, which is why increased recycling is desirable from a waste, energy and resource perspective. Meanwhile many of the older building products which are now producing waste due to demolition and re-construction, contain potentially harmful substances such as various plasticizers, flame retardants, anti-corrosion, waterproofing, etc., which may pose problems during recycling.

The EU target for recycling of construction and demolition waste is set to 70 percent by the year 2020. The target is transposed into the Swedish national environmental objectives. According to the Swedish Environmental Emission Data (SMED) the current recycling (year 2012) is about 50 percent, but it is acknowledged that all treatment of waste is not covered by the current statistics (the treated amount is lower than the generated amount) (Palm et al., 2015). The Swedish EPA however is of the opinion that the target is probably already fulfilled, provided that some of those waste streams currently not covered by the statistics can be included in the follow-up to the target (Naturvårdsverket, 2015). Today, the national waste statistics do not fully cover waste treatment of construction and demolition waste, but improvements in reporting waste statistics came into place in 2015 and thus the fulfilment of the target will be easier to evaluate. Even though there are uncertainties in the data it is clear that the aim is to strive towards increased material recycling.

Arm et al. (2014) selected waste streams which were considered important to fulfil the EU-target as stated above:

- Bituminous mixtures not containing coal tar ("asphalt")
- Concrete
- Bricks, tiles & ceramics and mixtures of these and concrete
- Track ballast
- Gypsum-based construction materials
- Wood

Arm et al. (2014) concluded that the EU recovery target does not ensure sustainable waste recovery in its current form: it favours recycling of high density waste types when environmental savings might be more significant on other waste types, it does not support the most sustainable recovery option and it is sensitive to interpretations of what is considered as waste and waste recovery. Among other recommendations, the authors recommended recovery targets for individual waste types that would favour the low-density waste flows as well. They further recommended the recovery methods to be ranked in the reporting process e.g. backfilling should not be regarded as equally beneficial as other recovery methods due to the risk of down cycling. Arm et al. (2014) also states that even if the recovered material is contaminated, re-use and recycling into new constructions often carries with it environmental benefits due to less transportation and use of virgin material.

1.1 Aim and Objectives

The aim of this project is to use the current knowledge of construction goods and chemical contents to investigate the overall recyclability of chosen building products. The objectives are thus to study:

- the recyclability of the selected product in their current condition according to current recycling methods.
- if the recycling processes require pre-treatment of some kind or modifications in the recycling process in order to guarantee safe materials
- the possibility of carrying out risk assessments of the building materials with regards to hazardous substances and use area.
- if recycled building and construction material are more appropriate to use for other purposes than its original function.

1.2 Method

The main focus of the project is on materials where recycling currently is limited due to various reasons. This can be due to that the material contains hazardous substances not desired in the secondary product, that the material is not properly separated in the demolition process, or that the material is contaminated with other material etc. This study partly builds on experiences gained in an earlier study carried out by IVL Swedish Environmental Research Institute, where the potential for material recycling of plastic from demolition sites was investigated (Elander and Sundqvist, 2014).

The selection of building products were based on the following criteria:

1. Limited material recycling occurring today
2. Large waste flows
3. Large potential environmental benefits in recycling
4. Known content of problematic chemicals
5. Available and functioning recycling technology, excluding chemical separation techniques.

In order to identify obstacles and opportunities in the recycling of the chosen product groups, a literature review was made along with interviews with relevant actors. A study visit was also made to Meason Bygg (Meason) to obtain more knowledge on how selective demolition and subsequent sorting may be applied. A reference group consisting of representatives from the industry and actors with experience regarding construction, demolition, hazardous substances and waste management was also consulted.

The data used for assessing the construction and demolition waste amounts in Sweden was taken from waste statistics reported in Palm et al. (2015) and Fråne et al. (2012). The generated waste of the specific product groups were estimated with the help of 2014 data from Plastics Europe. Climate data for the product groups was retrieved using the Gabi Database.

1.2.1 Selected building products

In this study we focus both on pre- and post-consumer waste and only regard building materials that can be recycled (i.e. we do not consider other waste types that may be recycled for use in building products). Pre-consumer waste is defined as construction and demolition waste arising in the construction process and post-consumer waste as construction and demolition waste arising in the demolition process. During reconstruction of a building, both pre- and post-consumer waste will arise.

Based on the selection criteria presented above and after consultation by the reference group four waste categories were selected.

- **PVC floors -** PVC is the most commonly used plastic in the construction of buildings (Plastics_Europe, 2015). It can be found in floors, ceiling and wall covers, lists, pipes etc. (Elander and Sundqvist, 2014). In this study we focused on PVC floors only in order to more thoroughly study a specific product group and its connected obstacles and opportunities in relation to increased recycling. The use of hazardous substances is highly debated obstacle in terms of increased recycling of this product, particularly in Sweden. Regarding PVC in general however, extensive recycling occurs on the EU level, in particular of flexible products, and since the early 2000's recycling has increased from nearly zero to over 500 000 tonnes. Due to the ongoing discussion on authorisation of recycled DEHP-containing materials the increase in recycling of PVC has caused some uncertainty in the recycling market (VinylPlus, 2016, Lundberg, 2016). Fulfils criteria 1, 3, 4, and 5.

- **Plaster waste** (from here on referring to plaster boards), is an interesting product in terms of the effects from the demolition process i.e. the amount of plaster waste that can be collected and recycled is highly dependent on how the demolition process is carried out which is also investigated in this study. From a hazardous substance perspective plaster is considered to be relatively unproblematic. Fulfils criteria 2, possibly 3, and 5.
- **Flat glass** - Approximately 45 percent of the glass waste from construction and demolition is currently recycled, thus there is potential for an increase. Since a functioning recycling process exists it was considered relevant to investigate and identify any obstacles that hinder the remaining 55 percent from being recycled. Fulfils criteria 4 and 5.
- **Insulation material – EPS boards** - Since most insulation materials end up being incinerated or landfilled it is interesting to study the potential for increased recycling for insulation material. Many insulation materials are also treated with chemicals to attain the desired properties. This study focuses on the insulation material expanded polystyrene (EPS) that is frequently used in modern buildings. The oil-based insulation material is interesting both from a resource perspective and from a hazardous substance -perspective. Fulfils criteria 1, 2 (large waste flows will occur in the future) 3, 4 and 5.
- **The demolition process –** In addition to the aforementioned product groups, a special focus will also be put on the demolition process. The kind of demolition processes used will highly determine the possibility to further sort and thus recycle construction and demolition waste. In Elander and Sundqvist (2014), selective sorting at the demolition site is mentioned as a prerequisite for increased material recycling.

2 Quantitative potential for increased recycling

Excluding contaminated soil and other soils, the construction and demolition sector generates 1 312 000 tonnes of waste per year (Palm et al., 2015). 1 167 200 tonnes were directly generated by the Building and Construction (B&C) sector and the remainder from other sectors. Out of the generated amount, it is estimated that 43 000 tonnes (3.3 percent) consists of plastic waste (Fråne et al., 2012), 38 200 tonnes (2.9 percent) plaster waste and 4 850 tonnes (0.4 percent) glass waste (Palm et al., 2015). Although this may not represent a major fraction of the total waste generated on a weight basis, they represent energy and/or chemical intensive product groups which may serve as illustrative examples on how to deal with recycling of contaminated waste and Table 1 presents generated amounts of the chosen building products as well as estimated shares of what is currently recycled.

Table 1. Generated plastic, plaster, glass and insulation waste within the B&C sector in Sweden as well as estimated current recycled amounts.

Generated waste per year [tonnes]		Waste to material recycling [tonnes]	Percentage of generated waste that is material recycled [%]
Generated construction and demolition waste: 1 312 000 tonnes **(1 167 200 tonnes from the building sector and 144 800 tonnes from other sectors)**	**43 000 plastic**	200-3000	0,5-7
	5 160* EPS insulation	-	-
	1 390 PVC floors**	300-400	22-29
	38 200 plaster	24 000	63
	4 850 glass	2 200	45

*According to data from PlasticsEurope, 12 percent of the plastic raw material (polymer) was in 2014 used to produce EPS for thermal insulation.

**According to data from PlasticsEurope, 36 percent of the plastic used in construction in 2014 was PVC and 9 percent of the PVC was used to produce floors (Sevenster, 2016). These numbers are used to estimate the generated PVC floor waste arising from the total amount of generated plastic construction and demolition waste.

There are high uncertainties associated with the data for plastic waste from the construction- and demolition sector, going to recycling in Sweden. The data from SMED (200 tonnes collected for recycling) is obtained through interviews with construction and demolition companies and then modified to estimate the national amount. According to Sternbeck et al. (2016), IKEM estimates that approximately 3000 tonnes of PVC is recycled annually in Sweden. Most of the PVC plastic is used in the building and construction sector. Additionally, not all the collected plastic is actually recycled meaning the numbers are an overstatement.

For EPS insulation waste and PVC floor waste, data from production in 2014 was used to estimate the generated amounts of waste today. Since the generated waste was produced years ago, this carries with it uncertainties as well. Since the amount of plastic used in construction has increased, these figures are likely to be an overestimation of the current generation of EPS and PVC waste. Additionally, the use of plastic in Swedish construction differs from the average use in Europe as a whole.

Table 2 demonstrates the existing potential in terms of potential climate savings. Note that this assumes that all recycled material replaces the original product/material. The table merely indicates the size of the potential gross savings and does not consider the resources and energy required during the recycling process. Nor does it account for the energy gains due to incineration with energy recovery. The data on global warming potential was obtained from the GaBi database and the system boundary covers a cradle-to-gate perspective[1].

[1] A cradle-to-gate perspective considers activities from material extraction (cradle) to when the product is ready to be transported from the factory gate.

Table 2. Estimated global warming impact caused by the production of the product groups together with potential climate savings if landfilled/incinerated fractions were to be recycled into its original application. Data is retrieved from the Gabi database.

Product group	Global warming potential [tonnes CO2-eq* per tonne produced]	Potential climate savings [Tonnes CO2-eq.]
PVC floors	1.55	1 612
EPS	2.72	14 011
Plaster	0.15	2 130
Flat glass (coated)	1.11	2942

* CO2-equivalents i.e. all climate emissions are converted into this measure for comparability.

As the table shows, EPS carries with it the heaviest environmental impact in terms of global warming potential. Considering no EPS is recycled today, the product group has the most potential for climate savings. Additionally, more EPS waste is expected in the future as 28 000 tonnes of EPS is used annually in Sweden according to Sternbeck et al. (2016). Plaster has the lowest estimated impact in production but considering the large amounts of waste generated, the total environmental benefits of recycling may still be large. In addition, plaster does not contribute to energy generation when incinerated, and thus the primary alternative to recycling is landfill.

3 Current practices in waste treatment of building products

In new construction projects, approximately 5-15 percent of the building material is estimated to be wasted (Naturvårdsverket, 2016a). In 2011, the main part of construction waste from the building sector was used as construction material for landfills, backfilling and covering of landfills, the majority of which represents various types of soil, concrete and stone. The treatment of demolition waste is largely dependent on the sorting process at the demolition site and this may vary depending on available space, time, knowledge etc. The demolition process is further evaluated in section 5.1.1. In the following, the current practices in construction and demolition waste treatment of our target product types will be presented (current recycling is summarized in Figure 1). Unless otherwise stated, construction and demolition waste (pre- or post-consumer waste) are treated in the same way.

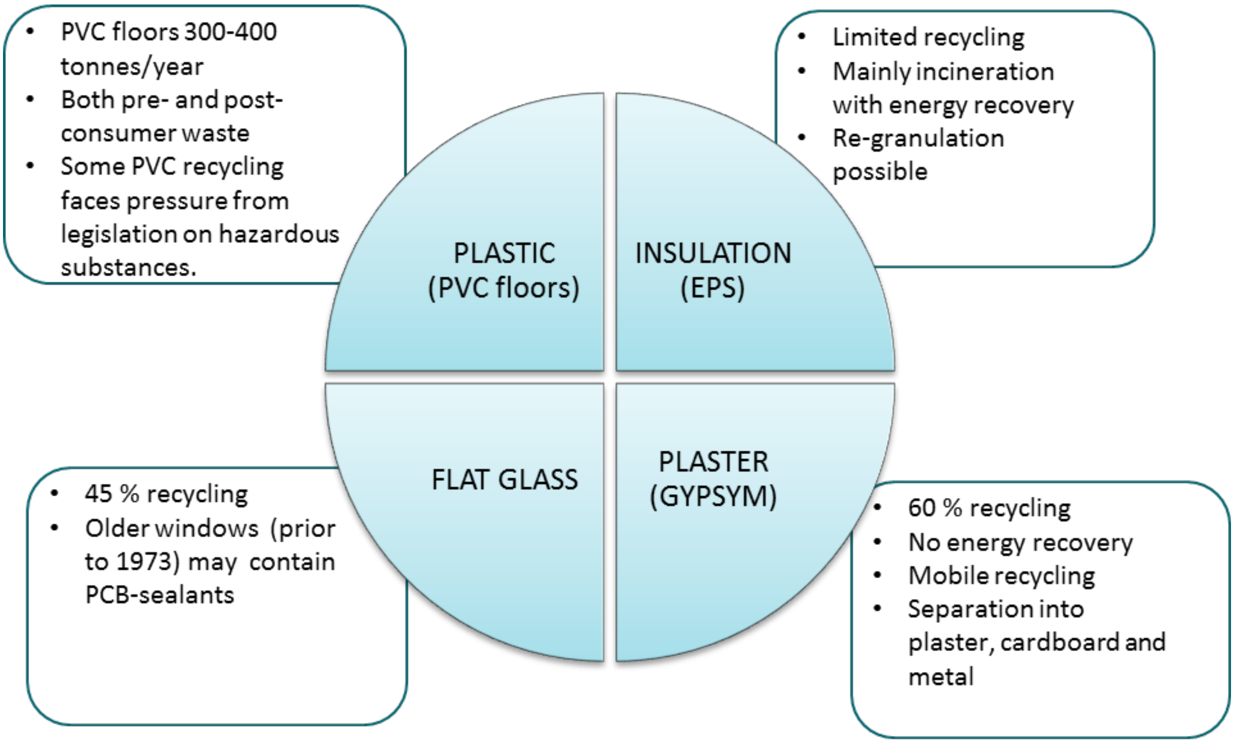

Figure 1. Current recycling of the selected building product groups.

3.1 Plastic waste

According to the national waste statistics compiled by Swedish Emission Data (SMED), approximately 150 tonnes (out of the 43 000 tonnes generated) of plastic construction and demolition waste was sorted out for material recycling in the year 2010, the majority of which consists of shrink and stretch film (LDPE) (Fråne et al., 2012). It should be noted, however, that the national waste statistics are not complete, thus the actual volumes of recycled plastics may be larger, as indicated by industries own figures in the coming sections. However, most plastic waste generated during construction as well as during demolition ends up in the combustible or mixed fractions of construction and demolition waste and is incinerated with energy recovery (Elander and Sundqvist, 2014). The Swedish Construction Federation's guidelines recommend that plastic waste be sorted separately and suggest the following sub-fractions: plastic pipes, plastic floors and sanitary room tapestry, plastic profiles, plastic insulating foam/insulation and plastic roof and film covers (Sveriges_Byggindustrier, 2015). According to the available statistics these guidelines are, however, currently not likely to be followed to any a significant extent. The current practices of recycling of plastic waste are described below:

3.1.1 Shrink and stretch film

The plastic mainly consisting of PE from packaging material and spillage from installation is sorted out in very limited amounts. Shrink and stretch film is grained and washed after which the granulates are dried in a centrifuge or a warm air dryer. The plastic is then used to produce new film or plastic bags (Fråne et al., 2012, Carlsson, 2002). Generally, the main reason for sorting and recycling stretch and shrink film is that it is economically profitable, while lack of space, time and accustomed routines sometimes hinders sorting and recycling (Sternbeck et al., 2016).

