Sustainable Vehicle Interior Solutions

Public report

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FFI Fordonsstrategisk Forskning och Innovation

Content

FFI in short

FFI, Strategic Vehicle Research and Innovation, is a joint program between the state and the automotive industry running since 2009. FFI promotes and finances research and innovation to sustainable road transport.

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1. Summary

Sustainable Vehicle Interior Solutions - the SVIS project started in March 2020 and was finalized in September 2024. The project has addressed the need for a holistic approach on a more sustainable production of vehicle interiors and suppliers from all relevant areas were included in the project. The project's main goal was to reduce the amount of production waste by more than 50%, but also to find collaboration opportunities within the supply chain to utilize each other's waste. Another goal was to design with materials that enable recycling of the product after end of life. The project has focused on case studies of instrument panel, door panel, carpet, textile covered pillars and seat with upholstery. The outcome of the project can be summarized in some main points:

Learnings from work within the value chain:
The project has contributed to new innovations through the collaboration that has taken place in workshops that have focused on design for recycling, using each other's waste for recycling and as raw material for new products. Workshops that have focused on specifications of recycled materials have also given insights about the linearity of the current supply chain and how collaboration must change, especially when it comes to the objective of increasing the amount of recycled materials in different components

Assuming that the results from the project are implemented, the following reductions of production waste, or recycling of materials can be realized: For door panels of thermoformed natural fiber and polypropylene, so called NF PP with about 50% fibers, the production generates waste that makes up 30-40% of the weight of the panel. One project partner develops the production with the objective to utilize 100% of the waste. There are several possibilities to reach this target:

Milling the waste and incorporate a certain amount in the mats for thermoforming that is supplied as input in production. Development of this recycling is done in collaboration with the supplier and will realize closed loop recycling. Another possibility is that production waste can be blended with more PP through melt processing to produce an injection molding compound to be used in other products, for example furniture.

Results from a diploma work on polyester textile covered pillars showed that it is possible to mechanically recycle the complete pillar of PC/ABS with polyester textile. Further tests showed that pillars with 30% recycled content passed crash testing.
The production process i.e. back-injection molding generates only a small volume of waste at start of the machinery. It is estimated that production waste from several types of pillars can be collected and will make up 1-5% in a component. The production waste can then be eliminated. The results indicate the possibility to recycle PC/ABS/PET pillars from end of life vehicles (ELV).

A design of the carpet based on the concept "one-polymer solution" was prepared by substituting parts of the construction with polyester-based alternatives. A diploma work performed during 2023 verified the recyclability of the new design. A scenario based on chemical recycling of the carpet is energy intensive but will add high value as closed loop materials recycling. Assuming that a process for chemical recycling by depolymerization is available, it is possible to extract 60 % molar yield of monomer from the carpet to produce new fibers and yarns from re-polymerised polyester. In a nutshell, chemical recycling can help to close the loop, and fulfill the proposed ELV regulation and create high value-added recycled material without any downgrading in properties.

The conclusions of the project can be summarized in the following way:

Collaboration within the value chain:
The fact that time has been set aside for workshops focusing on sustainability and recycling have given the opportunity for creative ideas to be shared. This would not have happened, had the project not reserverved time for the topic. This is an important learning for the future. Partners also share that they have a new way of thinking when it comes to how resources are handled, if materials can be reused or recycled and if a material can have a second life.

Real reduction of production waste
The most successful examples of reduction of production waste have been made possible due to good planning and short geographical distances. The fact that transportation is a cost both regarding costs and emissions is an important hinder for resource efficiency.

Lack of value chains for recycling
The concept of “One-polymer solution” is a good starting point when it comes to design for recycling. However, even though good results have been achieved in the project, the lack of specific recycling processes is probably the biggest hindrance for a more resource efficient use of material, when it comes to interior vehicle components.

2. Sammanfattning på svenska

Hållbar fordonsinteriör - SVIS projektet startade i mars 2020 och avslutades i september 2024. Projektet har adresserat behovet av en helhetssyn för att åstadkomma en mer hållbar produktion för fordonsinteriör och relevanta underleverantörer inkluderades i projektet. Projektets huvudmål var att minska mängden produktionsspill med minst 50% men också att hitta möjligheter till samarbeten inom värdekedjan för att utnyttja varandras spill. Ett annat mål var att designa med material som möjliggör återvinning av produkten efter användningsfasens slut. Projektet har fokuserat på studier av fem interiöra komponenter: instrumentpanel, dörrpanel, textilbeklädda stolpar, mattor, säte med fokus på klädsel. Resultatet av projektet summeras i några punkter nedan.

Lärdomar från samarbete inom värdekedjan

Projektet har bidragit till nya innovationer genom samarbetet som har ägt rum i workshops som har fokuserat på design för återvinning, användning av varandras spill för återvinning och som råmaterial för nya produkter. Workshops som har fokuserat på specifikationer för återvunna material har också gett insikter om hur linjärt den nuvarande värdekedjan fungerar och hur samarbetet behöver förändras. Detta gäller speciellt när det gäller att nå målet att öka mängden återvunnet material i olika komponenter.

Om man antar att resultaten från projektet implementeras, så kan man minska produktionsspill och återvinna material på följande sätt:

Dörrpanel

För dörrpaneler som termoformats av mattor med 50% naturfiber och PP fiber (NFPP) genereras produktionsspill som uppgår till 30-40% av panelens vikt. En projektpartner utvecklar produktionen med målet att utnyttja 100% produktionsspill. Det finns flera möjligheter att nå det målet:

1. Spillet kan malas i kvarn och en viss andel kan läggas in i fibermattorna som levereras till produktionen, vilket blir att sluta cirkeln genom återvinning. Utvecklingen av denna återvinning görs i samarbete med leverantören av fibermattor.
2. En annan möjlighet är att blanda produktionsspillet med mer PP genom smältbearbetning för att producera granulat för formsprutning, som kan användas i helt andra produkter tex för möbler.
3. Resultat från ett examensarbete om textilbeklädda stolpar visade att det är möjligt att mekaniskt återvinna hela stolpar av PC/ABS med polyestertextil. Ytterligare tester visade att stolpar med 30% återvunnet material blev godkända i krocktester. Produktionsmetoden med formsprutning mot textilen genererar små volymer spill vid uppstart i produktionen. En uppskattning som gjorts utgår ifrån att man kan samla stolpar från flera olika typer för återvinning och dessa kan sedan utgöra 1-5% återvunnet material i nya stolpar. Produktionsspillet skulle på så sätt helt kunna undvikas. Resultaten indikerar att det kan finnas en möjlighet att återvinna PC/ABS/PET stolpar från skrotade bilar.

Matta

Design av mattan baserat på konceptet ”konstruktion med en polymer” genomfördes genom att byta ut delar av konstruktionen med polyesterbaserade alternativ. Ett examensarbete genomfördes som verifierade återvinningsbarheten av den nya designen. Ett scenario för kemisk återvinning av mattan kostar energi men ger högt värde i form av sluten cirkel för materialåtervinningen. Med antagandet att en kemisk återvinning genom depolymerisering finns tillgängligt, så är det möjligt att återvinna monomer från mattan med ett utbyte på 60mol% , för att producera nya fibrer och garn från återpolymeriserad polyester. Det betyder att mattan kan tillverkas av 60% återvunnen monomer och ersätta rPET från flaskor. För att sammanfatta, kemisk återvinning kan möjliggöra återvinning med sluten cirkel, och därmed uppfylla kraven i den föreslagna ELV lagstiftningen. Därmed adderas också ett högt värde till produkten eftersom den innehåller återvunnet material utan någon nedgradering av egenskaperna.

Instrumentpanel
Bäraren i en instrumentpanel, gjord av polypropen med 20% glasfiber återvanns genom malning i kvarn och efterföljande kompoundering och formsprutning. Glasfibrerna förkortas under återvinningen vilket försämrar de mekaniska egenskaperna. Ett enkelt sätt att förbättra egenskaperna är att sikta bort de malda partiklar som är minst och som innehåller de kortaste fibrerna. Detta innebär en materialförlust på bara ett par procent men en betydlig förbättring av egenskaperna. Det återvunna materialet möter specifikationen på andra komponenter på en bil (inte instrumentpanel) och kan därmed återvinnas från bil till bil.

Säte-klädsel
För komponenten säte med fokus på klädsel genomfördes en design baserad på konceptet ”konstruktion med en polymer”. Detta gav ett betydligt bättre resultat än den ursprungliga designen i efterföljande LCA. Fortsatt arbete med den nya konstruktionen gjorde det även möjligt att förverkliga fyra olika koncept för återvinning av klädseln. Ett exempel som redovisas i rapporten är tillverkningen av en nackkudde.

Sätet var föremål för en workshop med målet att förenkla designen vilket resulterade i att två studier genomfördes: en med inriktningen att mäta termisk och fysiologisk komfort hos olika ytmaterial och en med inriktning att testa om polyuretanskum kunde ersättas med ett annat , mer återvinningsbart material.

Resultaten visade det positiva resultatet att vävd textil ger minst känsla av (temperaturskillnad) värme resp kyla vid kontakt, medan vinyl ger högst känsla samt att perforering av ytmaterialet är ett effektivt sätt att öka fukttransporten. Resultaten visade också att polyuretanskum kan ersättas med ett fiberformat alternativ av polyester och att samma upplevelse av yttryck erhålls.

Slutsatserna i projektet kan summeras på följande sätt:

Samarbete inom värdekedjan
Genom att tid avsatts för workshops som fokuserat på hållbarhet och återvinning, så har det därmed uppstått tillfällen att gemensamt utforma kreativa idéer. Detta skulle inte inträffat om inte tid reserverats för detta pga. projektet. Detta är en viktig lärdom för framtiden. Projektpartners berättar också att de fått ett nytt sätt att tänka när det gäller hantering av resurser, om material kan återanvändas eller återvinnas och om material kan får ett ”andra liv”.

Minskning av mängden produktionsspill i verkligheten
Det mest framgångsrika exemplet på minskning av produktionsspill i praktiken har varit möjligt att genomföra pga. God planering och korta geografisk avstånd. Det faktum att

transport är en kostnad både avseende utsläpp men också ekonomiskt är ett viktigt hinder för resurseffektivitet.

Brist på värdekedjor för återvinning
Konceptet ”konstruktion med en polymer” är en bra utgångspunkt när det gäller design för återvinning. Trots att goda resultat erhållits i projektet så är bristen på specifika återvinningsprocesser sannolikt det största hindret för mer effektivt materialutnyttjande när det gäller interiöra fordonskomponenter.

3. Background

The background to the project was thoroughly described in the application and is therefore included below in this part of the report.
Volvo Cars recently announced a strategy on recycled plastic with the target of 25% recycled plastic (corresponding to 40% - 65% CO_2 reduction) in all cars that is introduced from 2025 and onwards[1] which is the most progressive strategy any premium car manufacturer has had to date.