3.1.2 PVC materials

In Sweden, only a small fraction of PVC waste is recycled today and it is dominated by waste from installation. Therefore, potential environmental and climate savings can be made by recycling both pre- and post-consumer waste. Recycled PVC (rPVC) is used in e.g. garden hoses, pipes, window profiles, flooring, roofing membranes and coated fabrics. rPVC from grained plastic cables is included in a polymer mix and thus the material is used for applications with lower quality demands such as traffic signs (Sternbeck et al., 2016). The European PVC industry has initiated a voluntary commitment, VinylPlus, with the aim to increase PVC recycling to 800 000 tonnes per year by 2020 (VinylPlus, 2016). In 2015 the recycled amount within the EU reached 514 900 tonnes. The flooring sector of VinylPlus, EPFLOOR collected 4 100 tonnes of flooring waste to recycling in 2015 (3 940 tonnes were recycled) (VinylPlus, 2016). Most PVC floor waste was collected in Germany, the UK and France and 75 percent of the recyclates from post-consumer PVC flooring was used to manufacture new flooring. VinylPlus however states that recycling of PVC faces pressure from legislation on hazardous substances and financial constraints (VinylPlus, 2016).

3.1.2.1 PVC floor production and installation spillage (pre-consumer waste)

Some waste arises during production. Tarkett reports that 10 000-15 000 tonnes of PVC production waste is recycled back into the process (Duberg, 2016), and on-going work focus on decreasing the production waste through the manufacturing processes rather than to promote increased recycling, and a target has been set that by 2020 no production waste will go to landfill (Duberg, 2016). During the installation of new floors, about 10 percent spillage waste is generated. The Swedish Flooring Trade Association (GBR) has a collection and recycling system for PVC and polyolefin flooring from installation spillage administered by the floor producer Tarkett, a company producing 1.3 million m^2 of flooring each year. The collection is available for a number of companies on the Swedish market (Golvbranschen, 2015) and the spillage is collected by the same company that installs it. According to the association approximately 300 tonnes (corresponding to ca 100 000 m^2 floor) of spillage is annually collected and the majority is recycled into new floors, i.e. melted and added in the production process. The collected installation waste is sorted manually at the facility in Ronneby. The demands on input material are determined though the REACH regulations and two thirds of the input material is analysed by a third party (Duberg, 2016).

3.1.2.2 Used PVC floors (post-consumer waste)

Tarkett also collects approximately 100 tonnes in own collection systems in the Nordic countries and Germany. They recollect floors produced by the manufacturer for recycling provided they are loosened and installed during 1993 or later. The recycling includes both homogenous and heterogenic PVC[2] and polyolefin flooring. Floor deliveries are kept separate in order to keep track of different content in different collected batches (Tarkett, 2016). No testing method is

[2] Homogenous products consist of layer/multiple layers of the same quality/color/pattern. Heterogenic products consist of layers with different properties.

used but the present information is passed on to the material producers in connection to the sale.

3.1.2.3 PVC cables

Stena Recycling has developed a process in which PVC from cables can be recycled into new cable insulation (Sternbeck et al., 2016). According to a recent study, approximately 2000-3000 tonnes of cable granulates (mostly PVC) are recycled in Sweden every year but according to their study there is a declining trend in Sweden (Sternbeck et al., 2016, Sveriges_Byggindustrier, 2015). On the European level, however the recycling of PVC cables is steadily increasing (VinylPlus, 2016).

3.1.3 Plastic pipes

The Nordic Plastic Pipe Association (NPG) started in Sweden in 1996 and is a collaboration between four plastic pipe producers that finance the collection of their plastic pipe spillage in Sweden (mostly pre-consumer spillage but also waste from reconstruction activities). The recycling system includes plastic pipes made of PVC, PE and PP from the four major producers on the Nordic market. The association also collaborates with a few municipalities that contribute with spaces for container placement and the municipality supervision of the collection areas and so far eight containers have been placed throughout Sweden (NPG, 2010, Sternbeck et al., 2016). As opposed to leaving plastic pipe waste at recycling stations, it is free of charge for municipalities and construction companies to leave the plastic pipe waste in these containers. If the waste is left at a recycling station instead a cost of approximately 600-1000 SEK/ton is charged (NPG, 2010). It is possible that waste arising far away from the NPG containers is left unsorted due to the higher cost.

3.1.4 Roof covering material (pre-and post-consumer waste)

As part of VinylPlus, Roofcollect collects both spillages from installation as well as used thermoplastic roofing and waterproofing membranes (including PVC roof covers) in many European countries (Roofcollect, 2016). Customers buying new roofing membranes can turn in the material after use. Roofcollect offers to pick up the material from the construction or demolition site and transport it to a recycling unit (e.g. Hoser, a recycling company who they are partners with). The roofing materials are grinded and new plastic drainage sheets are produced and may be used in various applications (greenhouse mats, equestrian mats such as lawn grid or paddock grid, riding arena mats, stable mats, box mats and roof protection applications) (Roofcollect, 2016). During a 6 month period 2 472 tonnes of PVC roofing and waterproofing membranes were recycled in 2014 (Roofcollect, 2014). Among the manufacturers covered by the recycling system are Protan, Renolit Nordic, Sika Sverige and SealEco. Roof covers are especially suitable for recycling as they are mechanically fastened and thus easy to demount (Sternbeck et al., 2016).

3.2 Insulation waste

Insulation materials can be made of different materials, e.g. wood fibers, cellulose fibers, straw, clay, glass or oil based materials such as expanded polystyrene (EPS) and extruded polystyrene (XPS). The two latter are really plastic products and could be viewed as a subcategory under plastic waste. Here we treat insulation materials separately due to their function in the building. From a recycling perspective, EPS presents challenges due to the incorporation of potential hazardous substances, but also opportunities due to the great energy and resource saving potential.

Currently, the amount of generated EPS waste is rather small, due to the long service life of the material and the fact that they were introduced on the market in the 1960's. EPS plastic used for insulation is unlikely to be recycled, but if it occurs it is most probably in the pre-consumer stage i.e. as construction spillage. Most insulation material is sorted in the combustible fraction or, albeit to a lesser extent, in a mixed fraction for subsequent sorting(Sundqvist et al., 2013). Thus, the majority of the EPS insulation waste is incinerated for energy recovery. The amount of EPS demolition waste is expected to increase significantly in the coming 10 years (EUMEPS, 2016). Insulation built into concrete could require on-site separation (Sveriges_Byggindustrier, 2015).

According to EUMEPS (European Manufacturers of Expanded Polystyrene), EPS can be re-granulated (for various applications although demolition waste does not undergo this kind of recycling today i.e. mostly EPS-packaging material) or shredded for production of road constructions or in tile production (EUMEPS, 2016). The recycling activities in Europe are mainly carried out in the Netherlands, Germany, Belgium, Italy and France. The collected material is manually sorted and recyclers control the input material by requiring specifications from the deliverers. EPS containing HBCD[3] is not accepted. Samples of the collected materials are sent to a testing lab to test for HBCD. However, this type of testing is today not carried out at large scale as it is work-intensive and thus expensive (EUMEPS, 2016). In the EU circular economy-package however, one goal is to create more work opportunities (European_Commission, 2015) meaning in the long-term, this should not be seen as an obstacle.

3.3 Plaster Waste

Plaster boards belong to a waste category where the majority (~60 percent of generated plaster waste in Sweden or 24 000 tonnes) is already being recycled, but due to the large volumes generated, potential savings of increased recycling are significant. Still, approximately 14 200 tonnes are landfilled on an annual basis. Besides the material's inability to add to energy generation, plaster is not allowed in the combustible fraction as it contributes to acidification when incinerated (Sveriges_Byggindustrier, 2015). Further, the guidelines state that plaster is to be sent to recycling when it is not contaminated and when there is a recycling facility within reasonable distance (Sveriges_Byggindustrier, 2015).

[3] hexabromocyclododecane

The main plaster recycler in Sweden is Gips Recycling. They have worked with the recycling of plaster material since 2003. Both pre- and post-consumer plaster waste can be recycled in the process. The recycling process is mobile and there are six mobile facilities in Scandinavia (Gips_recycling_Sverige, 2016). Gips recycling either collect the plaster in a location pre-agreed with the customer or the customer leaves the waste at one of the two storage facilities in Halmstad or Bålstad in Sweden. When the facilities are filled to 85 percent the mobile recycling facility is sent to the storage to start the recycling process indoors in the local storage facilities (Gips_recycling_Sverige, 2016). The recycling process includes mechanical fragmentation of the plaster waste followed by separation of non-plaster material such as cardboard, wood, nails etc. and three main fractions are sorted by the machine: plaster (90 percent of the recycled material), cardboard and metal. The plaster fraction is then used as raw material for the production of new plasterboards (Gips_recycling_Sverige, 2016). The paper is also recycled after being further separated from contaminants in two separated fractions, wood waste and plastic waste. Two operators are needed for the recycling of gypsum and one for the paper recycling process (Gips_recycling_Sverige, 2016). According to the Swedish Construction Federation, the plaster must be clean, dry and without any contamination from glue residue when collected for recycling. A schematic overview of the recycling process of Gips Recycling is shown in Figure 2.

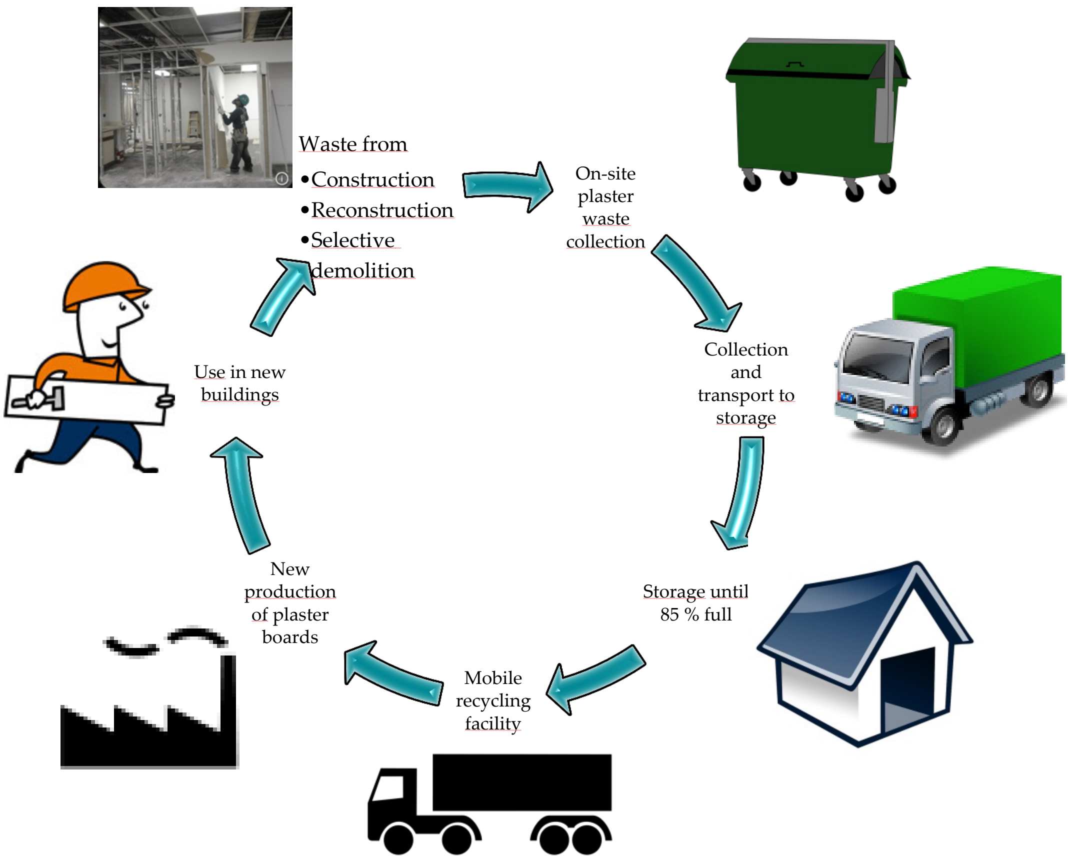

Figure 2. Illustration of the plaster recycling process in Sweden (freely from gipsrecycling.se)

3.4 Flat glass

When it concerns flat glass, there is already a functioning recycling process in use, and currently, 45 percent of the flat glass is being recycled. Therefore, increased climate savings would mainly be made by increasing recycling using existing techniques.

Flat glass is a type of glass normally used in construction that might have an inbuilt function such as flame retardant functions, insulating functions or security functions (laminated glass) among others. Window glass can for example be treated with a metal layer for insulating qualities (Huddinge_Trångsund_Glasmästerier_AB, 2016). According to the Swedish Waste Management Association flat glass does not contribute with energy in the incineration process and creates bottom ash residual waste (Hallberg and Grönholm, 2008). As mentioned in chapter 2, about 45 percent (2 200 tonnes) of the generated glass waste is currently sent to material recycling. The rest of the glass waste is landfilled (Sveriges_Byggindustrier, 2015).

Swede Glass United is a flat glass recycling company that recycles colored and transparent glass in various qualities(SwedeGlass_United, 2016). The company also recycles laminated and hardened glass from vehicles and buildings, mirror glass and reinforced glass and offers to pick up the waste themselves. The glass is exported to Reiling in Germany for recycling (SwedeGlass_United, 2016). Although PCB is prohibited in current use the seal mass used for insulating glass of older type (produced in Sweden during the period 1965-1973 and abroad up until 1980) contain PCB (Svensk_Planglasförening, 2013). The hazardous substances demand proper handling when buildings are demolished. After an inventory, glass containing PCB must be labelled and whether or not it is a PCB containing glass is determined by the production year that in most it cases can be found in the inner window glass (Svensk_Planglasförening, 2013). If many insulation glass panes are suspected to contain PCB it is possible to send probes on the seal mass for analysis in a laboratory. Dismantled PCB insulation glass from demolition sites is managed as hazardous waste and sent to destruction.

3.5 Other waste fractions

Out of the total amount of generated construction and demolition waste (1 312 000 tonnes) 187 400 tonnes are sorted as mixed construction and demolition waste sent to further sorting. After sorting, metals, glass and plastics are materially recycled and the rest fraction is landfilled. Landfill fractions are also sorted directly on-site meaning a total of 103 700 tonnes out of the generated construction and demolition waste is landfilled A total of 175 000 tonnes of metals are recycled. Mineral waste e.g. bricks are landfilled or used as construction material in landfills. Wood waste is incinerated. All treated wood waste should according to the Swedish Construction Federation be treated according to the cautionary principle as hazardous waste and thus be sent to an incineration facility with permission to treat such waste (Sveriges_Byggindustrier, 2015). Concrete and asphalt are already recycled to a significant extent according to Palm et al. (2015).