Today, Volvo Cars uses about 2-4% recycled plastic in its cars. These components are of simpler kinds such as wheel housings, motor protection plates, subfloor panels, carpets and in cargo floors. The composition of the products and the communication about recycled materials vary in the automotive industry. For example, Daimler states[2] that in the Mercedes E-Class they have 72 components with an overall weight of 54.4 kg that can be manufactured partially from high-quality recycled plastics. Nissan describes[3] that they have 25% recycled materials in there Nissan LEAF. Toyota[4] [5] has presented an ambitious plan, “Toyota Environmental Challenge 2050”, where one challenge is to establish “a recycling-based society and systems”. BMW is focusing on the i3 model with 25% renewable and recycled plastic in the interior and exterior.

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[1] Volvo Car Corporation, "Volvo Cars aims for 25% recycled plastics in cars from 2025," 18 June 2018. [Online]. Available: https://group.volvocars.com/news/sustainability/2018/volvo-aims-for-25-per-cent-recycled-plastics-in-cars-from-2025. [Accessed December 2019].

[2] S. Maccarrone, "Daimler’s Approach to Sustainable Vehicles: Recover, Reuse, Renew," 1 March 2018. [Online]. Available: https://matmatch.com/blog/daimlers-approach-sustainable-vehicles-recover-reuse-renew/. [Accessed December 2019].

[3] S. Hanley, ”2015 Nissan LEAF Made From 25% Recycled Materials,” 16 July 2014. [Online]. Available: https://enrg.io/2015-nissan-leaf-made-from-25-recycled-materials/. [Använd December 2019].

[4] Toyota Motor Corporation, "Vehicle Recycling," Environmental Affairs Division, Toyota Motor Corporation, 2017.

[5] Toyota Motor Corporation, "Environmental Report 2019: Toward the Toyota Environmental Challenge 2050," Environmental Affairs Division, Toyota Motor Corporation, 2019.

In Europe in 2018, the automotive industry accounted for 9.9 % of the total plastic demand[6]. According to the EU strategy for plastics[7], 10 million tonnes of recycled plastics are to be used in 2025, where the target based on the total plastic demand in Europe, for the automotive industry, should be at least 1 million tonnes by 2025. Media attention on Volvo Cars' new strategy and the response from both material and component suppliers has been very large. The driving force behind the strategy is to increase the demand for recycled materials throughout the production chain and to increase availability and quality of recycled materials on the market. The use of recycled materials in interior components is also one of the steps required towards a circular economy at Volvo Cars. To meet the target of 2025, it is important that the entire chain is represented, from recycling companies through material suppliers to component manufacturers and car manufacturers. Collaboration and common knowledge are required to carry out the transition from fossil-based materials to recycled or biobased materials. The challenge internally at Volvo Cars lies in demanding new materials, starting to evaluate and use them, and collaborating with the suppliers. Cars are complex with high technical requirements on the components in terms of service life, quality and safety as well as other characteristics such as aesthetics and perceived quality.

Plastic has many advantages in vehicles such as weight reduction which saves fuel and reduces carbon dioxide emissions. Plastic material also enables excellent design opportunities at low manufacturing cost. The proportion of plastics in vehicles is increasing today, and today a car contains on average 10% by weight of plastic material. However, it is still a fact that a very small part of this material is today recycled. Both the recycling of plastic components from scrap cars and the use of recycled plastic in new vehicles need to increase dramatically to reach the EU's target that 25% of the plastic produced will be recycled in 2025. For every kg of new raw material that is replaced with recycled plastic, 40% -65% CO_2 is saved, depending on the type of material[8]. Volvo Cars recently came out with the strategy that in each newly produced car, 25% of the input plastic should be recycled raw material by 2025, a goal that requires cross-border collaboration and where the automotive industry is an important driver.

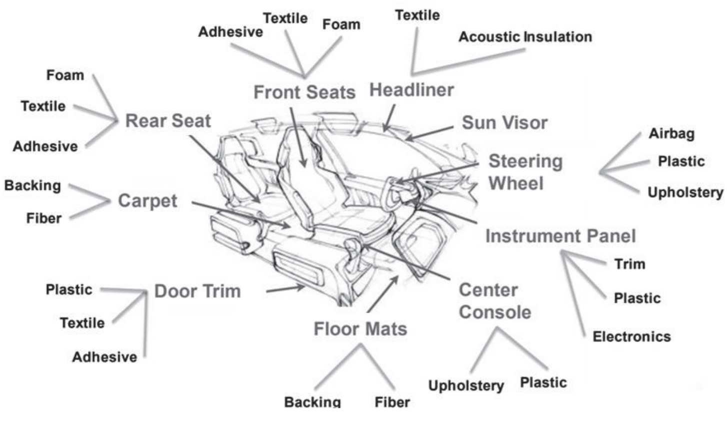
Another material of great relevance to the automotive industry is textiles and leathers. The textile waste stream today is mainly used for incineration and is a material resource that must be utilized in a much more efficient way in a future where circular systems are prioritized. In September 2016, the Swedish Environmental Protection Agency submitted

[6] Plastics Europe, "Plastics - the Facts 2019," 2019. [Online]. Available: https://www.plasticseurope.org/download_file/force/3183/181. [Accessed December 2019].

[7] European Commission, "A European Strategy for Plastics in a Circular Economy," Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions, Brussels, 2018.

[8] CES Selector, "Materials selection: LCA software," 2019.

a proposal[9] to the Government regarding the handling of textiles. In this work, new targets for textile waste were proposed, i.e. that the amount of textile waste in the residual waste in 2025 should have decreased by 65% compared to year 2015, and that 90% of separately collected textile waste in 2025 should be prepared for reuse or material recycling using the waste hierarchy. Paragraph 38 of the January Agreement[10] addresses textile materials directly by introducing producer responsibility. Possible avenues for greatly increasing the reuse and recycling of textiles should be tested where the industry and non-profit actors are involved. Here, it will be of the highest importance to act cross-industry by working with the exchange of materials between textile, plastic, composite and nonwoven applications. As textiles are used and subjected to wear, it is broken down which may make it unsuitable for the original product but suitable for another product type. Claims regarding plastics are likely to be followed by a direct counterpart with regard to textile materials and it is of the utmost importance for the industry to come up with future policies and regulations. Working proactively also means market benefits and increased opportunities for environmental profiling. Consumer awareness is rapidly increasing in terms of sustainability issues and recycling, which is why an increased focus on producers in the use of secondary raw materials and material recycling can have many positive effects on the market. Since 2015/2016, RISE has operated two test beds for evaluating recycling of plastics and textiles. Here, a high level of expertise and a large experience bank have been built up together with a large network that forms a stable foundation for this project, which intends to take a greater grip on both these categories of material as the problems are closely related and the opportunities for collaboration are very large. Vehicle interior materials and components:



[9] Naturvårdsverket, "Förslag om hantering av textilier – Redovisning av regeringsuppdrag," SWEDISH ENVIRONMENTAL PROTECTION AGENCY, 2016.

[10] "Utkast till sakpolitisk överenskommelse mellan Socialdemokraterna, Centerpartiet, Liberalerna och Miljöpartiet de gröna," 11 January 2019. [Online]. Available: https://www.socialdemokraterna.se/download/18.1f5c787116e356cdd25a4c/1573213453963/Januariavtalet.pdf. [Accessed December 2019].

Today, vehicle interior is mainly based on synthetic materials like polyester textiles, vinyl foils, urethane foams or natural materials like leather, wool, wood. Often interior components consist of multimaterial combinations where different materials are laminated with suitable adhesives, cf. Figure 1. As the shape of the components often are complex a lot of trim waste is created in the production. For leather the waste is generally between 30% and 45% [11]. This kind of waste is often downgraded in the waste hierarchy to for example insulation, energy recycled (incinerated), or in worst case used as landfill. The hypothesis here is that a lot of this kind of production waste can be used in products or components with a substantially higher value and contribute to a better environmental profile. To do this there is a need for an active collaboration between various actors such as vehicle manufacturers, suppliers of materials and components, recyclers, and research actors.

4.Purpose, research questions and method

The purpose, research questions and approach were described in the application and the language tense has been prepared to describe to the original plans.

4.1 Purpose

The novelty of this project and the results is that all kind of suppliers have been included in the project and have worked together towards the implementation of sustainable solutions for vehicle interiors. This was regarded to have the potential to form a platform for the entire European automotive industry as it had not been done before in this cross functional context. The project was intended to strengthened RISE (IVF) as a complete provider of knowledge within all materials connected to vehicle interiors and it was the purpose that RISE possibly would be extended to a “sustainable vehicle interior centre of excellence”.

The project has addressed the need for a holistic approach on a more sustainable production of vehicle interiors and suppliers from all relevant areas were included in the project. By having this kind of project,” the centre of excellence within sustainable vehicle interior” would move towards Sweden and be facilitated by the fact that most of the actual companies act on an international market.

[11] Leather Dictionary, "Leather cutting waste in leather processing," 2019. [Online]. Available: https://www.leather-dictionary.com/index.php/Leather_cutting_waste. [Accessed December 2019].

4.2 Research Questions

The project had the ambition to "drive the state of art" in the following areas:

1. Classification of recycled materials, LCA and chemical content. LCA is essential to compare different material sources and different recycling processes. Chemical content is especially important for end of life (ELV) recycling to avoid harmful chemicals, e.g. volatile organic compounds (VOC)
2. Effective production with zero waste by redesign, reuse and recycling. Redesign is for example one-material components or easy to separate components. Reuse is for example the use of trim cuts in another product. Recycling can be done internally (recirculated in the production line), at a recycling plant or at another producer.
3. Development of supply chains and classification system within vehicle industry and synergies with other industry. To make the recycling possible, there must be a classification system for recycled waste that secure and enable the use of recycled materials in the production of new components.
4. Mapping of available materials and components and how to recycle them. For different waste the most efficient recycling route (thermomechanical, chemical, reuse, energy, etc.) will vary, the mapping will result in a handbook for all kind of interior parts and materials.

4.3 Methods

Figure 1. Illustration of the components chosen for the project and the themes handled in the work packages.

Initially four interior components were chosen as an approach to run the project and let each work package address the components upholstery, instrument panel, textile pillar and vehicle floor system. The components were chosen due to their build-up of materials and the possibility to include several partners for each component trials. Later in the project there was a need to include the *whole seat* and *the door panel* for more trials/discussions as illustrated in Figure 1.

The approach was developed from the original work packages as described in the application:

WP1: Recycled material as raw material for new components
WP 2: Specifications and legislation
WP 3: Recycling of production waste and ELV
WP 4: Value chains and upscaling
WP 5: Consumer and market analysis
WP 6: Utilization of project results
WP 7: Education package
WP 8: Project management, dissemination and communication

to be illustrated by Figure 2. The original titles of WP 1 and 3 were specified and divided. The themes in WP 1 and 3 were then applied to the components as shown in figure 1, while the other work packages and some specific activities as LCA, were illustrated as support. Work package 7 Educational package is "missing" in the illustration in figure 1 but has been an important and appreciated part of the project as many lectures have been held with the opportunity to ask questions to different experts.