4 General obstacles and drivers for increased material recycling

One of the problems concerning goal-setting of increased material recycling concerns the waste statistics, which is currently incomplete and needs to be at a more detailed and structured level. The lack of reliable, detailed statistics hinders both adequate goal-setting as well as stringent follow-up work of such goals. The work in developing the waste statistics within construction and demolition waste is currently on-going (Naturvårdsverket, 2016a). Stenmarck et al. (2014) identified a number of reasons and obstacles that currently hinder increased material recycling in general:

- High capacity and low cost for waste incineration
- Low cost for virgin materials
- Lack of knowledge on environmental advantages
- Technical/logistical difficulties in waste sorting
  –Lack of recycling technologies
  –Bad "material hygiene"
  –Inability to separate waste fractions

Many of the general obstacles are relevant also for building products, depending on the content of hazardous substances, volumes, product life span, material separation possibilities etc. From a circular economy perspective, recycling of building waste into new building material is advantageous as it replaces new products made from virgin materials in the building sector which is often preferable from a resource- and energy efficiency point of view. However, as many older building materials contain hazardous substances that are phased out or banned, the toxicity perspective is an obstacle in achieving closed-loop recycling. Many stakeholders argue that hazardous substances should not be recirculated at all while others state that it may be possible to find other applications for the recycled material without generating any increased risk exposure of the possible hazardous substances in the material. In April, 2016, EU member states agreed to allow the use of diethylhexylphthalate (DEHP) in recycled products, by authorising three companies this use. This substance is listed on the REACH candidate list and requires authorisation for use. The permission for recycling will last until February 2019 (ENDS_Europe, 2016). Meanwhile stricter definitions of endocrine disrupting chemicals (EDCs) are awaited, which may pose other obstacles to the recycling industry (Davies, 2016).

Floors, wall and ceiling materials are often regarded as hazardous waste during demolition which hinders increased recycling. The potential content of hazardous substances in the four product groups discussed in this report is presented in sub-chapters of chapter 5.

A study commissioned by the Swedish Chemical Agency (Kemikalieinspektionen, 2012), investigated possibilities and hindrances of increased recycled material and the decreased use of hazardous substances in four product groups, one of them being interior products including flooring in different materials e.g. wood, vinyl, linoleum etc. The main general obstacles found include:

- The same quality and safety requirements are demanded for both recycled material and virgin material.
- As the origin of the recycled material often varies from batch to batch there is the need to test the recycled materials more often compared to virgin material.
- Costs of testing and lack of traceability of recycled material.
- Limited availability of recycled material.
- Risk of contamination due to poor recycling processes and old products containing unwanted hazardous substances.
- Need for cleaner material streams and thus cleaner input material.
- Need for enhanced separation and cleaning technologies, and
- Standards for recycled materials

Barriers and drivers for increased use of recycled materials (other than the above-mentioned) communicated by three companies in the interior products' sector, one of them a floor producing company (Kemikalieinspektionen, 2012):

Barriers:

- Other issues than chemicals such as odor, strength, durability where recycled materials may fail.
- Lower or uncertain quality of recycled materials (may be adjusted by modifying the manufacturing process)
- Logistics and transportation for material collection and administration of various material fractions.

Drivers:

- Expected increase in virgin material prices might create more value for the recycled material (today the low value is a barrier).
- Enhanced resource efficiency and prevention of resource depletion due to limited resources.
- Corporate culture of not wasting materials.
- Contribution to sustainability by using recycled material for their environmentally beneficial effects

A few of the interviewed companies often used recycled material blended with virgin material in their products suggesting that some uncertainties regarding recycled material could be accepted without increasing quality and chemical risks (Kemikalieinspektionen, 2012). However, this varied significantly between the different companies and the products they produce.

In the study conducted by Kemikalieinspektionen (2012), it was also concluded that irrespective of sectors, waste actors rarely, if ever ask questions on the chemical content of the building products and a few companies proactively communicate the information with the intention to improve the end-of-life performance of their products. The reference group for the same study agreed that voluntary systems are not sufficient in order to attain a non-toxic environment in the building and construction sector. There is also the need for clear and guiding rules which should preferably be set at the EU-level (Kemikalieinspektionen, 2012).

In a recent study conducted by Kemikalieinspektionen (2015) the need for national regulation of hazardous substances in building products in order to decrease children's exposure was investigated. A typical indoor environment may contain 6000 organic substances out which 500 is estimated to arise from building products and from a literature study it was concluded that emissions of hazardous substances from building products do occur (Kemikalieinspektionen, 2015). The study identified 46 hazardous substances[4] in building products used within the EU out of which 32 are regulated in Germany, France or Belgium. In Sweden the only similar regulation applies to emission of formaldehyde from wood based material (Kemikalieinspektionen, 2015). The study which was conducted with consultation from the National Board of Housing, Building and Planning and with the Public Health Agency in Sweden recommended the following: implementation of national regulations for the use of hazardous substances in building products. Regulations should apply to products used in floors, walls and ceilings except chemical products[5]. The recommended regulation is stated to be in line with the EU Construction Products Regulation that will require documentation for emissions of VOC[6] and SVOC[7] in order to be able to sell the products in the Swedish market. The Swedish Chemicals Agency should be responsible for issuing regulations concerning threshold values (Kemikalieinspektionen, 2015). However, the study has not taken into consideration targets regarding increased recycling and circular economy.

5 Qualitative potential for increased recycling

5.1 Case studies

In the following section five case studies are presented together with obstacles and opportunities for increased recycling. The examples given below are not guaranteed to cover the general practices of the industry buy rather present some initiatives that may provide useful insights on the subject.

5.1.1 The demolition process

According to Elander and Sundqvist (2014) the most used demolition method regarding total demolition is using a 30 ton heavy excavator with a demolition grip. The excavator is used to demolish the building piece by piece by removing material from the building and place it in different containers (in fractions of wood, combustible waste and mixed waste). The method

[4] Carcinogenic, mutagenic or toxic for reproduction (CMR), suspected endocrine disruptors or allergenic.
[5] The proposed regulation covers the following substances: VOC (Volatile Organic Compounds), SVOC (Semi-volatile organic Compounds) and CMR.
[6] Volatile Organic Compounds
[7] Semi-volatile Organic Compounds

requires the containers to be in reach of the excavator grip arm and thus the containers need to be moved as the demolition process proceeds. Due to high hourly rental costs, demolition companies try to use the machine as effectively as possible by for instance not sorting out the smaller fractions (such as plastic waste or other waste types) and avoid storing waste on the ground but place it directly in the containers to save time. Elander and Sundqvist (2014) suggests that selective sorting of plastic waste take place prior to the total demolition with the expensive excavator i.e. in selective demolition.

Selective demolition is a method that is becoming more frequently used. Roughly 70-80 percent of demolitions in the public sector are required to be selective but it is unclear to which extent this actually happens and to what level of selection, due to the general lack of follow-up and statistics (Elander and Sundqvist, 2014),. Examples of what can be sorted on site in selective demolition are: electrical equipment with cable and metals, metals, electrical equipment excl. cables, glass, wood, combustible waste, non-combustible waste and hazardous waste (Elander and Sundqvist, 2014). Unlike total demolition, the use of an expensive demolition machine is not necessary at this stage and the extra work needed to separate other fractions e.g. plastic in a separate fraction is limited. Other studies have however shown that selective demolition is more time consuming than traditional demolition (Palm et al., 2015).

According to the Swedish EPA, it is required that the waste is sorted at the construction and demolition sites in order to increase re-use, material recycling, collect hazardous waste in a controlled manner and decrease the amounts landfilled (Naturvårdsverket, 2016b). Central sorting may be allowed in exceptional cases. The most basic sorting requirements are (Naturvårdsverket, 2016b):

1) hazardous waste
2) reusable material/products
3) waste to material recycling
4) waste to energy recovery
5) waste that cannot be material recycled nor energy recovered (waste to landfill).

These main fractions can further be divided in sub-fractions to optimize recycling possibilities. Prior to the demolition it is further required that a material inventory take place in order to identify hazardous substances, components and material(Naturvårdsverket, 2016b).

5.1.1.1 Obstacles

The main obstacle in implementing the selective demolition process is that it is considered to be time consuming and therefore costly, a fact that may not be considered a hindrance in the long-term, since one of the purposes of a circular economy is to produce more jobs. According to Sundqvist et al. (2013), the cost of separating the material exceeds the cost of discarding mixed waste fractions. Not all actors agree with this statement, however (see 5.1.1.2). Ragn-Sells, a major waste management company in Sweden, recycle 80 percent of the incoming sorted material; the rest comes in mixed fractions due to a lack of demand in the market (Tolgen, 2015). As aforementioned, the circular economy package also aims to create more job opportunities meaning that selective demolition being a costly and time consuming process should not be viewed as an obstacle in the long-term although today, this is used as a main argument.

Another obstacle related to selective demolition as stated in Palm et al. (2015), is the lack pf space. The containers used in the demolition process are normally very large (10 tonnes containers) and they take up too large spaces, especially in central areas (Palm et al., 2015). In their study they propose the use of bags instead of containers as a solution to the problem.

If selective demolition is not carried out prior to demolition with an excavator (when this is necessary), there is limited possibility in sorting the demolition waste in sufficient fractions to facilitate material recycling due to the high cost using the excavator. It is thus crucial that selective demolition is implemented in order to have the possibility to recycle building material collected from the demolition process.

According to Meason, the following factors hinder comprehensive selective sorting on the demolition site:

- Lack of time: the demolition process need to be done fast so different fractions end up in the same container.
- Machine demolition: Machines used for demolition are not selective enough.
- Permission/renting street area: according to Meason it is nearly impossible to get a permit for 7 containers in the Stockholm area.
- Lack of space: when using containers, a limited number of containers may be placed on the site.
- Insufficient waste analysis: Poor expectancy on what fractions will be generated.
- Insufficient planning: causing a hasty demolition process without sorting.
- Unqualified workforce: lack of knowledge on what is possible to sort. Crushes the material instead of demolishing it piece by piece.
- Separating plaster walls: plaster walls sawed in boulders made out of layers of plaster, plywood, insulation and steel bolts are difficult and thus costly to separate into four fractions. The entire boulder is therefor in most cases sorted to landfill.

5.1.1.2 Opportunities

The possibilities for increased recycling of demolition waste are illustrated by the example process conducted by Meason. The company implements selective demolition and small-scale sorting of both pre- and postconsumer construction and demolition waste (Meason_Bygg, 2015).

Meason's demolition process also includes demounting of the plaster boards by unscrewing the boards instead of demolishing them. This enables the company to sort the construction and demolition waste at a more detailed level on site. Sorting unseparated wall-parts after the demolition has been made is too costly. The following fractions are sorted in their facility:

- **Combustible waste -** Approximately 10 percent of the incoming waste ends up in the combustible fraction. The content of this fraction mainly consists if hard plastics, plastic carpets, linoleum carpets, cardboard and cardboard packaging material, contaminated corrugated cardboard etc. The ambition is to also separate the plastics from the combustible fraction.
- **Waste to landfill -** Many insulating materials end up here together with tile, porcelain and other inert material. Meason has attempted to sort out mineral wool for recycling however the receiving company could not guarantee sufficient quality and therefore the recycled

material cannot be used. Ballast is sorted to this fraction; however, it is a material Meason does not wish to manage in the facility as it is too heavy.

- **Metal -** This fraction consists of mixed metals. Copper and cables are further separated from this fraction.
- **Corrugated cardboard -** Corrugated cardboard is sent to recycling.
- **Non-treated wood**
- **Treated wood -** The treated wood can be identified and separated by colour (blue and green shades) and they are often used out-doors in porches for example. According to Meason, this fraction is difficult to sort out as most wood is placed outdoors in gardens where containers on wheels cannot properly glide. The wood is sent to Kovik waste management facility and is there treated as hazardous waste.
- **Soft plastic -** This fraction is compressed before it is weighed and sent to IL recycling.
- **Flat glass -** The fraction is sent to recycling.
- **Plaster -** Plaster is sent to Gips Recycling.

All fractions above can theoretically be sorted on site through selective sorting, and further sub-fractions can be sorted at the facility as in Meason's case, see Figure 3 and Figure 4. With sufficient waste analyses, panning, a professional demolition contractor and logistics adjusted after the site's condition, Meason has in some cases been able to reach 90 percent pure fractions. Regarding the separation of plaster walls, Meason states that experienced demolitionists are able to separate the various layers of plaster, plywood and insulation in practically the same time as conventional demolition practitioners (Meason_Bygg, 2015).

During the writing of the report Meason's service was shut down as there was not enough interest in the market. According to Meason it is too costly to sort construction and demolition waste compared to having mixed fractions going to incineration i.e. there is a lack of incentives to choose sorting and recycling above incineration of mixed fractions.

Figure 3 Containers with sorted material at Meason's sorting facility. All incoming material is weighed, sorted and weighed again before being sent to suitable treatment.

Figure 4.Waste found at the demolition site is further sorted in sub-fractions such as (from left to right) insulation material, fire extinguishers and silicone and metal parts.

Other material from the sites covered by the producer responsibility are turned in though contracts with various trade organisations (Meason_Bygg, 2015). According to Meason approximately 30 percent of the waste received is mixed and 100 percent of the out-put material is pure fractions. All fractions entering the Meason facility is weighted, sorted and then weighted again (Meason_Bygg, 2015).

Meason has solved the space issue and improved the work environment by using 660-liter containers with four wheels instead of Bigbags or larger conventional containers. This allows more fractions to be sorted out (Meason_Bygg, 2015)

Besides the on-site construction and demolition waste, Meason also functions as a micro-recycling centre. This type of business model would increase the sorting level according to Meason (2015). Other companies and individuals can also, for a charge, turn in their mixed construction and demolition waste for Meason to sort and treat accordingly (Meason_Bygg, 2015).

The development of this selective demolition process was helped by the fact that Meason originally started out as a construction company and expanded to also include demolition (Meason_Bygg, 2015). According to the company, the selective sorting in various fractions does not take more time than conventional demolition processes; however there is a period of relearning when changing the demolition method that is time consuming before settling into the new routines.

Another contributing factor that has helped Meason develop this demolition/sorting method was high demands from a significant contract with a large company that needed their construction and demolition services. The buyer demanded every fraction to be weighted and reported (Meason_Bygg, 2015).

An important aspect in a demolition process is considering the working environment. It is important to consider such questions at the start of a project e.g. limiting the extent in which the containers can be filled etc. (Meason_Bygg, 2015).

Meason further attempted to increase the fractions going to reuse. One initiative was in collaboration with Kompanjonen, a company selling second hand products for construction, lighting and furniture (Meason_Bygg, 2015). Kompanjonen would visit the facility and inspect it for materials that could be sold in the second-hand market, however the process was too time consuming and Meason was forced to end the collaboration (Meason_Bygg, 2015). Another obstacle stated by Meason is the low competitiveness with virgin material; collecting, sorting and managing used building material costs more than buying new products (Meason_Bygg, 2015).

Stenmarck et al. (2014) examined suggestions on political and economic instruments on how to stimulate increased recycling for construction and demolition waste among other waste streams. One of the instruments described involves requirements on material recycling for construction and demolition projects regulated by safety fees payed by the constructor and repaid once recycling levels of certain waste fractions can be demonstrated (Stenmarck et al., 2014). This type of instrumental regulation could have significant effects on waste management practices.

5.1.2 Recycling of PVC floors

There are several existing initiatives on the EU market to increase the recycling of PVC materials. According to VinylPlus, recycling of flexible PVC has increased over the last decade and recycling of flooring waste increased by 19 percent between 2014 and 2015. The main obstacles associated with recycling of PVC floors is connected to the uncertainty regarding content of hazardous substances and the perception that PVC recycling into new applications could lead to unforeseeable exposure and negative health effects to humans. Providing that plastics containing more than 0.1 % DEHP have ceased to be waste, all use within the EU requires authorisation according to REACH. In June 2016, the EU Commission granted a four-year authorisation to three recycling companies to use DEHP in recycled soft PVC, with the exception of "toys and childcare articles; erasers; adult toys (sex toys and other articles for adults with intensive contact with mucous membranes); household articles smaller than 10 cm that children can suck or chew on; consumer textiles/clothing intended to be worn against the bare skin; cosmetics and food contact materials regulated under sector-specific Union legislation." The argument behind the authorisation was that "socioeconomic benefits outweigh the risk to human health arising from the use of the substance and there are no suitable alternative substances or technologies in terms of their technical and economic feasibility for the applicants and some of their downstream users." The producers of goods based on the recyclate are obliged to follow the conditions and the time constraints given in the authorisation (EU, 2016).