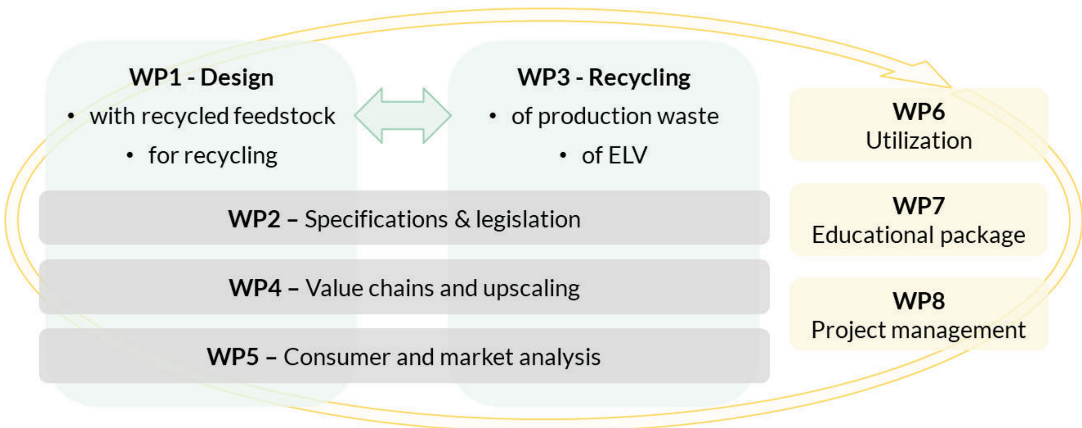


Figure 2. Original project plan based on work packages.

Figure 3 shows a detailed illustration of how the project partners were involved in the activities with each component. The meaning of abbreviations for some materials are as follows: PVC – polyvinyl chloride; PUR-polyurethane; PET-polyethylene terephthalate;

multiknit – a polyester structure i.e. of fibers made of PET; PA 6-polyamide of a certain type; TPO-thermoplastic polyolefin; PPG -polypropylene reinforced with glassfibers; PC/ABS – blend of polycarbonate and acrylonitrile-butadiene-styrene; NFPP-naturalfibers blended with polypropylene fiber in mats for thermal pressing.

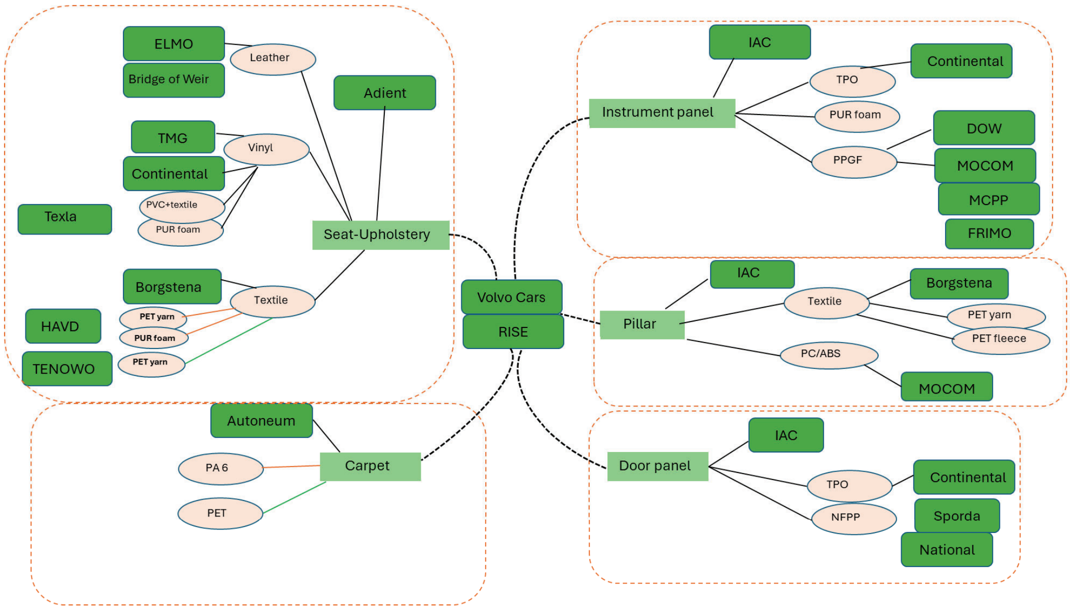


Figure 3Illustation of each partners connection to the individual components

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5. Objectives

The objectives, as described in the project application are given below.
"The overall goal of the project is to make it possible to reduce the production waste that is not recycled/reused today by at least 50%. The project will contribute to the following objectives:

1. Environment neutral production and establishment of closed material cycles by defining new supply chains
2. Methods and production techniques to reduce the amount of input materials and energy, and to eliminate/reuse production waste
3. Increase the material/product competence regarding recycled and biobased materials within the supply chain throughout the different tiers
4. Feedback from suppliers regarding recycled and reused materials
5. High flexibility in the production to allow for recycled/reused materials/components

6. Meet new requirements and customer values by for example conceptual studies and product clinics
7. High life cycle efficiency
8. Enable the supply chain and upscaling of industrial recycling and reuse "

The objectives above have been relevant throughout the project, but the project has focused on reduction of production waste and recycling to increase the utilization of the materials.

6. Results and deliverables

6.1 Results and deliverables as described in the application with comments

In the application, the following was stated concerning the contribution to the objectives of the FFI programme:

"The present project clearly complies with the overall challenge of the sub-programme Sustainable Production: "Ability to produce new products/components with new materials with minimal environmental impact". The project intends to focus on the programme area "Resource efficiency in production for reduced environmental impact and increased competitiveness" and to some extent "Robust and efficient production of new products, functions or features" defined within the strategic road map for sustainable production. The aim is to run the project with a shorter-term time perspective (Challenge driven - presumed introduction 2-4 years after project completion)".

Comments
The results described below are divided into sections for each of the interior components. The FFI program aim "Ability to produce new products/components with new materials with minimal environmental impact" has been met largely, for example through the different concepts of recycling the seat upholstery, which meant using a "new", though recycled material that had different properties than a virgin material.
The case study of textile covered pillars contained results from testing a real component containing 30% closed loop recycled material, which is an example of using a new material in the production and thus reducing the environmental impact. The case

Instrument panel resulted in the conclusion that the properties of the recycled material made is suitable for another automotive component. The concept has not been tested yet, but the result is in line with the aim expressed in the FFI program.
Resource efficiency as mentioned above as one of the FFI program areas, has been an obvious target throughout the project which is reflected in all the activities and results described. The fulfillment of the main objective, to reduce the production waste by 50%, as an example of resource efficiency, is described in the next section. The overall conclusion is that this objective has been reached, had it been possible to implement all

findings during the project time. This is not the case, since there are several parts of the "real materials recycling" chain missing when it comes to handling of interior car components. A specific example is the lack of dismantling components when treating end of life vehicles (ELV)

The main results/deliverables from the project were intended to facilitate the transformation to more sustainable solutions for vehicle interiors with a focus on a *higher degree of material utilization in the production processes.* The project was to develop and deliver results for:

1. Material flows (complete value chain) today and optimized for tomorrow
2. Recyclability after usage (contamination, degraded, wear)
3. One-polymer material solutions (for example PET textile with PET laminate)
4. Easy divorce concepts (easy to separate materials in components)
5. Guideline recycling method (chemical, mechanical, etc.) per material/polymer/concept
6. Guidelines and testing to replace fossil-based with biobased/recycled per polymer or other raw material
7. Possibility to reuse or remanufacture per material type, e.g. leather trims used for gloves
8. Conceptual car or equivalent to demonstrate the solutions developed in the project
9. LCA on the main materials and components
10. Several diploma workers in collaboration with universities
11. Another important result should be the training of personnel within material and process knowledge, life cycle analysis, design for sustainability, both as traditional teacher-centred teaching but especially in workshops where real cases from the own production would be in focus.

Comments

Higher degree of material utilization in the production processes has been guiding the various activities and the work for each component. Recycling experiments and testing of "one-polymer solutions" are examples of how higher degree of material utilization can be accomplished. Comments on how the topics in the list above have been handled follow:

1. A lot of work has been performed within the value chains, among other activities through work shops. A survey was performed among the partners investigating volumes and handling of waste. Some of the results are confidential. A conclusion concerning material flow for tomorrow is that in order to really minimize or use production waste, there is often a need to involve companies with recycling equipment, which may mean specific type of equipment. Another conclusion is that transportation and geographical distance is a real hindrance and many time causes too large expenses for realizing recycling.
2. Recyclability after usage have not been studied to a large extent. For the Instrument panel, there was a sample that had been exposed in desert climate for 6 years. Most of the other materials or components tested for recycling have been made of virgin materials.
3. One-polymer solution has been tested fully or partially. The carpet was designed in 100% polyester and recycling was compared to the original design. One-polymer solution of seat-upholstery was also prepared as physical sample, which then was recycled.

Experiments simulating one-polymer solution of an instrument panel were performed so that the influence of having polyolefin based foil and foam could be studied. The results showed positive impact on the mechanical properties.

4. Easy divorce concepts have not been tested in experiments with the components. Easy divorce constructions were gathered initially, for example as a type of Velcro that would have to be sewn or glued to the material. Adhesives that can be “unlocked” through heat are known but have not been applied during the project.
5. Guidelines for recycling methods has been taught as general principles but many times experiments and tests are required to understand the possibilities and limitations of recycling certain materials and components. Lecture about recycling strategies have been given.
6. Very few if any experiments were performed on biobased raw materials but recycled materials have been evaluated for all of the components studied.
7. The activities in the project have focused more on recycling than reuse or remanufacture.
8. An exhibition was held 14-15 May 2024 in Volvohallen, Gothenburg, presenting results from work with each component. Presentations by several partners were held, with topics such as how waste can be reduced, sustainability strategies and how to design for circularity. The program for the event and photos are shown in section 6.5.
9. LCA has been performed on the “One-polymer solution” for Seat-Upholstery which is described below. Several lectures have been held on the topic as the demand for education within the consortium has been large.
10. Three master of sciences theses have been written within the project: one thesis concerning recycling of instrument panels carriers of PP glass fiber, one thesis on recycling of polyester textile covered PC/ABS pillars and one thesis on recycling of One-polymer solution carpets.
11. Several lectures (11 different, listed in section 6.5) have been given through the project with possibilities to ask questions and discuss the information presented. Generally, the lectures have been very appreciated. Workshops (listed in section 6.5) with different topics have been held to discuss topics within the value chain. Important exchanges of ideas and conclusions have come out of these events as part of the education and training that have been going on within the consortium during the project.

The application mentions the potential forming of a platform for the European automotive industry or a sustainable vehicle interior centre of excellence. While such a purpose could serve the industry from some perspectives it does not naturally fit into the landscape of how the automotive industry works or will have to work in the near future to increase its sustainability. It is true as described in the application, that the collaboration in the value chain has opened new perspectives and given new ideas and insights. This was also emphasized as one of the unique features of the project, in the application

6.2 Reduction of production waste by at least 50%

Assuming that the results from the project are implemented, the following reductions of production waste, or recycling of materials can be realized.