5.1.2.1 Hazardous substances in PVC floors

PVC floors are manufactured by mixing PVC powder with softeners to produce a liquid mass called plastisol which is applied in multiple layers on a floor base consisting of foam, a decorative layer and a layer for durability (Elander and Sundqvist, 2014). The floors have a long life span of approximately 20 years, but sometimes longer, even up to 50 years. Generally, older

PVC floors may contain lead, cadmium (prior to 1982) as well as various types of hazardous phthalates and flame retardants, although the use of each substance has varied over time and thus varies with the age of the floor (Elander and Sundqvist, 2014). Lead stabilisers may still be used in some imported PVC products but has been phased out in Sweden (Sveriges_Byggindustrier, 2015). Prior to 1976 asbestos could occur in PVC flooring (Elander and Sundqvist, 2014). The limit for when a material containing cadmium should be classified as hazardous waste varies from 0.01-25 wt% depending on the form of cadmium used (Sveriges_Byggindustrier, 2015). Sternbeck et al. (2016) investigated the presence of hazardous substances in a number of waste streams, one of them being PVC plastic waste from construction and demolition waste. The study focused on 25 hazardous substances and the possibilities (risks) that these substances would be present in the recycled materials. They found studies indicating a use of organotin compounds such as DBT[8] and DOT[9]. Although mainly found in rigid PVC, the compounds were found in PVC floors when compiling investigations carried out between the years 2000-2003 (Sternbeck et al., 2016). Since then, regulations of the substances have been implemented and it is unclear to what extent they are present in PVC floors today. Additionally, polychlorinated biphenyls (PCB) have been used in sealants for some types of plastic floors (Sveriges_Byggindustrier, 2015). Most of these floors were installed during the 60's (Miljökonsultgruppen, 2016), and most of these floors are likely to have been replaced by now.

At present, the main discussion on PVC floors and hazardous substances concerns plasticisers, in particular phthalate esters. In 2012, 93 percent of the phthalates used in Europe were used in PVC plastics (Kemikalieinspektionen, 2012), consisting mainly of ortho-phthalates such as DINP[10] , DIDP[11] and DPHP[12] (57 percent of the European plasticisers market), but also to some extent of DEHP[13] (10 percent), a substance which is listed on the REACH candidate list for substances of very high concern. There is also some use of DIPP[14], which is also listed on the candidate list (ECPI, 2016, Kemikalieinspektionen, 2012). Approximately 30 percent of the plasticisers market consists of alternative plasticisers such as sebacates, adipates, terephthalates and cyclohexanes such as DINCH[15] , the use of which has increased 47 times over the last year.

Since these substances are not chemically bound to the material they may migrate out of the products and into the surrounding environment which has been illustrated in numerous emission experiments as well as through indoor environmental monitoring, in particular of indoor dust. Several phthalates are classified as toxic for reproduction and nine are included on the REACH candidate list for substances of very high concern[16], namely: DHP[17], DPP[18], DIPP[14], N-pentyl-isopentylphthalate, DMEP[19], DIBP[23], BBP[22], DEHP and DBP[21]. Four of these are also included on the authorisation list[20] of REACH: DEHP, DBP[21], BBP[22] and DIBP[23]. Only two of the

[8] dibutyltin
[9] dioctyltin
[10] diisononylphthalate
[11] diisodecyl phthalate
[12] di(2-propylheptyl) phthalate
[13] Bis(2-ethylhexyl)phthalate
[14] Diisopentylphthalate
[15] 1,2-cyclohexane dicarboxylic acid diisononyl ester
[16] List with substances of very high concern (Substances that may have a serious effect on human health and the environment). Regulated by ECHA, the European Chemicals Agency. Includes the phthalates,
[17] Dihexyl phthalate
[18] Dipentylphthalate
[19] Bis(2-methoxyethyl) phthalate
[20] Substances registered in the candidate list may also be included in the authorisation list i.e. Annex XIV of REACH.

listed phthalates are registered for use in Europe: DEHP and DIPP. The phthalates of main use (e.g. DPHP and DINP/DIDP) are, however, not considered to be hazardous, but an on-going process within the EU have recently launched a proposal for new criteria on endocrine disruptors and it is currently unclear if DINP or DIDP will fall under these criteria.

The Swedish Chemicals Agency report on chemical substances in pre-school environments and found that in older pre-schools, the use of DINP, DEHP and DIDP was significantly higher than in new schools (Kemikalieinspektionen, 2013). PVC floors are usually used in schools as they are easy to clean. The highest concentration was found for DEHP (Kemikalieinspektionen, 2013). The same report also conducted risk assessments for reproductive effects based on a high-exposure scenario exposure via dust (i.e. highest measured levels in dust) and concluded that no risks could be identified for individual phthalates, but a cumulative assessment resulted in a risk ratio of 1.1 for the youngest child group, with the main contribution from DEHP. Considering that other exposure pathways also contribute the total risk ratio for this group is likely to be higher. However, given that DEHP has been phased out from floors in Sweden, this high-exposure scenario to DEHP via dust is probably not representative for the majority of floors and children in Swedish pre-school environments today. The study was also limited, since only three pre-schools were included.

Tarkett, one of the major floor producing companies in Sweden, producing 1.3 million m^2 of flooring each year worldwide, reports that no phthalates have been used in primary production since January 2014 and biocides have not been used since 2013 (Duberg, 2016). Some phthalates not listed in the REACH legislation, such as DINP, are accepted for recycling if present in collected installation spillage from other floor companies. In these cases the recycled materials are used in the bottom layers of floor sheets (Duberg, 2016).

In summary: the older the floor, the higher the likelihood that it contains a wide variety of hazardous substances, whereas modern floors are mainly associated with phthalates and other plasticisers, most of which are considered to be of low or no hazard. Thus, recycling of installation spill is unproblematic, whereas potential problems arise when it concerns older floors.

5.1.2.2 Obstacles

Production waste

According to Tarkett the work towards reducing production waste is ongoing and no major obstacles have been identified. It is mainly a question of refining the manufacturing process. In 2020, no production waste should go to landfill (Duberg, 2016).

Installation waste

The majority of the installation waste is collected by the floor industry, but approximately 10 percent (~40 tonnes) is lost due to poor knowledge on floor recycling among waste

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[21] dibutyl phthalate
[22] benzyl butyl phthalate
[23] diisobutyl Phthalate

management entrepreneurs, which are often hired at larger construction sites. A project on how to incorporate the collection system with one major Swedish waste management company is however currently carried out (Duberg, 2016). The majority of the collected installation waste (80-90 percent) is recycled, but a minor fraction (10-20 percent) cannot be recycled due to contamination, or because it contains a polyester backside that causes problems in the grinding process (Duberg, 2016).

One obstacle that may hinder increased installation waste recycling concerns the uncertainty in market requirements and future legislation on DINP, since some of the collected installation waste origins from other countries (Nordic countries and the EU), where DINP may be present in the material.

Post-consumer waste

Obstacles that may hinder the recycling of post-consumer waste include technical and practical problems arising when emptying a container with mixed plastic waste from a construction and demolition site, since the material is heavy and often attached to other materials, which makes fine sorting difficult (Elander and Sundqvist, 2014). Two companies assessed the quality of plastic from construction and demolition waste: Swerec found that plastic from construction and demolition waste was of poorer quality compared to other plastic waste and that currently the costs would outweigh the returns, but pointed out that this could be solved with higher demands on granulates from plastic waste. VinyLoop Ferrara S.p.A. (VinyLoop), on the other hand, found that construction and demolition plastic floor waste was of sufficient quality for an economic recycling in the company's own recycling process (Elander and Sundqvist, 2014).

Obstacles associated with legislation include the definition of hazardous waste which states that products containing substances considered to be carcinogenic, toxic to reproduction and allergy-causing at concentrations above 0.5 percent should be treated as hazardous waste. This implies that PVC-floors containing plasticizers with these properties should be considered as hazardous waste, since the plasticiser level in PVC floors is commonly 20-50 percent. This is valid e.g. for floors containing DEHP. Although the concentration of phthalates in new floors made from rPVC would most likely be lower than concentration of phthalates in the rPVC itself, GBR states that there is concern of recirculating phased-out chemicals such as DEHP in new products (Lassen, 2016). The use of four phthalates in production and in recycled material requires authorization according to REACH. The EU Environment Committee are currently discussing to remove DEHP from this requirement meaning the phthalate cannot be used in recycled/new material which would be a significant obstacle in increasing recycling in PVC material as it is a common additive.

Another obstacle to increased recycling of post-consumer waste is associated with market demands and requirements. As an example, Electrolux has a policy of not using rPVC in their products due to anticipated risks with hazardous substances (Sternbeck et al., 2016). Thus, even if a risk has not been stated, certain companies are unwilling to invest in products that contain chemicals with hazardous properties. However, since the majority of the use of recycled flooring and cables is likely to be used within the same industrial branch, there is still a market for rPVC, especially if the entire European market is considered.

In a report from the Swedish Chemicals Agency (Kemikalieinspektionen, 2015) the content of hazardous substances was investigated[24] in building products by cross- checking various lists and databases[25]. According to the Swedish Flooring Trade Association (GBR) cited in the report, the two main manufacturers of PVC floors no longer use phthalates as softener in PVC floor production. Instead, DINCH[26] or plant-based softeners are used and this development is ongoing in Europe (Kemikalieinspektionen, 2015). To increase PVC floor durability, the floor is sometimes treated with polyurethane. Other softeners used in PVC floors are Mesamoll and DOTP (Kemikalieinspektionen, 2015).

[24] The study included carcinogenic, mutagenic and reproduction toxic (CMR) substances, allergy-causing substances and endocrine disrupters.

[25] EU's EDC-database, the SIN-list, REACH, ECHA's CL-inventory database, the Swedish Chemicals Agency's product register, SundaHus and Byggvarubedömningen.

[26] Di-isononyl-cyklohexan-1,2 dikarboxylat

In their study, WSP argued that closed system recycling, i.e. recycling into a similar product should not increase the exposure, and thus not increase the risks associated with chemical exposure. We agree with this conclusion in that the annual exposure should not increase. Recycling could lead to higher total exposure, providing that the alternative to recycling is complete destruction and elimination. Such an increase may be of concern if the chemical is persistent. But on an annual basis a closed-system recycling process could even lead to a gradual decrease in exposure, providing that the added chemicals in the recycling process does not exceed the concentration in the original product. Furthermore, WSP pointed out that an open system recycling may result in unintentional chemical occurrence in products with different use and exposure scenarios. On the basis of the common occurrence in particular in older PVC products of for example chemicals such as phthalates, organotin compounds, lead, cadmium and nonylphenol ethoxylates, WSP recommended that this waste stream should not be stimulated for increased material recycling, since it may lead to uncontrolled occurrence in products where they are not desirable (Sternbeck et al., 2016). It is, however, relevant to consider also the potential health risks associated with chemical exposure prior to dismissing materials from recycling entirely.

5.1.2.3 Opportunities

Floor manufacturers are willing to use rPVC in their products, but they state it is difficult to find PVC that is not softened with DINP and DIDP (Lassen, 2016), and market demands as well as uncertainties regarding future legislation causes uncertainty within the business regarding the use of recycled PVC.

As of June, 2016, EU member states have agreed to authorise the continued use of DEHP in recycled soft PVC for certain applications until February 2019. The authorisation is given to three companies out of which one is Swedish (EU, 2016).

In a recent guidance document, funded by the IVL foundation and the Swedish Floor Industry regarding PVC floors treated with DINP and DIDP, it was recommended that DINP and DIDP may be accepted in floors when they are derived from recycled material, due to the potential high gains in climate savings. Estimates indicated that exposure levels deriving from release of DINP from floors are approximately 2500 times lower than levels for tolerable daily intake proposed by the European Food Safety Authority, EFSA (Cousins and Lindholm, 2016).

According to Duberg at Tarkett, there are two main options for recycling post-consumer PVC-floors. Either to find techniques to entirely remove undesired substances or find applications where there is no risk of harmful effects (Duberg, 2016). The first option focusses on technical development, whereas the second option addresses a change to a risk-based way of thinking when defining appropriate uses for recycled products.

An example of the latter option is given by Arbeitsgemeinschaft PVC-Bodenbelag Recycling (AgPR), a company established by PVC producers, who down-cycle PVC into e.g. park benches and pallets, with low likelihood of leading to high chemical exposure (AgPR, 2015). An example from Sweden is that some of the Tarkett post-consumer PVC is recycled into traffic cones.

An example of the first option is VinyLoop, a physical plastic recycling process for PVC, which uses organic solvents to dissolve the plastic completely (VinyLoop, 2013). The plastic can thus be separated from other materials such as polyester, textile, rubber and other plastic types. It can also separate the PVC plastic from additives e.g. softeners, fillers, stabilisers and pigments.

However, this is currently not conducted in a large scale due to the high cost (three times higher than for virgin PVC), and today it is not possible to separate the plastic from all other material (Golvbranschen, 2016). The method is used to soften PVC floors and plastic in cables and pipes where the latter constitutes of 70-80 percent of the waste inflow to the company (Elander and Sundqvist, 2014). According to VinyLoop the quality of the rPVC is comparable to that of virgin material. Further, according to an LCA study conducted on behalf of VinyLoop, the process reduces climate impact by 40 percent compared with virgin PVC (Elander and Sundqvist, 2014). IKEM, Innovation and Chemicals Industry in Sweden have applied to launch a VinyLoop facility. At the time of writing no notification has yet been made regarding the launch of such a project. According to the reference group (Referensgruppsmöte, 2015), pyrolysis can also be used for separating hazardous substances from PVC, a technique that turns the plastic into oil by degrading the organic content but not the heavy metals. The problem with such methods is however the high energy demands.

A Danish project attempts to recycle PVC waste from construction and demolition (such as pipes, gutters, cables and shingles) to use in cultivating food in city environments (Mentor_Newsroom, 2016). PVC is mentioned as suitable for hydroponics, a type of cultivation where plants grow in water, in a closed system without the need of soil. Since PVC waste from construction and demolition may contain a number of hazardous substances, these kinds of application should be preceded by thorough testing to ensure that no undesired chemicals may leach into soil and be taken up by the plants. Other applications, such as those mentioned above, are preferred options since they require very limited testing to ensure safety.

According to Duberg (2016), the following is needed for increased recycling of post-consumer PVC-floors:

- Cost and time effective quality control techniques that can be applied at an industrial scale.
- Increase risk assessment approaches and discussions determining when a material is recyclable or not with regard to the content of hazardous substances. A suggestion is to increase communication between the National Board of Housing, Building and Planning and the Swedish Chemicals Agency. Post-consumer PVC could for example be used in applications such as pipes, components for the automobile industry, wind turbines, tank covers etc. besides being recycled into new floors.
- Management of post-consumer waste contaminated with glue/fillers and unknown content/brand/manufacturing year. (AgPR has developed a separation technique for glue and fillers and VinyLoop has also managed to separate PVC from glue, nail and other contaminants). Post-consumer waste can also be affected by detergents and other chemicals during their 10-20 year product life.
- Development of large scale and cost effective separation techniques for hazardous substances in PVC.
- Development of logistical solutions. The collection time is crucial in terms of removing fractions from B&C sites due to lack of space and the relative low value of the material.
- Economic incentives in favour of recycling to create a functioning market for example removing taxes on the secondary material (as it has already been paid in the first cycle) and for leasing functions. The recycling of PVC spillage waste is today a financial loss.
- New business models for leasing/lending floors instead. Selling floor functions instead of the actual product would create incentives for increased recycling.
- Integrating PVC spillage collection in the work process of waste management companies.

5.1.3 Recycling of EPS

Regarding EPS insulation material specifically, the material could be recycled if not contaminated with hazardous substances or cement attached from the construction (EUMEPS, 2016).

For the EPS material there is a functioning recycling technique. EPS packaging material is today recycled in relatively large scale. In Europe, 136 000 tonnes of EPS is generated from the construction sector and 60 percent is recovered out which 7.5 percent is materially recycled, the rest energy recovered (Meuwissen, 2016). The generated waste that is not recovered in any way (40 percent of generated waste) the treatment is most likely landfilling. EPS Recycling International recycles EPS packaging into e.g. hardwood replacement for garden furniture, slate replacement for roofing tiles as well as new plastic articles such as coat hangers and CD and video cases (EUMEPS, 2013). Nine Lives Products has developed a glue product made from recycled polystyrene and plant-based ingredients as another example (EPS_Industry, 2013).

The problems linked to increased recycling of EPS used in construction is thus not limitations in the recycling technique itself but rather the limitations are linked to contamination and logistics of the material as is explained below together with opportunities in new separation techniques being developed.

5.1.3.1 Hazardous substances in EPS insulation

The main issue concerning hazardous substances in EPS insulation regards the content of brominated flame retardants, more specifically hexabromocyclododecane (HBCD). Recycling of contaminated EPS insulation waste will not be possible if HBCD is not first separated from the material (EUMEPS, 2016). Therefore, conventional recycling used for EPS packaging material is not possible when HBCD is present. Waste containing HBCD should be treated as hazardous waste and therefore be sent to destruction.

According to the Stockholm Convention on POPs, HBCD is a persistent chemical with abilities to bioaccumulate and biomagnify. The production of HBCD has decreased over the last years and replacement for the flame retardant is available on the market for high- impact polystyrene and textile back coating.

In Sweden the majority of the EPS does not contain flame retardants (Palm et al., 2002, EUMEPS, 2016). According to Palm et al. (2002), 1 percent of the EPS-production was flame protected in the early 00’s (0.5 percent concentration) and in Sweden most was used for insulation of blocks of apartments. EPS produced after 2005 does not contain HBCD (Sternbeck et al., 2016).

Deca-BDE[27], a flame retardant included in the REACH candidate list, have also been used in EPS insulation and packaging. According to Sternbeck et al. (2016), EPS insulation produced before 2002 may contain 2-28 percent of the hazardous substance. As of 2008 no use of the substance has been registered in the Swedish Product’s Register (Sternbeck et al., 2016).

[27] Decabromodiphenyl ether

5.1.3.2 Obstacles

A project funded by the German Ministry of Trade and Employment coordinated by Fraunhofer IVV has the aim to develop a recycling process for contaminated EPS waste (such as construction waste) and to develop a logistics plan for a cost effective transport of the EPS (Fraunhofer_IVV, 2016). They have identified the following obstacles in recycling EPS from construction waste:

- High transport costs because of low bulk density of 6.5 kg/m^3. Improved logistics is needed.
- Poor effectiveness in purification processes and low economic viability makes it difficult to produce high quality recyclate from contaminated EPS. This is why most contaminated EPS waste is incinerated and only a small fraction is used in milled products for use in floor leveling, insulation bricks or recycled into polystyrene recyclate for injection molding.
- Content of hazardous flame retardants. Due to mixing of materials, some EPS containing brominated flame retardants end up in other product areas such as packaging (Fraunhofer_IVV, 2016). Brominated flame retardants are however scarcely used in Swedish EPS insulation.

According to the European Manufacturers of EPS Spare Parts (EUMEPS, 2016), other obstacles than those stated above include:

- Inadequate demolition and sorting processes to obtain a pure fraction fit for recycling. E.g. EPS is a foamed product which may easily be confused with other foam-material and there is a need for trained eyes to be able to separate the material.
- In Europe, there are significant infrastructural problems as there are regional differences in the attitude towards recycling e.g. there is a lot of EPS waste in Spain but a proper collection system is missing. Some parts of Europe have a different mindset on recycling and there is a need for improved communication with authorities stating that it is worthwhile to recycle plastic.

Regarding the issue of contamination, separation techniques need to be developed not only for separation of HBCD, but also for the cement attached to the material. Further, although aging affects the EPS material due to air exposure and the long life of the product, the change is not considered a problem regarding the applications EPS is used for today (EUMEPS, 2016).

5.1.3.3 Opportunities

The project on recycling contaminated EPS by Fraunhofer IVV aims to find solutions to the aforementioned obstacles concerning transportation costs, economic viability and purification(Fraunhofer_IVV, 2016). The obstacles are addressed accordingly:

- The high transportation cost will be decreased by lowering the EPS volume. This is done by dissolving the volume by a factor 50. The solvent used is not under any declaration requirements from the EU.
- The recycling process is done through the CreaSolv® process involving selective dissolution of EPS, purification of unwanted materials such as cement and contaminants such as brominated flame retardants and precipitation of the purified EPS(Fraunhofer_IVV, 2016).

In the same process, it is possible to convert HBCD into bromine and reuse the chemical in other processes (EUMEPS, 2016). According to Fraunhofer IVV, the recycled EPS is comparable to that of virgin EPS even if contaminated EPS is used as the in-put and will thus create more value than other grinding recycling processes or injection molding polystyrene applications (Fraunhofer_IVV, 2016). The process is however only at its pilot-stage and a few 100 kg is expected to be treated in the facilities. A new consortium based in the Netherlands is attempting to realize an industrial plant using this process with planned first cycles in 2018 (EUMEPS, 2016, Fraunhofer_Institute, 2016).

According to EUMEPS (2016), prohibitions such as the one regarding HBCD in REACH regulation may drive the industry to innovative solutions although the industry might prefer not having such prohibitions at all. This might very well be the case when regarding products of high economic value such as plastic compared with material of lower economic value as the economic incentive to recycle high-value materials is more significant.

5.1.4 Recycling of plaster products

There is a functioning recycling process for plaster products today. As mentioned in section 2, 63 percent is today recycled in Sweden.

5.1.4.1 Hazardous substances in plaster products

A report from Kemikalieinspektionen (2015) states that plaster boards or plaster boards in combination with color or glue might contain organic substances such as toluene, phenol, styrene and 2-ethyl hexane acid. Emissions from an entire wall-complex might differ from emission from the different separate materials and as such KemI recommends emissions' testing to be conducted on authentic material combinations. Plaster might also contain naphtalene and vinyl acetate (Kemikalieinspektionen, 2015). The authors of the same study however regard plaster and plaster board to most part meet the health-based limits.

Although rare and prohibited in use today, plaster waste may also contain asbestos (asbestos discs) or lead from lead paint. The lead paint can be found in the cardboard/paper material in a plaster board and it is possible to separate the plaster from the paper in the Gips recycling process, however it demands separate handling of the paper and therefore is it not practical or economical (Lassen, 2016).

5.1.4.2 Obstacles

According to the Swedish Construction Federation, the plaster must be clean, dry and without any contamination from glue residue when collected for recycling. According to Gips Recycling plaster that cannot be recycled includes contaminated plaster, wet plaster and plaster that have been heated to 250 °C or higher (Lassen, 2016).

The most significant obstacles concerning recycling of plaster products is according to Lassen (2016) economical: it still costs less to landfill the waste. Although the handled volumes are increasing, the price development has not had the same rise due to increasing competition, both legal and illegal according to Lassen (2016). Lassen also communicates that recycling of plaster is not prioritized by authorities in Sweden as there are limited numbers of approved facilities for collection of plaster waste.

According to Lassen (2016) the closer sorting occurs to the demolition site, the purer the waste fractions are. When demolishing an entire wall (without selectively separating the material) other materials such as plastic pipes, wood and metal are not separated from the plaster boards. Often the wall complexes are handled by a waste treatment facility where an excavator is used and as plaster is a porous material, not much is left for separate collection for recycling and most is landfilled. More plaster could thus be recycled would the walls be selectively demounted on site, similar to the method used by Meason.

When deconstructing old buildings plaster often sticks to bricks, which makes the recycling of gypsum difficult. Gypsum construction waste consists typically of cut off pieces of plaster and boards as well as boards damaged during e.g. transport to the building site. However, contamination with other materials (e.g. paint, fastenings, screws, nails, wood and insulation materials) can make recycling of gypsum waste difficult. Selective demolition of gypsum-base material is hard to carry out, which results in a large fraction of mixed waste ‐ containing gypsum ‐ that cannot be recycled properly.

5.1.4.3 Opportunities

According to Gips Recycling construction spillage is rare today as many companies order the plaster boards by measures to avoid unnecessary wastage (Lassen, 2016). 95 percent of the plaster that Gips Recycling manages comes from demolition sites and municipal recycling stations. Larger construction companies deliver their plaster waste to Gips Recycling themselves.

The process used by Gips Recycling accepts up to 2 percent contamination. An optical examination is made on incoming material and if requirements are not met the waste fraction is sent back to the deliverer. Bigger pieces of contaminants are removed manually prior to the automated recycling process (Gips_recycling_Sverige, 2016).

Gips Recycling does not accept plaster boards containing asbestos or lead. Asbestos has been found on very few occasions and in such cases, the asbestos discs are optically identified and sent to destruction. Tests are also made by the recipients of the recycled plaster (Lassen, 2016). The cases with asbestos have arisen from collection at recycling stations. Coloring buildings with lead paint was mainly done during the 60-80’s. When Gips Recycling is to receive large quantities of demolition waste, the routine is to ask for the buildings’ construction year. If the buildings were built during the aforementioned period, plaster is sent for lead testing before the waste is accepted into the recycling process.

According to Lassen (2016) aging does not affect the plaster significantly. However, weather conditions such as rain, wind and sun does, especially if the plaster is exposed to salt water. This is why containers with a protective roof are used in the collection system. The recycling processes further need material that is not too crushed as the machine needs certain resistance in order to crush all the input material (Lassen, 2016).

Lack of space is a common problem related to increased recycling at demolition sites as previously mentioned. According to Gips Recycling, the issue can be managed with careful planning. Many times the demolitionists know when in the process the plaster boards are going to be demolished. Gips Recycling can then place a container at the site during this specified time frame. In this period, only plaster boards are demolished, thus only one container is in place before substituting it for another. Another solution used by Gips Recycling has been to use Bigbags (1 m^3). 10-15 Bigbags are collected at the same time once they are filled.

From 2013 to 2015 a European project was carried out in collaboration with the recycling industry, the demolition sector and the gypsum industry. The Gypsum to Gypsum (GtoG) project resulted in a European handbook on the best practices for deconstructing gypsum-based products as well as a European manual for best practices in audit before the deconstruction of buildings (Gips_recycling_Sverige, 2016). The handbooks have derived from results of deconstruction projects in Belgium, France, Germany and the UK and the aim is that these handbooks is to become standard guidelines in eco-efficient demolition for European demolition companies in accordance to the Waste Framework Directive (Gips_recycling_Sverige, 2016).

5.1.5 Recycling of flat glass products

Like with plaster recycling, there is a functioning recycling system for flat glass waste today. About 45 percent of the generated flat glass waste from construction and demolition is today recycled leaving room for further improvement.

5.1.5.1 Hazardous substances in flat glass

As previously mentioned, seal mass used for insulating glass of older type may contain PCB. In order to ensure that no PCB reenters the glass when recycled, all PCB containing window frames must be identified before demolition and managed as hazardous waste.

5.1.5.2 Obstacles

In a study carried out by the Swedish Waste Management association (Hallberg and Grönholm, 2008), windows were collected in a recycling central and 6 percent of the insulation windows manufactured between 1956 and 1980 were found to most likely contain PCB. The study states the importance of source separation of PCB contaminated windows in order to recycle non-contaminated glass.

In the same study, window glass with window frames are stated as difficult to separate and recycle as most window frames are made from treated wood (hazardous waste). The quality demand set by the glass industry lead to a too costly recycling process. According to the study, one possible application is to use crushed glass for drainage when covering landfills (Hallberg and Grönholm, 2008).

Today approximately 10 000 tonnes of flat glass is recycled through SGU (the number includes flat glass from municipal businesses, glass producers, recycling stations and car dismantling businesses). However a significant amount of flat glass from demolition sites is still landfilled and according to SGU the main obstacle for increased glass recycling concerns legislation i.e. it is still allowed to landfill glass (SGU, 2016). This is for example done when the transportation costs are higher than the cost to landfill. According to SGU, the landfill cost for glass is not sufficiently high (SGU, 2016).

Another obstacle communicated by SGU is the insufficient quality of the fractions sorted at the demolition sites (too high levels of other materials than glass). Stone can for example cause problems in the recycling process but is sorted out both during collection and prior to recycling. Heavily contaminated fractions collected for SGU might in the worst case scenario be sent for landfill as it is too costly for the company to sort the waste.

5.1.5.3 Opportunities

According to SGU (SwedeGlass_United, 2016) both pre- and post-consumer flat glass waste can be recycled. Recycled glass can be used for original applications just like virgin glass. The advantage of recycling pre-consumer waste though is that the glass is surely not PCB-contaminated as PCB is no longer used in new construction. SGU does not accept PCB-contaminated glass into their recycling process. Besides PCB-contaminated glass, heat resistant glass (e.g. oven-doors) and crystal glass are types of flat glass that cannot be recycled. The process is able to sort out non-glass materials e.g. plastic and metal from the input fraction. The plastic and metals are sent to material recycling. 1-2 percent out of the input material goes to incineration or landfill.

SGU states that the demands set on building contractors and demolitionists play an important role as to the sorted amounts on-site and the quality of the sorted material. SGU’s demands include no PCB-containing glass and as pure fractions as possible (wood and metal should be sorted out). SGU sends samples to a laboratory for quality control. The drivers behind the demands according to SGU are the prevention of spreading hazardous substances, suitability for the material recycling process and to meet demands from the glassworks that use the recycled material in their production.

Historically the value of recycled glass has increased over time since many are now aware of the possibility of recycling and thus the demand on recycling has increased (SGU, 2016). The price the customer pays for SGU handling of the glass has decreased over time. The price is set after quality, volume and location.

5.2 Summary

5.2.1 Recyclability of selected products in their current condition

This chapter summarizes the recyclability of the selected building products. Table 3 shows if there is an available recycling technique for the building product. The table does not take alternative applications into consideration. As shown in the table, all building products have an available functioning recycling technique.

The picture is however different regarding need for separation techniques for hazardous substances and other contaminants. As previously stated in Table 1, both plaster boards and flat glass already have a relatively high recycling rates although there is still room for significant improvement. The recycling of the two building products do not require further development of separation technique as shown in the table below which is partly connected to the higher recycling rates. Contaminants such as asbestos and lead can be separated from the process of plaster board recycling using current methods. Flat glass recycling does neither require further separation as PCB-containing glass is separated and not included in the recycling process.

As for PVC floor and EPS recycling, generally the content of hazardous substances requires further development of separation techniques for use of recycled material in new products for the original application. However, a proper risk assessment could make it possible to recycle the material for other applications that would limit the risks associated with the harmful content. Column 3 in the table below presents possibilities to increase recycling of the building products. Flame retardants in EPS-insulation have been scarcely used in Sweden meaning it would be possible to recycle Swedish EPS insulation waste without development of separation techniques. However, it is most likely not economical to collect, sort and recycle such limited amounts. Regarding plaster boards and flat glass the main obstacle against increased recycling is that landfilling the material is still in many cases more cost effective than recycling. Here, a landfill ban or higher landfill costs for the specific products would increase recycling rates.

Table 3. The table shows if the building products are recyclable in their current condition and whether or not there is a need for further development of separation techniques in regard to hazardous substances and other contaminants. Column 2 does not take hazardous substances/contaminants into consideration but merely states that a recycling technique is currently available.