Door panels of thermoformed natural fiber and polypropylene so called NF PP with about 50% fibers.
The production generates waste as cut off shown in Figure 4, that makes up 30-40% of the weight of the panel. One of the project partners develops the production with the objective to utilize 100% of the waste. There are several possibilities to use the cut off waste:

1. Milling the waste and incorporate a certain amount in the mats for thermoforming that is supplied to the partners' production. Development of this recycling is done in collaboration with the supplier of mats.

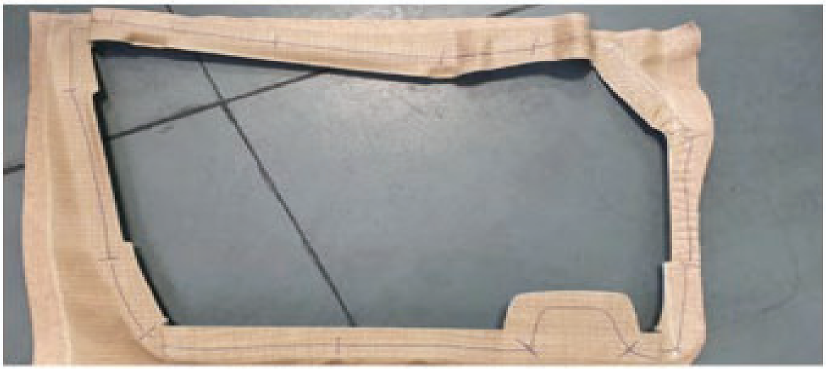

Figure 4Cut off waste from a NFPP door panel

2. The production waste can be blended with more PP through melt processing to produce an injection molding compound to be used in other products, for example furniture.
3. The NFPP can be blended with more PP through other processes and used in specific details that complements the door panel.
4. Recycling experiments of complete door panels resulted in material properties that make the compound possible to use in other automotive applications.

Figure 5. Textile covered pillar made of PC/ABS with polyester textile covering

Polyester textile covered pillars of PC/ABS
The results from a diploma work (Spring 2021) showed that it is possible to mechanically recycle the complete pillar of PC/ABS with polyester textile. Further tests showed that pillars with 30% recycled content passed crash testing.

The production process i.e. back-injection molding generates only a small volume of waste at start of the machinery. It is estimated that production waste from several type of pillars can be collected and will then make up 1-5% in a component.
The production waste can then be eliminated.
The results opens up for the possibility to recycle PC/ABS/PET pillars from end of life vehicles (ELV).

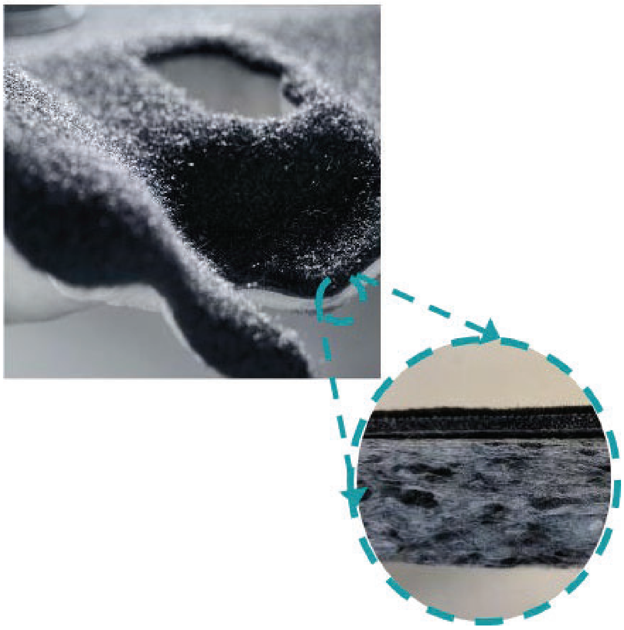

Figure 6. Overview and cross-cut of re-designed carpet based on "one-polymer solution i.e. all polyester in the structure.

Carpets

A design of the carpet based on the concept "one-polymer solution" was prepared within the project by substituting parts of the construction with polyester based alternatives. A diploma work performed during 2023 verified the recyclability of the new design. Three different recycling scenarios can be envisioned based on the new concept for design of the carpet, as described below:

1. Easy to implement with low value added (to the product) with less CO_2 emission

    Production Waste:
    The production waste can be shredded and used it in so called "B-Surface felt product" using air lay technology. The waste is blended in existing material mix . "Low value" is added as the recycled waste is competing or replacing shoddy cotton / polyester fibers from garments (which are inexpensive)

    End -of-Life Carpet:
    Assuming the carpet can be collected after its life span there is a need for developing a method for cleaning and shredding the material in order to recycle it. If the recycling is in place it can be used as the production waste in scenario 1.

2. Thermal processing, medium value added but more CO_2 emission than 1st scenario.

   Production waste:
   The production waste can be shredded and melted with a special type of extrusion and converted into polymer granules. These granules are of low quality as it is mix of different polyesters but can be mixed from 5 to 20 % with bottle flakes and fibers can be spun of the mixture. These fibers can be used for "B-surface products" and less critical "A-surface products".

   End -of-Life Carpet:
   The same need as for scenario 1.

3. *Chemical recycling*, energy intensive, higher value added and expensive (at this moment)

   Production waste:
   Assuming that a process for chemical recycling by depolymerization is available, it is possible to extract 60 % yield of monomer to produce new fibers / yarns from re-polymerised polyester**. This means that the carpet can be made up of 60% recycled content and substitute the rPET that today comes from bottles.**

   In a nutshell, chemical recycling can help us in the future to close the loop and fulfill the proposed ELV regulation and create high value-added recycled material without downgrading, as in scenario 1 and 2.

6.3 Results from work with components

6.3.1 Seat trim covering

A seat upholstery was analysed with regard to the multi-material details it was made up of. A suggestion of an "One-polymer Solution" was prepared and experiments on how to replace for example a polyurethane foam with a polyester based solution were performed. All steps were included for example such as lamination. Figure 7 shows the results.

Figure 7.Seat appearance with a one-polymer solution of polyester.

A LCA was performed comparing the multi material solution with a one polymer solution. The results showed that a car upholstery set based on a one-polymer solution with 100% recycled polyester textile, gives a lower environmental impact (in terms of climate impact, cumulative energy demand and water scarcity impact) than conventional PUR foam-based alternatives. The largest benefit of the one-polymer solution was due to the possibility to mechanically recycle the multiknit-based upholstery, compared to the PUR foam that was incinerated at end of life. The conclusions and recommendations from this study are to:

- Select materials that enables recycling at end of life, in this case a one-polymer based solution instead of PUR foam
- Select recycled fibre over virgin fibres
- Recycle (or decrease) production waste along the value chain
- Select renewable electricity when possible

6.3.2 Seat trim covering – recycling of textile waste

A workshop was held in autumn 2022, with the purpose to get innovative product ideas from textile waste to avoid down-grading to sound absorbents. All interested project partners participated, and the workshop resulted in different concepts with focus on recycling textile waste from a car to produce something that can be put on the market and sold as accessories. Four different concepts were studied more deeply. Below is an example of one of the concepts.

<u>Neck pillow</u>
One polymer solution upholstery was mechanically recycled by shredding at RISE. First, all plastic parts were cut off. Then the textile, including the backing, was prepared for shredding by cutting in smaller pieces. The shredding was done over several valses. Fibre length was measured and in combination with visual evaluation a decision was taken how far the material was to be shredded.

A mixture of 50% shredded textile and 50% rPET was used and yarn was produced by carding the material, then stretch it in the drawing frame and finally spin it through an Open-End spinning process, that is suitable for short, recycled fibres. Figure 8 show the material during the processing steps. Figure 9 show the slivers and the yarn spinning machine.

Figure 8. Cut one-polymer solution upholstery to the left, material during shredding in the middle and fibers going into the carding machine to the right.

Figure 9. Slivers prepared from the recycle upholstery to the right and slivers fed into open-end yarn spinning machine to the right.

The result was so good that it was decided to go for a bigger pillow as well, see Figure 10. The steps were repeated with more materials. This time the parameters were adjusted so a finer yarn could be spun, and a more delicate fabric produced in a piquet binding. A bigger neck pillow was sewn and assembled by one of the project partners.

Figure 10. Neck pillow prepared from yarn with 50% recycled content based on the recycled upholstery.

Conclusion

To take waste upholstery and mechanical recycle and produce other products is not only workable but also a great impact for the environment and a step forward to a sustainable future.

6.3.3 Seat – New Concepts: Improvement of thermal properties

Most seats in modern vehicles are equipped with electrical heating, and the use of active heating is predicted to increase even more in the future as buyers expect higher and higher comfort for each new vehicle model. Also ventilated seats have become more and more common the last couple of years, a trend which is expected to continue. However, while the demand for seat comfort from the customers increases, so does the demand for an overall more sustainable car industry. Hence, it would be of great benefit if it would be possible to achieve a satisfactory level of thermo physiological comfort without being dependant on active heating or ventilation in the seat. This will probably be an even more urgent problem in the future, with more electrical cars for which secondary consumption of electrical power should be minimized.

The aim of this activity was to explore the possibilities of making electrical heatings and ventilations redundant, or at least reduce the time it needs to be used, by improving the thermo physiological properties of the car seat materials. Therefore, a study was conducted to generate some basic knowledge regarding the influence of different material options for the seat.

A simplified way to express the target is expressed in the question: can we design for sustainability by a simplification i.e. can active heating or ventilation be removed?
In order to answer these questions, there was a need to build knowledge and understand what the thermo-physiological comfort would be like.

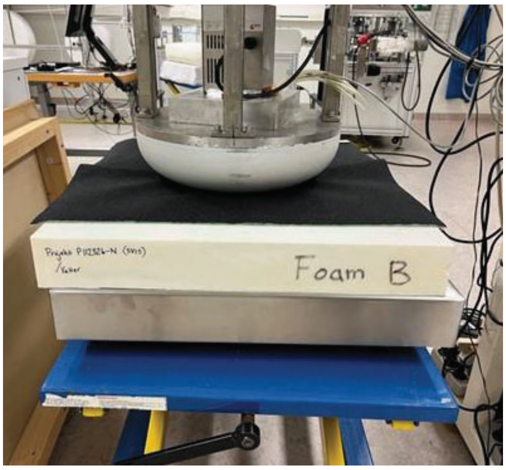

Figure 11. The Heated Indentor

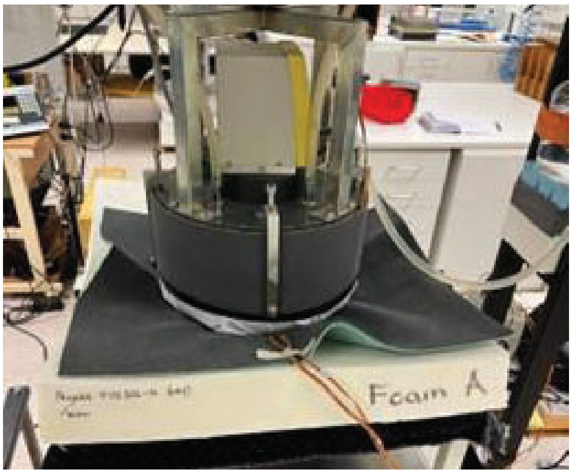

Figure 12. The Sweating Indentor used in the study.