Building product	Recycling technique available today*	Need for separation technique development for hazardous substances and other contaminants	Need for increased recycling with current available technology	Comment
PVC-floor	Yes	Yes	**Selective demolition.** Risk assessment considering alternative applications for recycled material.	Post-consumer flooring is today difficult to market due to a) legislation concerning hazardous substances b) lack of control of downstream uses, required to estimate risks posed by hazardous substances and c) market demands
EPS-insulation	Yes	Yes	**Selective demolition.** Recycling of only Swedish EPS-insulation waste or risk assessment considering alternative applications for recycled material.	Recycling not possible if not first separated from brominated flame retardants. In Sweden the use of brominated flame retardants is however very limited. Recycling could potentially be hindered due to construction obstacles (e.g. co-construction with concrete materials)

Plaster boards	Yes	No	**Selective demolition.** Incentives to increase collection for recycling e.g. higher landfill cost or landfill ban for plaster products.	Hazardous substances within health limits and asbestos and lead can be separated with available method. In many cases it is still more cost-effective landfill plaster.
Flat glass	Yes	No	**Selective demolition.** Incentives to increase collection for recycling e.g. higher landfill cost or landfill ban for plaster products.	PCB containing window glass is separated. High transportation costs might hinder the fraction from being recycled as landfilling is more economical in many cases.

*with no regard to separation of hazardous substances and other contaminants.

5.2.2 Applications for recycled material

As mentioned previously, Table 3 does not take into consideration the use of recycled material for other alternative applications. The study has presented some alternative applications; both applications that recycled materials are used in today as well as identified ideas for other applications, as summarized below:

- rPVC can be recycled into traffic signs, traffic calming products, road cones, foil for construction and hoses. It can also be recycled for use in park benches and pallets. PVC floor installation waste containing phthalates can be used in bottom-layers of floor sheets. Other possibilities for rPVC applications are components for the automobile industry, wind turbines and tank covers. An example of alternative applications was also given by the Danish project regarding the use of construction and demolition PVC waste for cultivation of food in city environments using hydroponics.
- EPS packaging material can be shredded for production in road construction or used in tile production. This type of recycling is not present in Sweden. Packaging EPS can also be recycled into hardwood replacement for furniture, new plastic articles such as coat hangers and CD and video cases. There is also one example of glue production from recycled polystyrene.
- Recycled flat glass is used in various applications comparable to virgin glass applications.

6 Methods for hazard and risk assessment in the recycling process

One of the factors that limit recycling of building products is the concern regarding potential hazardous substances contained within the products. This becomes particularly evident when it concerns plastic materials, which are often treated with additives in order to modify the properties of the material. Elander and Sundqvist (2014) and Sundqvist et al. (2013) identified a number of issues connected to hazardous properties which hinder recycling. These include: a) uncertainty regarding the use area of the recycled plastics b) low material value of recycled plastics c) lack of separation of unwanted substances and d) lack of knowledge on hazardous properties of chemicals in plastics. This latter point does not imply that there is a 'general' lack of knowledge, rather that the downstream users of recycled materials do not always possess adequate expertise on toxicity, hazard and risk assessment of chemicals, combined with that the chemical content of a bulk waste fraction is often unknown.

There are a number of systems and tools available that may be applied in order to judge whether sustainable and low-risk recycling of building materials is possible. Most of the currently existing systems use a conservative approach and focus on hazard to ensure that materials approved do not contain chemicals with properties that are considered problematic. The motivation for this is that the systems themselves cannot foresee the various uses and conditions that a material may undergo, which could potentially lead to unacceptable exposure. In the following, we describe some of the tools available and highlight the need for additional tools.

6.1 Voluntary systems for reducing hazardous chemicals in building products

There are three national, voluntary systems aimed to reduce the use of hazardous substances in building materials: Byggvarubedömningen, SundaHus and BASTA. These systems apply to finished articles and not to waste fractions. However, they are still relevant from two perspectives when it concerns recycling of building products:

1) Waste fractions may be evaluated to check if they meet the requirements of these systems. This, however, requires that the chemical content of the waste fraction in question is known
2) Future waste fractions may to an increasing extent be certified in one of these systems, which in the long-term perspective will improve the traceability of safe materials and facilitate future recycling processes.

All these systems provide some form of quality stamp which certifies that the product fulfils the specific requirements of the system. However, the exact requirements differ between the systems and are described in short below:

6.1.1 Byggvarubedömningen

Byggvarubedömningen is an economic association founded by some of the major actors on the Swedish construction market. The system includes information on chemical content as well as and environmental assessment of the product. The assessment is based on chemical content, raw material content, production stage, transport and packaging, the uses stage, demolition and waste and indoor environment and assesses properties such as chemicals toxic properties, but also recyclability, toxic waste generation, climate impact, emissions of formaldehyde and total volatile organic carbon (TVOC). For each category a number of criteria are assessed and judged according to three levels of performance: recommended, accepted or to be avoided. The overall performance of the product is judged and weighted according to a certain scheme(Byggvarubedömningen, 2014):

- **Recommended,** requires that:
  –All criteria on chemical content are judged as *recommended*
  –No life cycle criterion is assessed as *to be avoided*
  –At least 50 percent of the relevant life cycle criteria are assessed as *recommended*
- **Accepted,** requires that:
  –No criterion on chemical content is assessed as *to be avoided*
  –The number of life cycle criteria assessed as *to be avoided* cannot be higher than 1
- **To be avoided,** requires that:
  –At least one criterion on chemical content is assessed as *to be avoided*
  –At least two life cycle criteria are assessed as *to be avoided*

6.1.2 SundaHus i Linköping AB

SundaHus was founded in 1990 as an independent consultancy company aimed to support customers in the building and construction sector in choosing sustainable materials and to reduce and prevent the spreading of hazardous chemicals in the society. SundaHus uses a web-based system and offers counselling to help customers to systematize their work to phase out hazardous substances in a building's lifecycle. Their systems covers the entire life-cycle of a construction project, from planning to demolition and uses specific assessment criteria, which are based on the rules of the Swedish Chemicals Agency KIFS 2005: 7 classification and labelling, the European Parliament and Council Regulation (EC) No 1272/2008 and the Swedish Chemicals Agency prioritization guide PRIO. The majority of the criteria are based on chemical content but also some other aspects are assessed, such as waste and technical lifetime. Products are than judged on a scale from A-D, according to specified criteria, where A is highest performance and D means inadequate information (SundaHus, 2013).

6.1.3 BASTA

BASTA origins from a project initiated by four of the main contractors in Sweden – JM, Peab, NCC and Skanska. BASTA is a non-profit organisation jointly owned by the Swedish Building Industry and IVL Swedish Environmental Research Institute – the system contains two separate registers; BASTA and BETA, which are both based on chemical properties, i.e. a hazard based system which does not take exposure or risk into account. The criteria are based on the European Chemicals Legislation REACH. By registering their products in BASTA, the supplier guarantees that the product does not contain chemicals “with properties according to agreed criteria at concentrations equal to or above specified limits”. The supplier does not have to reveal the chemical content, instead the system is validated by third-party audits of the companies responsible for the registration. In addition to the register, BASTA also offers a web-based construction journal or a logbook, which is required to achieve certain environmental certifications such as Miljöbyggnad. To obtain the highest level in these certification, the logbook has to include information on the weight and placement of materials in the building.

6.1.3.1 The BASTA-register

The BASTA register contains articles and products that meet the systems more stringent chemical composition criteria. In addition the supplier has to certify that their products meet the demands of the system at any given point in time; that there is documentation to verify this; that there is a structured organisation clarifying the hierarchy of responsibility on the issue; and that the supplier has the qualifications needed to deal with the BASTA registration criteria (BASTA, 2016a).

6.1.3.2 The BETA-register

The BETA-register contains articles and products that meet the systems basic chemical composition criteria, which are less stringent than the BASTA criteria. As these criteria are less stringent than the BASTA-criteria, products registered in the BETA–register may be associated with risks. The supplier must therefore specify which BASTA-criteria the product does not meet" In addition the supplier has to provide information for risk evaluation and risk management during construction, use, demolition and waste stage; that their products meet the demands of the BETA system at any given point in time; that there is documentation to verify this; that there is a structured organisation clarifying the hierarchy of responsibility on the issue; and that the supplier has the qualifications needed to deal with the BETA registration criteria (BASTA, 2016b).

6.2 Other hazard assessment tools - The Green Screen method

The systems described above are all based on chemical properties and they are specifically aimed at reducing and phasing out problematic substances in building products. Within this project, we have evaluated an alternative method to assess recycled materials, which may be used to guide recyclers of a material into beneficial use areas – the GreenScreen method, and applied it to PVC plastics as an example (see Appendix). The conclusion of this exercise was that it has a similar function as the voluntary systems described above, and may be used to rank different products based on their chemical content, i.e. for a certain application it can help cust omers to choose the most sustainable option from a chemical perspective, or for producers to select chemicals for a certain function. It does not, however, provide a risk assessment module that takes use and potential exposure into account, and can thus not be used to direct recyclers into the most sustainable suitable uses of a certain recycled material. Therefore, the GreenScreen method can be viewed as an alternative or as a parallel method to the existing voluntary systems, but not as a complementary method.

6.3 Risk based approaches for environmental product assessment

The above mentioned systems are focussed on hazard, thus they cannot be used to assess whether use of a recycled fraction, with potential large savings in terms of energy, resources and money may pose a risk to health and environment. For this, different approaches are needed. In order to assess the risks of recycled building products it is important to consider the perceived use of the material and to estimate the risks associated with exposure to the chemicals incorporated in the products. A prerequisite to safe and successful recycling that minimises risks from hazardous chemicals is that the demolition and sorting process is material specific; in a mixed fraction any kind of material recycling will be problematic and the only potential recycling options would be in the form of landfilling or energy recovery (i.e. combustion). In essence two aspects of risk have to be considered in the assessment of recycled products:

- Absolute risk – i.e. the likelihood of an effect occurring at the site of production and/or use. This has to be assessed to ensure that no unacceptable risks are expected to occur at the site of exposure
- Relative risk from a life-cycle perspective – i.e. the size of relative toxicological effects compared to other products and other environmental impact categories. This should be addressed when comparing the overall environmental impact between recycled products and products made from virgin materials, and also to compare toxic impact to other environmental impact categories

Systems and tools for such assessments are already available and are described briefly below.

6.3.1 Assessments of absolute risks

The absolute risk associated with the use of a product, in this case a product made from recycled materials, should be assessed, ideally following the guidelines for exposure scenarios set up under REACH (ECHA, 2014). Although the exposure scenarios are aimed primarily for chemical products similar procedures can be applied to products, providing that chemical content and release patterns are known. The REACH guidelines provide examples on how this can be done, for example with the help of the chemical safety assessment and reporting tool Chesar[28], a procedure that may need to be modified slightly for application to products. In the following, we describe briefly the key elements of such an assessment applied to recycled products (also illustrated in Figure 5).

- The chemical content of the product
  - The minimum requirement for conducting such an assessment is to obtain knowledge of the chemical content which requires reliable documentation or chemical analysis of the raw material (i.e. the recycled fraction). In the longer term, upstream documentation and introduction of material logbooks may provide enough information and even reduce the need for risk assessment, but to date, this information is not readily available, and thus chemical analysis may be needed.

[28] https://chesar.echa.europa.eu/

- The analysis should primarily focus on chemicals which are banned or regulated for the product type of interest, to ensure that legal requirements are not trespassed. The second priority is to target chemicals which have hazardous properties, but are not regulated. A good starting point for this is ECHA's candidate list. However, it is usually not necessary to test for all chemicals on the list, since many chemicals are material specific. Clearly, there is a need for analytical laboratories to develop material specific "analysis packages" which are in line with EU legislations and product specific rules and which could be utilised by the sorting and recycling industry to market their waste fractions to downstream users.
- If the product does not contain any of the specified chemicals, it should be considered safe to use.

- Toxic properties of the chemicals and associated risk levels
  - If the material contains chemicals with problematic properties, their toxicological profiles should be compiled, including the associated risk levels (TDI or PNEC-values), which may be found in the database of the European Chemicals Agency (ECHA)[29].
- Use conditions
  - The perceived use of the product should be identified, whether it is indoors, outdoors, in close consumer contact or in contact with flowing media (air or water).
- Emissions
  - Emissions are dependent on the properties as well as the use conditions. For recycled products, the most relevant life-cycle stages are during processing and re-design as well as during end-use. Ideally, empirical measurements through emission testing under relevant use conditions should be performed. If adopted, the proposed national regulation for use of hazardous substances in building products (Kemikalieinspektionen, 2015) will be an important contribution to the decisions on what types of testing that should be done. Other tools that may be useful, especially in the lack of test results are specific environmental release categories (SPERCs) as developed under REACH (Reihlen et al., 2016) or emission models such as the one developed within the ChEmiTecs programme (Holmgren et al., 2012). As a last option, the OECD model (OECD, 2009) may be used to address emissions during end-use of products. When quantifying emissions, the receiving matrix has to be specified in order to calculate exposure.
- Exposure
  - Once emissions have been defined the next step is to calculate the exposure, which may vary depending on the use area. For example, if the product is aimed for indoor use, the concentrations in the indoor environment need to be assessed, followed by an estimate of daily intake via relevant pathways (breathing, dust ingestion etc.). Exposure assessments usually requires some kind of fate model, where concentrations are calculated based on properties of the chemical, the environment and the emissions. Recommendations on default exposure values for Nordic conditions are given in Höglund et al. (2012). An even wider compilation of available information on exposure factors from a global perspective is given in Zaleski et al. (2016)
- Risk evaluation
  - In the final step, the calculated exposure of chemicals derived from the product of interest should be compared to critical risk levels. In this assessment, it is important to take into

[29] https://echa.europa.eu/information-on-chemicals/registered-substances

account the "background" exposure to the chemical in question to ensure that the added exposure does not create a tipping point in the overall exposure. For example, if the background exposure from other sources (food, air etc.) is already near critical levels, additional exposure may lead to critical levels being exceeded.