The study included how:

- Conductivity and heat capacity affect the initial temperature sensation using the equipment shown in Figure 11.
- Thermal conductivity and moisture transfer affect the long-term comfort, using the equipment shown in Figure 12.

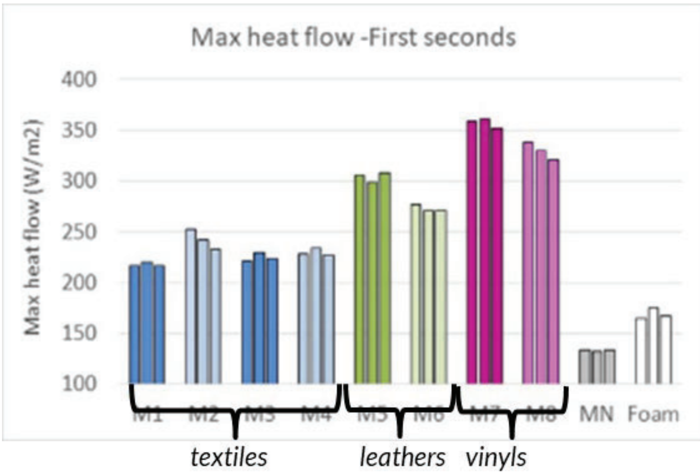

Figure 13 Example of results from the study of heat flow through various upholstery materials.

Conclusions

- Textile leads to the least hot or cold feeling upon contact – vinyl to the most
- woven textile materials allow moisture to be transferred more easily compared to vinyl and leather.
- perforation is an efficient way to increase moisture transfer

6.3.4 Seat-New Concepts: Replace or reduce use of PUR-foam

PUR is widely used in the automotive seating industry due to its good comfort properties, the ability to get complex design surface shapes and durability. However, the production of polyurethane foam is a major source of hazardous air pollutants and, furthermore, is difficult to recycle and therefore regarded as a less sustainable material option. Hence, finding more sustainable options for cushioning material in a seat would be desirable. Basically, the question was if there is an alternative to PUR foam for seats? This question is followed by questions such as what are the alternatives, what are their properties and how comfortable are they?

Answering these questions required building of knowledge and initiated a pre-study with measurements of seat contact pressure. Figure 14 shows a modified seat and Figure 15 shows ongoing pressure measurements.

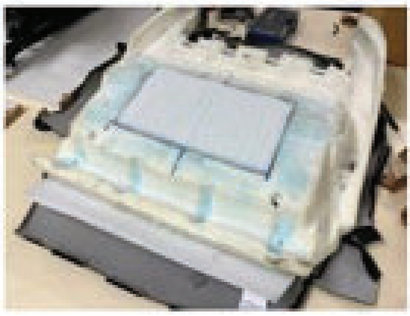

Figure 14. The seat was modified by cutting out a piece of the PUR foam and replacing it with a polyester fiber-based alternative.

The seat frame was provided with the original and modified foam respectively for the different measuring sessions	*The pressure sensor was of type Xsensor PX100 36x36, which was calibrated in conjunction to the measurements.*	*On going pressure measurement.* *Each seat version was tested ten times.*

Figure 15. Photos showing the modified seat and an ongoing pressure measurement.

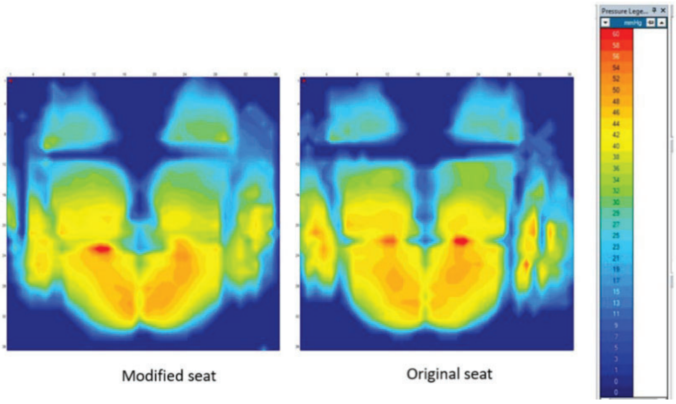

Figure 16. Pressure images of the modified and original seat respectively.

Conclusions show that a_polyester fiber based solution is in par with PUR foam when it comes to mechanical comfort which can be seen in Figure 16, showing almost identical pressure distribution images._The material replacement investigated would result in CO_2 footprint reductions of 0.33 kg /seat.

It should be pointed out that in this study, only short term properties have been investigated. If this solution is considered for real applications several other factors need to be looked into, including long term properties, fire resistance, production aspect, cost etc.

6.3.5 Carpets

All polyester solution

Typical vehicle flooring solutions are composed of a multitude of materials, consisting of fibres, films and foams from completely different polymer families, rendering a low recyclability. Designs with higher recyclability but maintained or improved performance have therefore been investigated within the SVIS project. The solutions delivered, named Scenario 3 and 4, have replaced the polyurethane (PU) foam with decoupler layers based on felts from textile fibres and Bico polyester, and made an effort to reduce the number of different polymers used. Details of the two proposed designs are given in Table 1.

Table 1. Proposed carpet designs

Scenario	Decoupler layer	Surface and substrate layers	Content of PET and derivatives	BHET yield
3	Cotton, rPET, bicoPET	SB rubber, PE, vPET, rPET, polyester derivatives	77%	51 mol%
4	rPET, bicoPET	rPET, vPET, polyester derivatives	100%	60 mol%

Polyester based solutions, most commonly PET, was developed since PET has good recyclability. However, whilst the recyclability of polyester and PET fibres are generally described as an advantage for its use, literature does not investigate or show the recyclability of polyester-based vehicle interior solutions based on different types of polyester. Therefore, the recyclability, through chemical recycling, of these polyester-based vehicle flooring system has been carried out, both a detailed investigation on the recyclability of different carpet components and of the full carpet solutions.

Most of this work was carried out by Master student Karin M Nilsson and the interested reader is directed to her master thesis *Chemical Recycling of All-Polyester Vehicle Interior Solutions - Investigating the Recyclability of PET and PBT Mixes, Including a Polyester Based Vehicle Interior Flooring Solution by Glycolysis, Chalmers University of technology, 2023.*

PET can be chemically recycled through different processes which all depolymerise the polymeric chain into smaller fragments, monomers, which can be utilised as new feedstock. The most widely researched route of the process for this is the solvolysis reaction glycolysis, which has also been applied semi-commercially. Through this process the monomer bis(2-hydroxyethyl)terephthalate (BHET) is obtained, which is traditionally synthesised from petroleum based feedstock. BHET can be used for polymerisation of new PET or used as feedstock for other reactions.

Glycolysis trials – full carpet

Depolymerization of the carpet designs Scenario 3 and 4 gave 51 and 60 mol% BHET yield, respectively. The yield is based on the polyester content of each carpet (Table 8). Depolymerization of a reference 100% PET, gave a yield of 79 mol%, shown in Figure 17. Seemingly the presence of hetero materials decrease the yield of BHET. This is consistent to previous studies performed at RISE where depolymerization of PET in the presence of cotton, elastane and nylon showed a decreased yield of BHET compared to depolymerization of neat PET. Interestingly, even the all-polyester carpet, Scenario 4, showed a decreased yield compared to depolymerization of neat PET. To elucidate the origin of this decrease, a detailed investigation on the recyclability of different carpet components was done.

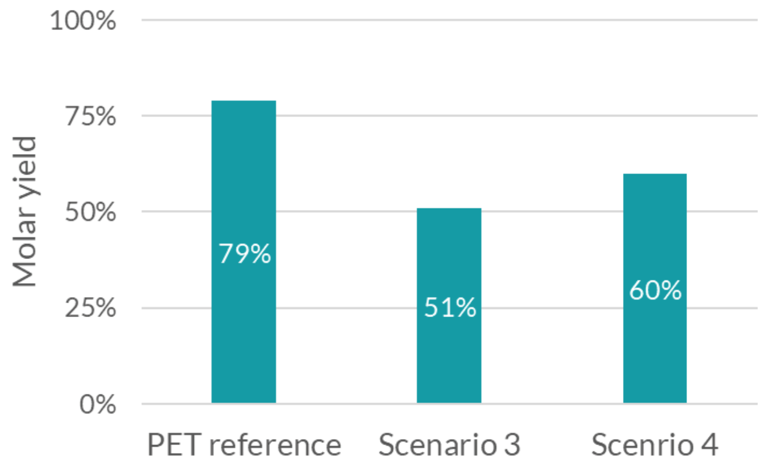

Figure 17. Molar yield of BHET after glycolysis of full carpet designs and PET reference

Glycolysis experiments – carpet components

Polyester based components: PET yarn, transition polyester fibre, polyester primary backing, bicomponent staple fibre and co-polyester film were analysed using Fourier-Transform Infrared (FTIR) spectroscopy and dynamic scanning calorimetry (DSC) to discern their chemical structure. FTIR spectroscopy reveal that all samples show great similarities to PET and poly(butylene terephthalate) (PBT), confirming all materials are terephthalate containing polyesters. While a complete structural investigation was not done, the samples could be clustered on the scale from more PET-like to more PBT-like which is shown in Figure 18.

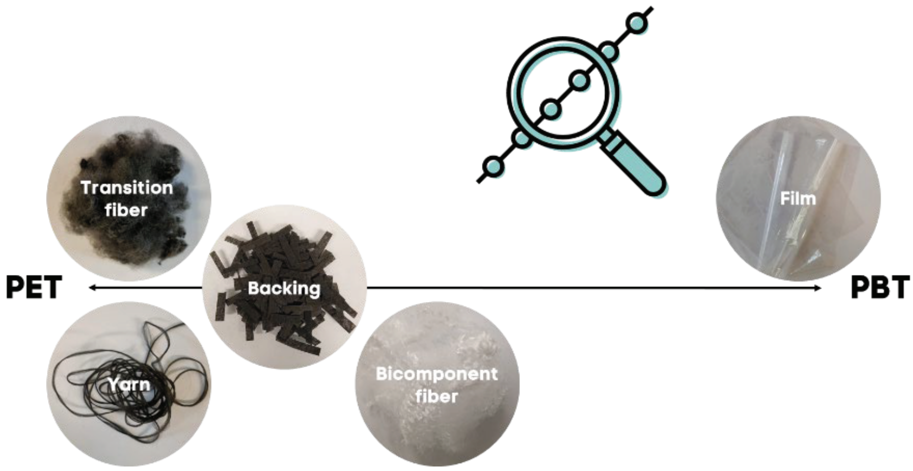

Figure 18. Carpet components clustered along the scale from PET-like to PBT-like

Glycolysis of the different components revealed that the PBT content scaled with the BHET yield, where the more PBT-like materials gave a lower yield as shown in Figure 19?

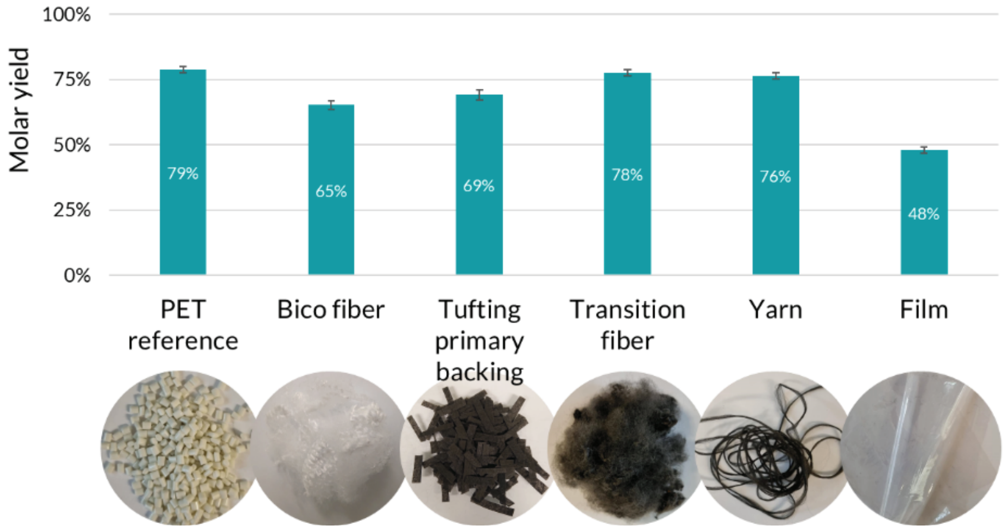

Figure 19. Molar yield of BHET after glycolysis of carpet components

The influence of PBT on the yield of BHET was further studied, using blends of pure PET and pure PBT. While pure PET gives a BHET yield of 79 mol%, pure PBT gave a BHET yield of merely 38 mol% as seen in Figure 20. Interestingly, the mass conversion, which is the conversion of polyester into soluble species, is constant, indicating that while PBT is not recovered as BHET crystals after reaction, it is degraded. The experimental protocol used, both reaction conditions and workup, is optimized to recover BHET from PET. Potentially it is not as efficient to recover BHET from PBT.

To elucidate the impact of workup, which is a series of filtrations and crystallizations at different temperatures, the BHET yields after reaction were compared to BHET yields after workup. For neat PET there is only 2% difference in the yield after reaction and after workup. For neat PBT, instead, the yield in solution is almost double (64 mol%) compared to the yield after workup. Seemingly, the solubility of BHET is different in the reaction mixture yielding from PBT compared to PET and the crystals harder to isolate. Hence, it is anticipated that adjustments to the workup could leverage a higher BHET yield from PBT. However, this is outside the scope of the SVIS project. To further increase the yield of BHET from PBT, the reaction conditions should also be optimized.

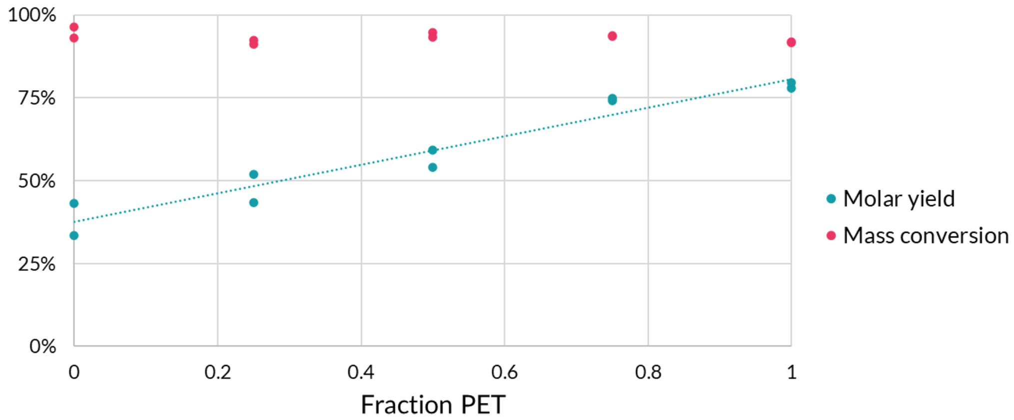

Figure20. Molar yield of BHET and mass conversion from glycolysis of PET and PBT in varying ratio.

Conclusions

The flooring solution is recyclable and gives 60 mol% BHET yield. The yield is at par with yields from other mixed materials, such as polyester/elastane blends but should ideally be increased, to render higher materials recovery. The recovered BHET crystals has a high purity and are white The presence of PBT decreases the yield, the decrease in yield is scaling with the PBT content. Optimisation is required, particularly for workup, to better recover BHET from PBT

6.3.6 Door panels

As described in section 6.2 cut off production waste from door panels can be recycled.

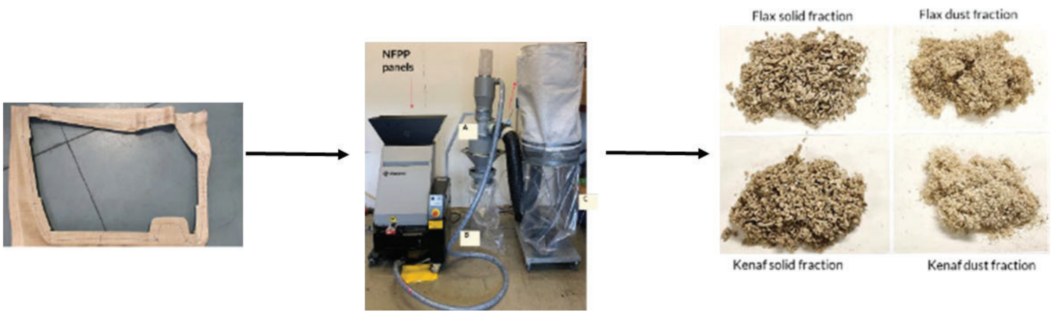

Figure 21. Cut of waste from NFPP panels to the left were fed into a mill (in the middle) with dust separation. The solid fractions and dust fractions are shown to the right.

The NFPP (i.e. pressed material with 50% natural fiber (NF) and 50% PP fibers) cut off was milled with equipment shown in the middle of Figure 21 and dust separation was included. This is necessary when recycling to prepare injection molding quality granulates of PPNF (PP plastic with 20% natural fiber). Figure 21 shows the solid fractions of NFPP and the dust fractions that is the output from the mill. The milled material is fed into a compounder to blend the NFPP with more PP to obtain the injection molding grades. The dust must be removed in order to avoid electrostatic charging of the dust particles that if present, would bridge in the feeder and thus make an efficient feeding impossible.

Door panels made of a composite of natural fibre and thermoplastic has become increasingly popular as construction material due to light weight and the possibility to introduce more biobased material in a component. Complete door panels with covering, were provided by VCC as shown in Figure 22 and used for recycling experiments.

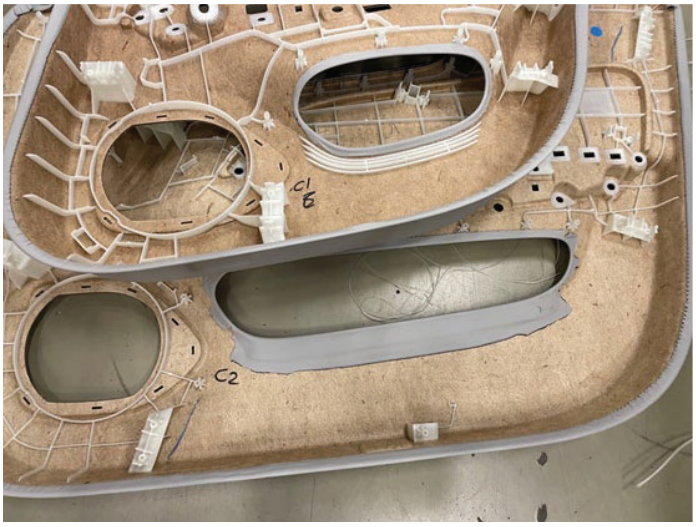

Figure 22. NFPP door panels that were subjected to recycling experiment. The panels had polyolefin foil and foam (TPO), thus representing a one-polymer solution.

The following conclusions were drawn from recycling experiments connected to the door panels and the production waste:

- The production waste of biocomposites can readily be recycled by milling with dust separation and further compounding with virgin or recycled PP to obtain PPNF injection molding grades. Kenaf fibers will contribute with higher impact strength than flax fiber but the properties of the polymer matrix used to prepare PPNF has a large influence on the properties.
- Recycling of complete door panels with thermoplastic polyolefin (TPO) foil and foam show promising results. Future recycling of panels from end-of-life vehicles is a possibility, provided that the biocomposites are separated into a stream that is processed at max. 180°C

6.3.7 Instrument panel

The possibility to recycle and upgrade glass fiber reinforced polypropylene (PPGF) from automotive instrument panel carriers is necessary to illustrate the potential for ELV composites to meet new regulatory standards. By examining mechanical and thermal property alterations through various recycling cycles, we aim to develop effective strategies for material reuse within the automotive industry, in accordance with upcoming ELV regulations. This study seeks to extend the lifecycle of PPGF composites, minimize waste, and contribute to sustainable manufacturing practices.

This study explores the recyclability and upgrading potential of glass fiber (GF) reinforced polypropylene (PP) composites. Results demonstrate that recycled PPGF composites retain considerable structural integrity and that mechanical properties can be effectively restored through strategic additions of glass fibers, impact modifiers & removal of shorter fiber fractions. Comparative analysis of end-of-life panels validates the recycling viability of aged composites, aligning with automotive sustainability ambitions. A diploma work was performed that reveals more details for the interested reader[12].

Newly produced instrument panel carriers, as shown in Figure 23, produced by IAC Group, made of 20 wt. % glass fiber-reinforced polypropylene composites (PPGF) were reprocessed through milling, compounding, and injection molding. After each processing step, fiber length characterization, testing of thermal properties (OIT) and testing of mechanical properties (impacts tests, tensile tests) were conducted. The process is shown in Figure 24.

In addition to testing the recyclate, experiments were also conducted by adding different types of glass fibers to the mix as well as impact modifiers. A separate experiment was also conducted by sieving the recyclate after the milling step in order to remove the smallest particles from the recyclate. A naturally aged instrument panel (AzPPGF) was tested as well to see how the properties had changed after several years in a desert environment.