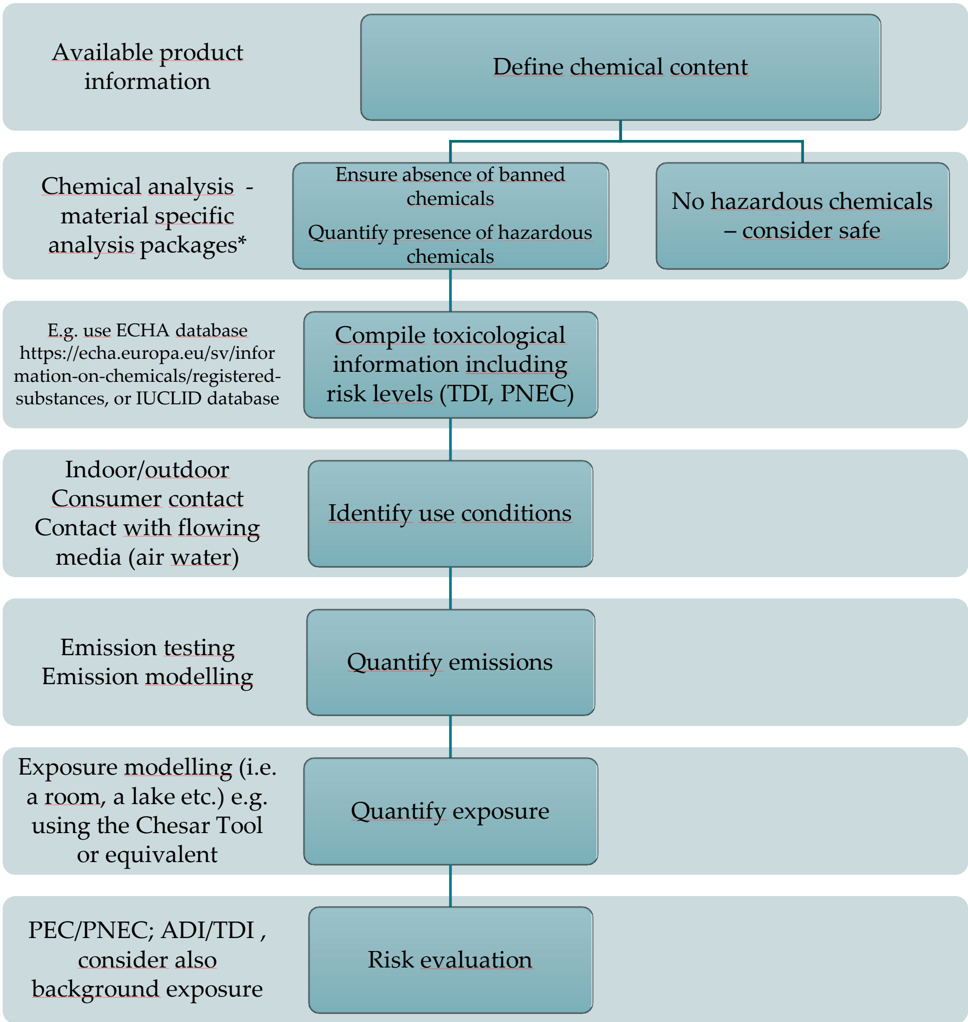


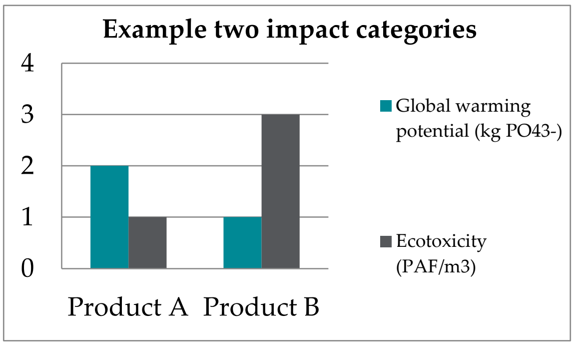
Figure 5. Key elements needed to conduct absolute risk assessment of recycled products. *Material specific analysis packages are currently not available on the market to our knowledge but present a development need in order to enable full assessments of recycled products.

6.3.2 Assessment of relative risks using a life-cycle perspective

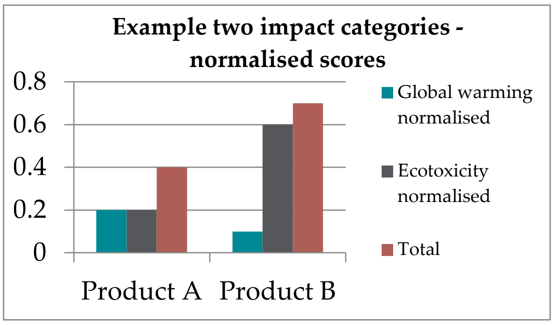
An assessment of relative risks is essentially a lifecycle impact assessment, where the lifecycle of a recycled product starts with the processing and re-formulation of the recycled material (i.e. primary production of the materials is not considered). This assessment is of particular interest for marketing to assess the environmental impact (and/or benefits) of products using new potential raw materials compared to "conventional" production processes and materials. The prerequisite for this assessment to be done is that no absolute risks have been identified (see 6.3.1). Again, a minimum requirement is that the chemical content of the recycled product and its production alternatives is known, which may require material-specific chemical analysis.

By combining life-cycle assessment tools with toxic impact assessment tools it is possible to compare environmental benefits and toxic burdens of recycled products with newly produced products. One option to do this is by following the guidelines in the international Environmental Product Declaration EPD® system where specific rules have been defined for different types of products (Product Category Rules – PCR). As such the EPD system provides a framework for environmental product assessment, which also allows for expansion and a certain number of degrees of freedom. Naturally, these assessments can also be conducted independently. The crucial steps of the assessments are outlined in Figure 6, and are briefly described here.

- Define functional unit
  - Since chemical risk assessment includes the element of exposure, the impact assessment has to be conducted for the end product, rather than for the waste fraction, since the end product is the one that might generate exposure. It is also the end product that is the target, and where various production options may apply. Thus the functional unit has to be defined, which may be something like: "a wall element with a lifetime of 20 years" years" or: "an industrial kitchen floor with a life-time of 20 years".
- Define possible raw materials and production processes
  - Here options for raw materials and production processes should be defined. If the recycled material replaces virgin material the differences between the recycled product and the alternatives should be specified, including differences in the production processes
- Conduct life-cycle inventories including chemical content and emissions
  - This is the most time-consuming part of the assessment. Here all the material and energy consumption as well as emissions of target substances should be documented for the recycled product as well as the alternatives. This should include chemicals as well as climate gases and other crucial LCA elements (e.g. SO_2, PO_4^{3-}).
- Conduct LCA and LCIA for relevant impact categories
  - Once all the relevant inventory data has been collected, a lifecycle assessment as well as a life-cycle impact assessment should be conducted using suitable software. For the latter we recommend the Use-Tox consensus model (Rosenbaum et al., 2008), which is endorsed by the UNEP/SETAC Life Cycle Initiative for characterizing human and ecotoxicological impacts of chemicals. The model takes into account fate, exposure and effects of chemicals and includes a large set of chemical data.
- Normalise against environmental objectives or planetary boundaries
  - The output of an LCA and an LCIA can be used directly to compare products if considering one impact category at a time, but what happens if product A performs better in one category and worse in another compared to product B (see example figure to the right)?



– Here we suggest that the impact factor of each category is normalised against a pre-defined environmental objective, which could be based on regional environmental objectives (e.g. the Swedish Environmental Objectives) or on global targets, as defined by e.g. planetary boundaries. This is currently an area of development and so far, reference values based on "carrying capacity" have been proposed for a number of impact categories (Bjørn and Hauschild, 2015), and further development is undergoing within the UNEP framework (Bjørn et al., 2015, Ryberg et al., 2016). An alternative to global targets could be to use national targets, as illustrated by e.g. (Erlandsson and Almemark, 2009) who compared the environmental impact of creosote impregnated wood poles to alternative materials including steel and concrete. In brief, the impact scores are normalised against national environmental goals using a normalisation factor which is defined as "critical impact per unit" and is based on national or global environmental targets and scaled to the appropriate unit (e.g. per person, per kg, per product), to illustrate the impact on the environment relative to a tolerated level. In this way, the impact factors obtain the same units and can be compared against each other, or added to obtain a total environmental impact (see example figure to the right). The minimum requirement is that no impact score exceeds its critical level.



- Comparison and final evaluation
  – In the final step, the normalised impact scores are compared and decisions are made regarding which is the most environmentally sound alternative, considering all environmental aspects. Additional economic calculations may also need to be performed, but should be used for company specific internal work only.

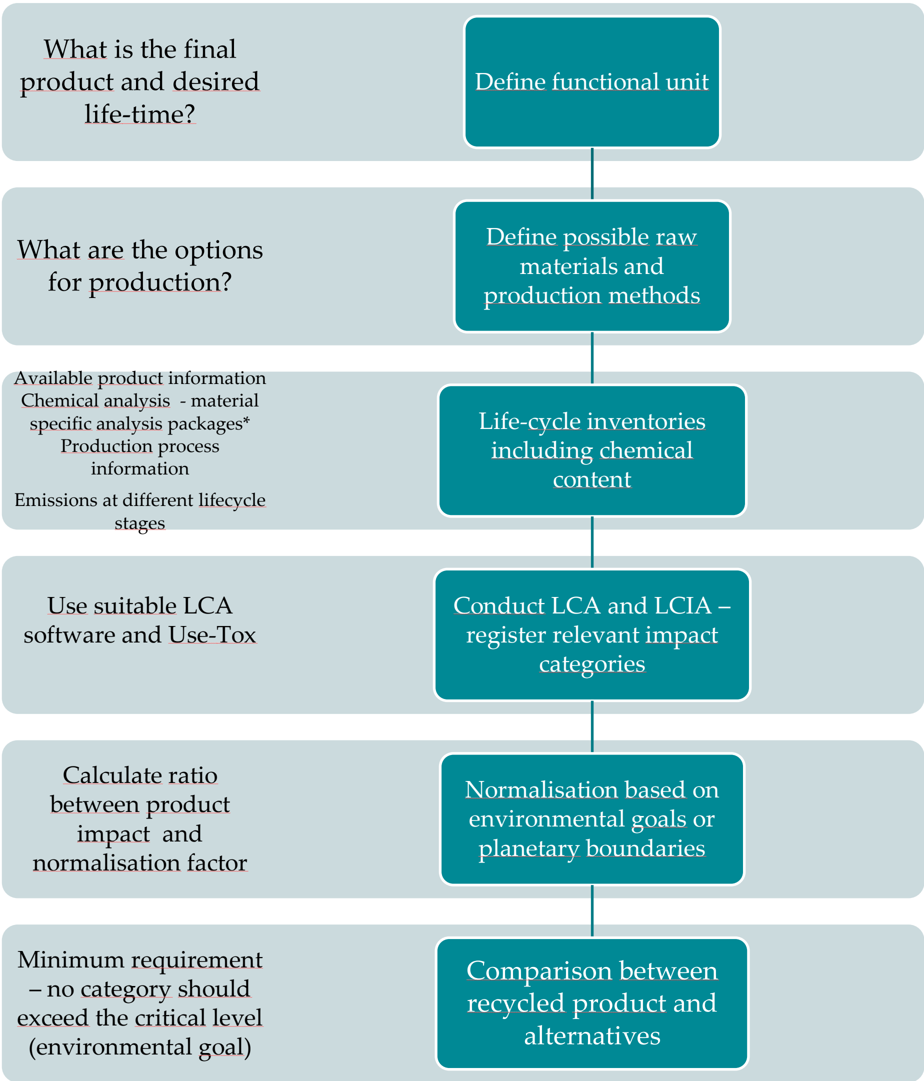


Figure 6. Key elements needed to conduct life-cycle impact (relative risk) assessment of recycled products. *Material specific analysis packages are currently not available on the market to our knowledge but present a development need in order to enable full assessments of recycled products.

7 Discussion and conclusions

The sole existence of a hazardous substance in a material does not necessarily dismiss this material from recycling activities. The benefits of recycling in terms of energy and resource savings have to be balanced against the potential health risks resulting from exposure to toxic chemicals. Key factors here are the physical-chemical properties in combination with the estimated exposure. In general, floors that were installed in the 20th century require detailed analysis regarding chemical content to ensure that they do not contain chemicals of high toxicity. If no such analysis is possible, older floors should be regarded as hazardous waste.

7.1 Need for selective demolition

Increased on-site sorting of construction and demolition waste is of great importance to increase the recycling of building products. Today, this is especially true for building products that already have a functioning recycling process with no significant problems regarding hazardous substances i.e. plaster boards and flat glass. Through selective demolition, it is possible to increase recycling rates in a relatively short time.

The case study of Meason demolition services indicated that there are functioning methods that could be used in order to increase recycling of construction and demolition waste through selective demolition. However, during the writing of the current report, Meason's service was shut down due to financial constraints and lack of market demand. The sorting procedure became too costly compared to having mixed fractions going to incineration. One aspect of this problem is that the value of the recycled material is not high enough to compete with conventional treatment and use of virgin material. Some fractions, such as plastic and cardboard do have certain value but requires collection of large volumes to compensate for transportation costs. In larger demolition projects large volumes may be generated at once, which facilitates recycling. Selective demolition requires more space for containers which is often available at larger demolition sites. However, since most demolition sites are of smaller size with smaller waste volumes and lack of space, mixed fractions and incineration becomes a more attractive option. To solve this, Meason had a storage place where sufficient volumes were collected and deposited from nearby demolitions sites, but even so they could not compete economically with conventional methods.

To increase the use of selective sorting also at small-scale demolition sites it is therefore vital to develop economic instruments on a policy level to increase sorting of waste and divert construction and demolition waste from incineration and landfill. One possibility could be to apply different incineration costs for different materials depending on the energy content of the material. Stenmarck et al. (2014) give further suggestions on instruments that could develop the recycling market. Collaboration between demolition companies and municipalities on permits (placement of several containers) could also enhance selective sorting. Public procurement could also help stimulating selective demolition. It may lead to lower prices for smaller actors. Legislation is another way to increase selective demolition.

7.2 Logbook for building materials

Introducing a logbook for building materials, as required in the certification system Miljöbyggnad, could facilitate recycling in the long term since it enables tracking of materials, products and their contents. In the short term perspective, other initiatives are needed in order to increase recycling. Prior to demolition it is required that a material inventory takes place in order to identify hazardous substances, components and materials fit for recycling. A building logbook would facilitate such an inventory. Currently, the problem is that the mandatory inventories are not conducted properly if conducted at all. It is thus a matter of enforcement and development of systems and tools to enhance this process.

7.3 Potential and obstacles to increased recycling of the studied building products

The minimum requirement for increased recycling of building products is that the chemical content of the material is known. Depending on the type of waste fraction, this information may already be known, but in many cases, chemical analysis may be needed to identify the chemical characteristics of the material.

According to the estimated generated waste amounts and the global warming potential related to the products, increasing EPS insulation recycling has by far the most potential in terms of climate savings. Since limited amounts of EPS waste is generated today and more is expected in the future, there is a great possibility in preparing infrastructure for recycling of EPS insulation in Sweden. Furthermore, Swedish EPS waste barely contains any brominated flame retardants which facilitates its recycling even more although special regard needs to be taken to EPS produced before 2005 (may contain HBCD) and before 2002 (may contain Deca-BDE) EPS containing brominated flame retardants should be sent for destruction. Although the environmental burdens for the other product groups are lower in comparison to that of EPS, increasing recycling for these products would still carry with it important climate savings. For products groups where recycling techniques and infrastructure are already in place i.e. for plaster and glass, where the alternative treatment is landfilling (PVC floors are incinerated with energy recovery if not recycled), increasing recycling rates could be achieved with relatively little effort.

In Tarkett's production, the use of phthalates is prohibited unless they are present in installation spillage to be recycled. The recycled material is in these cases used in the bottom layers of floor sheets which is a good example of how material containing undesirable substances might be used with regard to risk. In general, recycling of materials into the same use area ('closed recycling') is advantageous since the knowledge on use pattern and potential risks is more likely to be known.

Today, there may be an inherent conflict between the two environmental goals of i) reduced climate impact, and ii) a 'non-toxic' environment. The first requires limiting the use of natural resources and closing of production cycles, whereas the second goal calls for destruction of older materials which may contain hazardous substances. Thus, these goals have to be balanced using a risk approach, either using relative risk assessment approaches such as life-cycle impact assessments including toxicity or by absolute risk assessment of the end product where the waste fraction is used. Crucial for these types of assessment is knowledge or reliable documentation of the chemical content in the waste fraction, which may require chemical analysis to be conducted.

Sometimes the recycling is hindered not by hazardous substances in the target material itself, but rather by the chemical content in materials associated with the target materials. One example of this is window glass which may be connected to window frames made from treated wood. This example again emphasizes the need for a 'design to recycle' already in the construction phase, as well as the need for selective demolition.

7.4 Uncertainties

Currently, it is difficult to follow-up the national goal on recycling due to the poor quality of waste statistics (generated amounts and treatment for construction and demolition waste). This also makes it difficult to fully estimate the potential savings of increased recycling. Improving the national waste statistics would reduce these uncertainties but not the uncertainties regarding the chemical content of the material itself.