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Figure 23. Image of an instrument panel for recycling

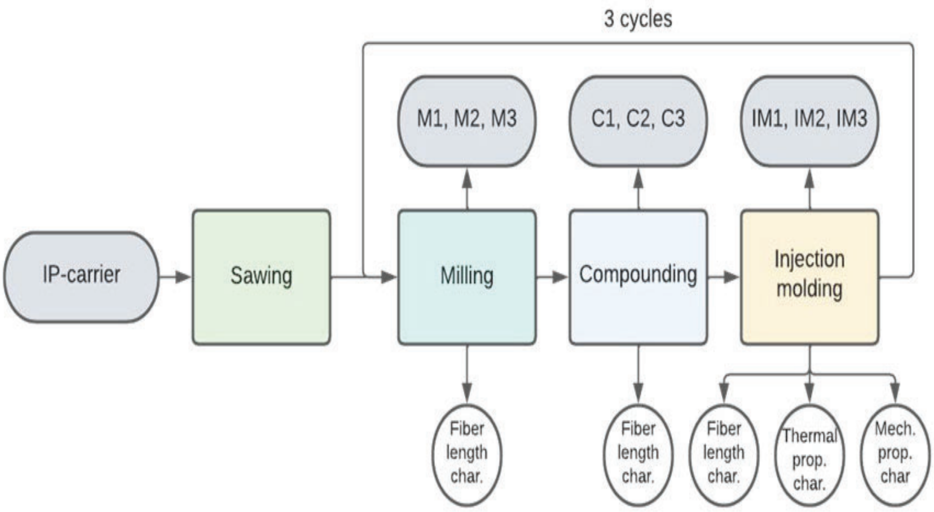

Figure 24. Processing route of PPGF samples

Results

Mechanical Property Retention:
Recycled PPGF composites displayed diminished tensile and impact strengths across cycles yet retained structural integrity, as shown in Figure 25. Upgrading with virgin and recycled glass fibers variably restored mechanical properties. The same can be said for the ELV component too.

Fiber Length:
Fiber length was directly linked to composite strength, with processing-induced shortening undermining mechanical properties. Maintaining length is vital for performance retention. The results of fibre length measurements in the relation to the recycling processing steps are shown in Figure 26.

Thermal stability:
Thermal stability decreased with each recycling cycle, with end-of-life panel (sample denoted AzPPGF) exhibiting lower oxidative induction times (OIT), indicating antioxidant depletion and matrix degradation which is shown in Figure 27.

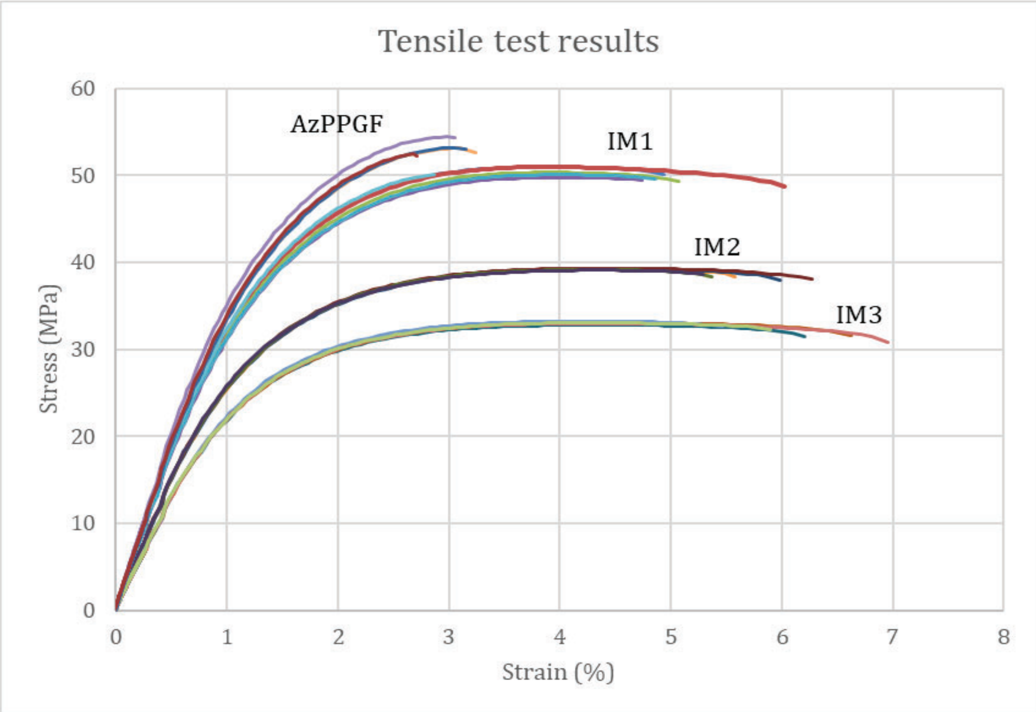

Figure 25. Mechanical properties of the recycled and ELV samples

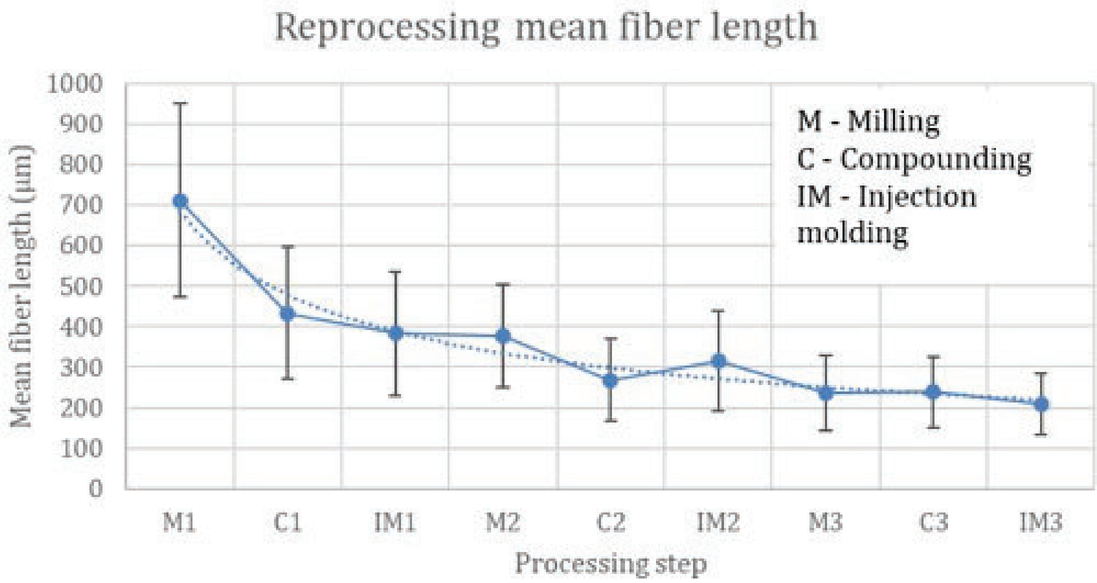

Figure 26. Fiber length of samples during recycling.

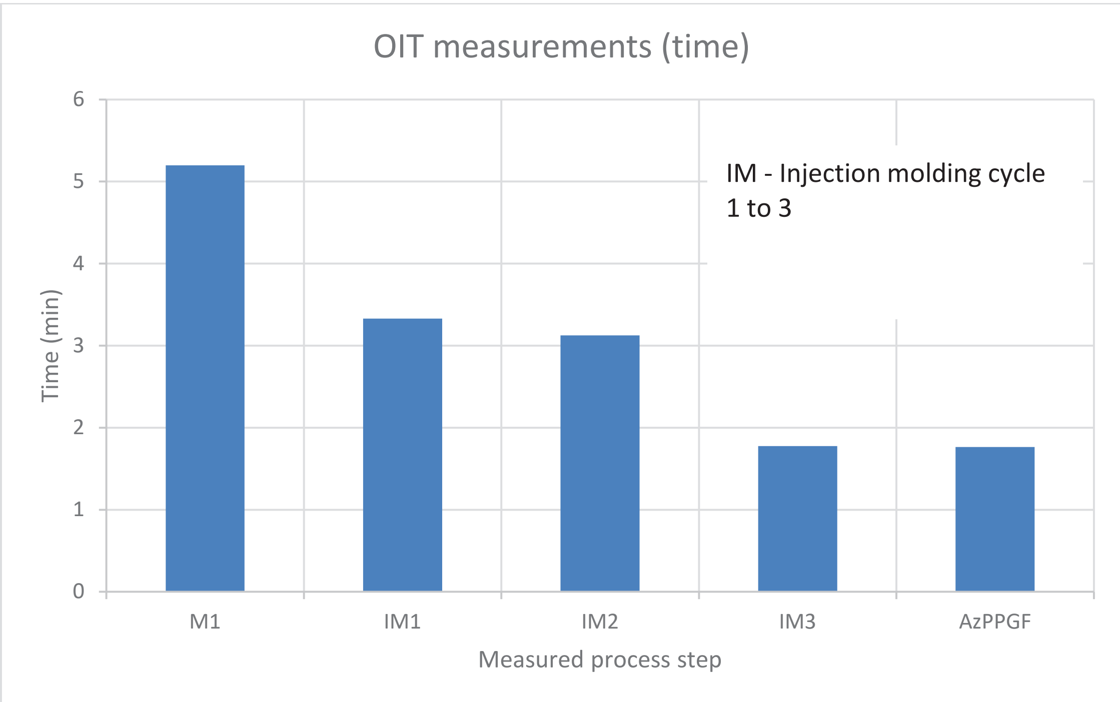

Figure 27. Thermal stability of recycled and ELV samples.

Upgrading Strategies
Sieving out sub-critical fiber lengths proved essential for enhancing mechanical properties, suggesting its utility as a cost-effective method for quality improvement in recycling. The results from sieving experiments are shown in Figure 28.
Post-consumer (PCR) and post-industrial (PIR) glass fibers showed potential for upgrading recycled composites. However, these fibers necessitated additional processing due to their lack of original sizing and this affects the adhesion between matrix and fiber.