8 Acknowledgements

The authors are grateful for valuable input from a reference group consisting of Lars Tolgen (Ragnsells), Marianne Hedberg (The Swedish Building Industry), Lena Lundberg (IKEM), Anne-Marie Johansson (KEMI), Pernilla Löfås (NCC) and Elisabeth Österwall (Swedish EPA). The study was jointly financed by the Foundation for IVL Swedish Environmental Research Institute (SIVL) and Miljöfonden Sveriges Ingenjörer.

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Appendix - GreenScreen(R) for Safer Chemicals

by Anais Voisin and Anna Palm Cousins

General description of the GreenScreen method

The GreenScreen(R) version 1.2 for Safer Chemicals is an open source tool developed by NGO Clean Production Action (CPA). It is based mainly on the work of the US Environmental Agency's (EPA's) Design for Environment (DfE) Program but other national and international classification are also included such as Canada Domestic Substance List Methodology (DSL), The European Union's Registration, Evaluation Registration, Authorization and Restriction of Chemicals (REACH), the Stockholm Convention on Persistence Organic Pollutants and the Global Harmonized System for Classification and Labelling Chemicals (GHS). These classifications are used in order to assess specific hazard endpoints. The GreenScreen method defines the levels of concern (high, moderate or low) for each hazard endpoints which are based on quantitative, qualitative or from expert references threshold values (Figure 1).

	Information Type	Information Source	List Type		High (H)	Moderate (M)	Low (L)
Carcinogenicity (C)	Data	GHS Criteria & Guidance			GHS Category 1A (Known) or 1B (Presumed) for any route of exposure	GHS Category 2 (Suspected) for any route of exposure or limited or marginal evidence of carcinogenicity in animals (See Guidance)	Adequate data available, and negative studies, no structural alerts, and GHS not classified.
	A Lists	EPA-C (1986)	Authoritative		Group A, B1 or B2	Group C	Group E
		EPA-C (1996, 1999, 2005)	Authoritative		Known or Likely		Not Likely
		EU CMR (1)	Authoritative		Category 1 or 2	Category 3	
		EU CMR (2)	Authoritative		Carc 1A or 1B	Carc 2	
		EU H-statements	Authoritative		H350 or H350i	H351	
		EU R-phrases	Authoritative		R45 or R49	R40	
		EU SVHC	Authoritative		Reason for inclusion: Carcinogenic		
		GHS-[COUNTRY]* Lists (*Korea, Japan, Indonesia, Australia, Europe, New Zealand, and Taiwan)	Screening		Category 1A or 1B	Category 2	Not Classified
		IARC	Authoritative		Group 1 or 2A	Group 2B	Group 4
		MAK	Authoritative		Carcinogenic Group 1 or 2	Carcinogenic Group 3, 4, or 5	
		NIOSH-C	Authoritative		Occupational Cancer		
		NTP-RoC	Authoritative		Known or Reasonably Anticipated		
		Prop 65	Authoritative		Known to the state to cause cancer		
	B Lists	EPA-C(1986)	Authoritative		Group D		
		EPA-C (1999)	Authoritative		Suggestive Evidence, but not sufficient to assess human carcinogenic potential		
		EPA-C (2005)	Authoritative		Suggestive evidence of carcinogenic potential		
		IARC	Authoritative		Group 3		

Figure 1. Carcinogenicity assessment based on own data or authoritative agency lists.

The method considers 12 human health endpoints (carcinogenicity, genotoxicity/mutagenicity, reproductive toxicity, developmental toxicity and endocrine activity, acute toxicity, systemic toxicity and organ effects, skin sensitization, respiratory sensitization, skin irritation and eyes irritation), two ecotoxicity endpoints (acute and chronic aquatic toxicity) and four physiochemical properties affecting also the chemicals’ environmental fate (persistence, bioaccumulation, reactivity and flammability) (Figure 2). In the first version of GreenScreen (2007) there were only two endpoints (persistence and bioaccumulation) which could encompass the highest level of concern: very high, whereas in the latest version 1.2 (2011) 9 more endpoints (acute mammalian toxicity, systemic toxicity and organ effect single exposure, neurotoxicity, skin and eyes irritation, acute and chronic toxicity, reactivity and flammability) may achieve this highest level of concern.

Group I Human					Group II and II* Human									Ecotox		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						single	repeat*	single	repeat*										
DG	*L*	*L*	M	M	DG	*L*	*L*	M	M	L	L	L	L	*L*	*L*	*vH*	*M*	*L*	*L*

Abbreviations:

C = Carcinogenicity	SnR = Respiratory sensitization	SnS = Skin sensitization
M = Mutagenicity	IrS = Skin irritation	CA = Chronic aquatic toxicity
R = Reproductive Toxicity	IrE = Eye irritation	P = Persistence
D = Developmental Toxicity	AA = Acute aquatic toxicity	B = Bioaccumulation
E = Endocrine activity	ST = Systemic toxicity	Rx = Reactivity
AT = Acute mammalian toxicity	N = Neurotoxicity	F = Flammability

Figure 2. Hazard end-point summary table.

The purpose of the GreenScreen method is to reduce risk by decreasing inherent chemical hazard and promote the development of green chemistry. It is designed to be useful for decision-makers, governments or individuals. It proposes four benchmarks (from 1 to 4) that progressively classify safer chemicals where benchmark 4 represents the safer chemical for human health but also for environment (Figure 3). The GreenScreen method allows the comparison between alternative chemicals by looking to their benchmarks.

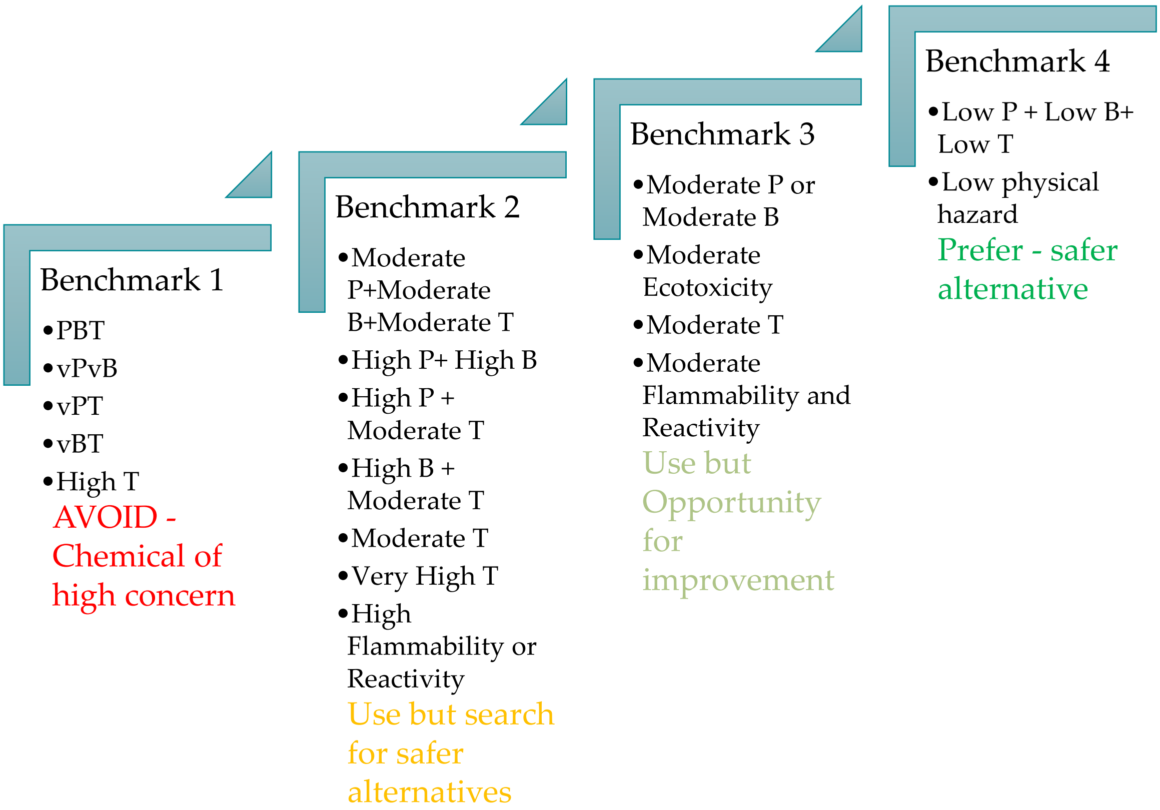

Figure 3. Benchmark criteria according to the Green Screen method. P = Persistence, B = Bioaccumulation, T = Toxicity, including

Application to whole products – the example of PVC

Product Information

PVC (polyvinyl chloride) represented 37.98 million metric tonnes (13%) of the global plastic production in 2012 (Black and Rossi, 2014). It has wide applications which include flooring, furniture, window frames, pipes, short life packaging, medical applications, electric and electronic equipment. Pure PVC is a hard, friable material which deteriorates under light and heat influence. Therefore it is supplemented with additives that improve its properties. Typical additives include:

- Plasticizers (mainly phthalic acid esters or phthalates)
- Pigments (titanium white, lead chromates)
- Heat and light stabilizers (mostly organic compounds based on lead, tin, zinc, barium, several organic antioxidants and co-stabilizer)
- Lubricants (wax, fatty alcohols, fatty acid ester)
- Fillers (chalk, china clay, talcum, magnesium oxide)
- Impact modifiers

A typical PVC content of these additives is shown in Figure 4.

	Component Share (weight - %)				
Application	**PVC polymer**	**Plasticiser**	**Stabiliser**	**Filler**	**Others**
Rigid PVC applications					
Pipes	98	-	1 - 2	-	-
Window profiles (lead stabilised)	85	-	3	4	8
Other profiles	90	-	3	6	1
Rigid films	95	-	-[13]	-	5
Flexible PVC applications					
Cable insulation	42	23	2	33	-
Flooring (Calender)	42	15	2	41	0
Flooring (paste, upper layer)	65	32	1	-	2
Flooring (paste, inside material)	35	25	1	40	-
Synthetic leather	53	40	1	5	1

Figure 4. Typical composition of PVC compounds (RANDA EU.003)

Hazard assessment of PVC

Polymers are usually assessed as low concern to human health and the environment (European commission 2012b), although this assessment excludes the possible life cycle hazards during manufacturing processing or end-of-life management (Black and Rossi, 2014). The PVC polymer (CAS # 9002-86-2) is suspected to be carcinogenic according to a non-genotoxic mode of action. Under these conditions no contribution to human cancer risk is expected but there is evidence that cellular proliferation, inhibition of apoptosis or disturbances in cellular differentiation are important in the mode of action (MAK, 2015). With more data, this would classify PVC in benchmark 2 category (Use but Search for Safer Solution). Moreover the precursors of PVC resin are listed as benchmark 1 or 2 (Figure 5). The final PVC products can contain residual of vinyl chloride monomer (0.0001%) which has benchmark 1 (Avoid).

Polymer	Primary chemicals CAS #	Intermediate CAS #	Monomer CAS #
Polyvinyl chloride (PVC)	Ethylene (74-85-1)	Ethylene dichloride (EDC)(107-06-2)	Vinyl chloride monomer (VCM) (75-01-4)
	Chloride (7782-14-5)		

Figure 5. GreenScreen Benchmark of PVC precursors (Clean Production Action, The Plastic Scorecards, 2015).

To compare two different PVC floors the exact composition is required, however some data are general to all floors (Figure 6 and 7). Bisphenol A is often used as solvent into PVC floors preparation and can be detected as a residual in the final product.

Chemical	**CAS number**	% weight	Benchmark
PVC	9002-86-2	35-65%	LT-P2
Vinyl chloride monomere (VCM)	75-01-4	0.0001	1
DEHP	117-81-7	25-32%	1

Bisphenol A	80-05-07	0.50%	1

Figure 6. PVC floor type 1.

LT-P2 is the abbreviation to potential Benchmark 2. There is not enough data to classify the PVC polymer properly. The replacement of DEHP by another less harmful substance, such as DINCH reduces the score but does not make PVC floors a low hazard product (Figure 7).

Chemical	**CAS number**	% weight	Benchmark
PVC	9002-86-2	35-65%	LT-P2
Vinyl chloride monomere (VCM)	75-01-4	0.0001	1
DINCH	474919-59-0	25-32%	2
Bisphenol A	80-05-07	0.50%	1

Figure 7. PVC floor type 2.

It is often difficult to know exactly the exact chemical composition of the product. For example some PVC floors contain titanium white (CAS # 13463-67-7) as pigment and zinc borate (CAS # 1332-07-6) as flame retardant, which are classified as benchmark 1. The comparison between PVC floor type 1 and type 2 show a decrease of benchmark for the plasticizer. However it is difficult to know which component is the most important in the product toxicity. It becomes evident here, that the Green Screen method, similar to voluntary systems such as BASTA, focuses on hazard and not on risk. Thus the main focus is to compare alternative chemical additives than products as a whole (Figure 8). Thus the method can be useful in substitution work, but not so relevant for hazard or risk assessment of complex waste fractions.

Chemicals	CAS number	Group I Human					Group II and II* Humans									Eco toxicology		Fate		Physical	
		C	M	R	D	E	AT	ST		N		SnS	SnR	IrS	IrE	AA	CA	P	B	Rx	F
								Si	Re	Si	Re										
DEHP	117-81-7	M	L	H	H	H	DG	L	M	DG	DG	L	L	M	M	vH	vH	DG	DG	L	L
BBP	85-68-7	M	M	H	H	H	H	M	DG	DG	DG	DG	DG	H	M	vH	vH	DG	DG	L	L
DBP	84-74-2	DG	L	H	H	H	DG	M	H	DG	DG	H or M	L	L	L	vH	H	DG	DG	L	L
DINP	28553-12-0	DG	L	H	H	H	L	DG	M	DG	DG	L	*L*	L	M	L	L	vH	vH	L	L
DINCH	474919-59-0	L	L	L	L	M	L	L	L	L	L	L	DG	M	L	L	L	M	L	L	L

Figure 8. Hazard summary table for different phthalates. Si and Re are for single and repeated exposure respectively.

Except for DINCH which has a benchmark 2, all the plasticizers used in PVC floors have a benchmark of 1 due to high toxicity in at least one Group I Human group (Figure 8).

To conclude, PVC floors could be classified as benchmark 1 or 2. Plasticizers such as phthalates represent important parts in PVC and all alternatives have not been assessed. After PVC polymer, the most important constituents are fillers, 40-41% of the weight. Most of the fillers used today in the industry are classified as benchmark 1 (many plasticizers) or possible benchmark 1 (chalk and china clay).

Discussion

The GreenScreen method only assesses chemicals of a product and may be a useful tool in substitution work, to preceed legaslative acts. In this way, it fulfills a similar function as the voluntarys systems already available in Sweden.

The first version of this Green Screen method does not take into account some classes of inorganics chemicals (such as mineral oxides) and it does not evaluate material and resource consumption, waste and end-of-life impacts, and other environmental impact such as ozone depletion or global warming potential (Jacobs *et al.*, 2015). It did not pay attention to potential chemical reaction during the use of a product/chemical which might result to bias in hazard assessment.

GreenScreen method is open to improvement. Version 1.2 implied decision strategies when there is gap in data, define a list of priority for chemicals and alignment with Chemical Policy Principles Implementation Guide and DfE. However this version neglects some priority lists that could be used in the decision process. For example the EU SVHC is not included. The assessment of chronic aquatic toxicity is poorly developed. Fortunately the method is open for improvement but the improvement can only come from licensed profilers.

To conclude this method can be considered as a good tool to design new products and for substitution but it is not suitable for risk assessment of waste fractions as recycling tool. The licensed profiler that reviews and validates all the GreenScreen assessments can be considered as good quality control. However it limits the use of this method and makes it less helpful outside of the US. So the organization only concentrates on proprietary ingredient over a certain amount (over 100 ppm). For the Swedish Building Industry, the voluntary systems already available are likely to be of more use.

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