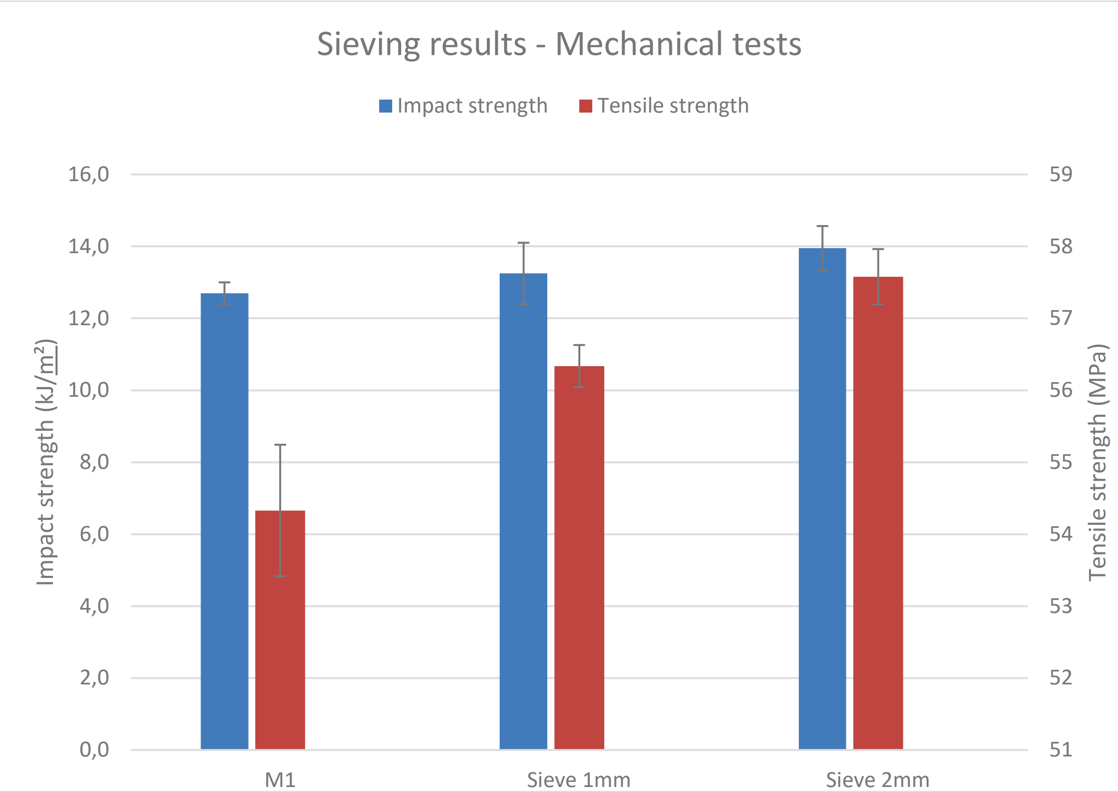

Figure 28. Comparative impact properties of sieved samples.

Conclusions
The study underscores the recycling viability of PPGF composites, crucial for meeting ELV regulations. Recycled composites maintain structural integrity, and their properties can be enhanced through strategic additions of glass fibers and additives. Removal of shorter fractions emerges as an effective technique to elevate material quality. Comparative analysis of new versus aged composites supports the potential of recycling end-of-life components, facilitating compliance with sustainability goals. These findings offer actionable insights for the automotive industry, promoting the adoption of sustainable practices in vehicle manufacturing and contributing to the advancement of material innovation, in line with ELV regulatory requirements.

6.3.8 Pillar

PC/ABS is a strong engineering plastic used in demanding applications such as interior pillars. The pillars must stand the impact of a collision without breaking when airbags inflate. Recycling of the complete pillars with PC/ABS and polyester textile show mechanical properties in the same level as virgin samples. Injection moulded pillars with 30% recycled content pass crash testing, thus indicating the possibility for closed loop recycling

Mechanical recycling of production waste by size reduction of the plastic, followed by feeding a certain proportion back into the process is an efficient way of using the raw material. Removing the textile from the pillars would therefore be the most efficient way of retaining the value of the PC/ABS blend.

Size reduction by shredding or milling of plastic production waste is common in the plastic industry. The textile covered pillars shown in Figure 29, were size reduced in a mill with a dust separating unit, making it possible to obtain the heavier PC/ABS in one fraction and the lighter polyester fluff in another fraction. However, it turned out that the adhesion created during back injection moulding between the plastic and the textile fleece was very strong.

A sample of milled pillars containing a mixture of PC/ABS and polyester textile pieces and a sample of milled pillars that had been separated twice, obtaining one fraction of almost pure PC/ABS and a fraction of textile fluff were prepared for compounding and injection moulding of test bars. The polyester textile fluff contained a large portion of PC/ABS due to the strong interaction mentioned above. The twice separated sample had therefore a very low yield of PC/ABS after separation. The fractions after milling are shown in Figures 30 and 31.

Testing of the mechanical properties according to ISO 527 and ISO 179 ea showed surprisingly enough only small differences between the separated and the not separated samples. The only property that showed a decrease was the strain at break, and this difference was observed also when virgin PC/ABS pellets were recycled. The decrease was concluded to depend on the thermal influence on the PC/ABS and not the polyester.

Figure 29. Polyester textile covered pillar of PC/ABS

Figure 30 Textile covered pillar milled with textile

Figure 31"dust separated" by milling twice

An interesting question is why do the mechanical recycling of PC/ABS/polyester works. Analysis by SEM on crosscut and ion etched sample surfaces showed, in Figures 32 and 33, that the polyester phase was incorporated in the PC phase as lighter ”islands”. The SEM images reflect the atomic number of the material by the grey shade as shown in the images below. The whitish PET islands are circled with red. The polyester content is at most 12 w% for a complete pillar in this study and this content had no influence on the mechanical properties. The positive insights led to the question: how can these results be used?

A larger amount of production waste i.e. complete pillars with polyester textile covering were milled, compounded and 30% recycled material was mixed with PC/ABS to produce new pillars.

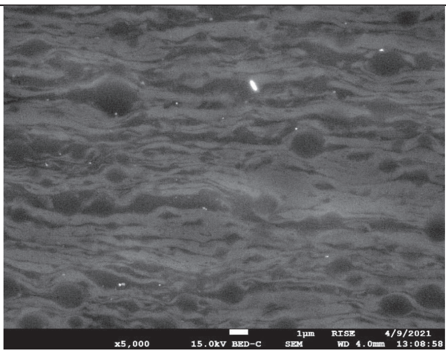

Figure 32Morfology of PC/ABS virgin material

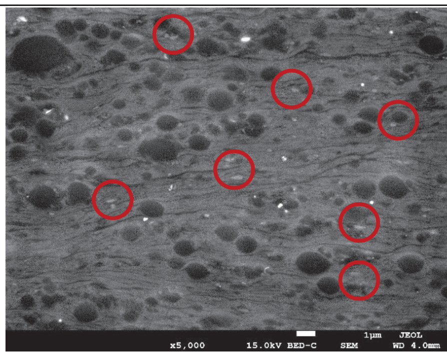

Figure 33 Morfology of PC/ABS recycled with polyester textile

Crash testing was performed and Free Motion Head form Requirement from National Highway Traffic Administration (FMVSS 201) and Occupant Protection In Interior Impact (standard No. 201) were used to test the performance of pillars with 30% recycled content in comparison with conventional pillars. The physical deformations on a pillar containing recycled content and a pillar with only virgin content, are almost identical. This is shown on in Figures 34 and 35, with arrows showing the deformed structures and resulting cracks.

The results in the diagram in Figure 36, display the head acceleration vs displacement and shows very similar results for the pillar with virgin material (green curve) and the pillars with 30% recycled content.

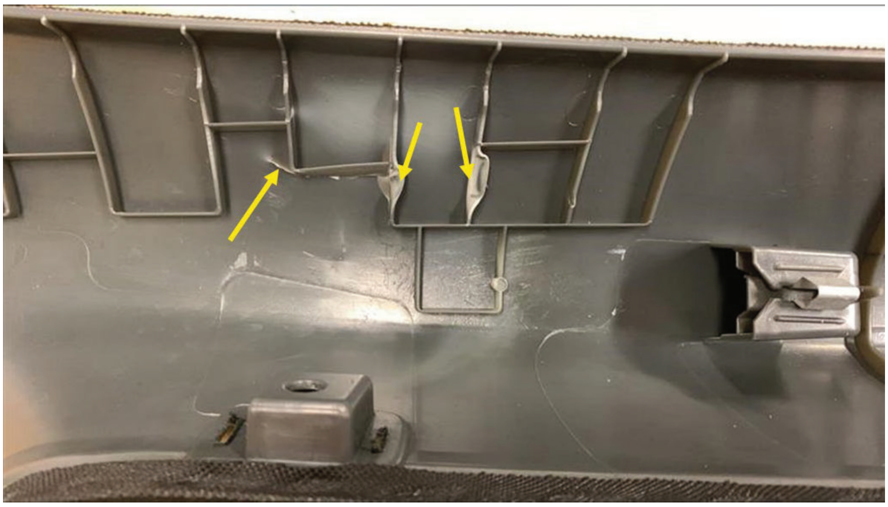

Figure 34. Pillar with 30% recycled content Arrows showing deformation and crack from crash test

Figure 35. Pillar with 100% virgin content . Arrows showing deformation and crack from crash test

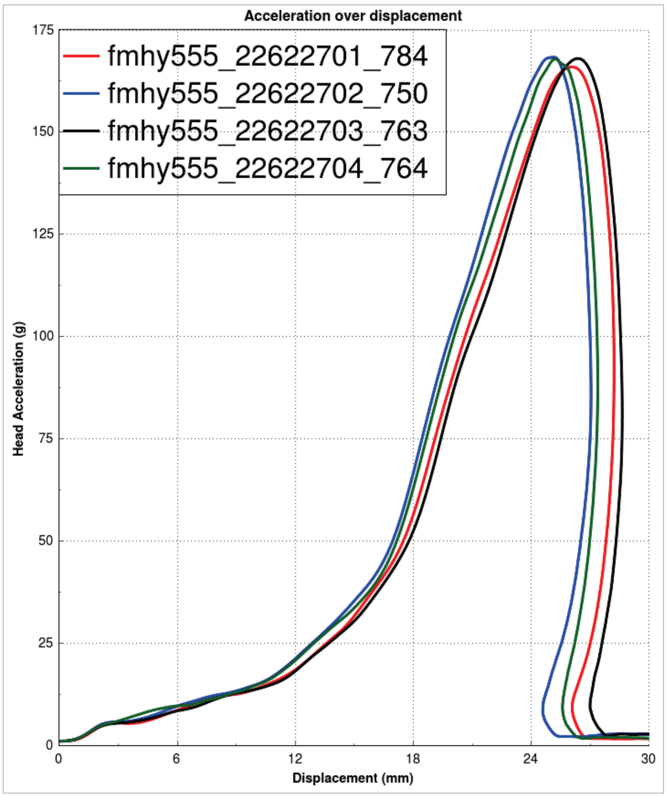

Figure 36. Head acceleration vs dispalcement for 3 samples of pillar with 30 recycled content compared to the pillar with virgin content (green curve)

Conclusions
Recycling of production waste of textile covered pillars of PC/ABS showed that the mechanical properties were very similar to the virgin PC/ABS even when the complete polyester textile (around 12 w%) was included in the material. It is suggested that the good mechanical properties of recycled PC/ABS/polyester can be explained by the fact that PET is compatible with the PC and appears to be incorporated in the PC matrix. Injection moulded pillar with 30% of recycled content pass the crash tests, thus indicating the possibility to close loop recycle the industrial waste of pillar.

More details on the recycling of polyester covered pillars of PC/ABS can be found in a master thesis[13]

6.4 Results from a workshop in the project-an example

Almost all upholsteries used on cars seats today consist of several different materials to create good appearance and durable seats. The visible surface materials are e.g. leather, vinyl and textile. The rear side of the upholstery consist in general of a number of different textiles, plastic and metal parts to keep the upholstery in place.
The aim of the case study "Reduction of production waste" for seat, was to see how we can create a more sustainable upholstery by thinking differently. We wanted to end up with less production waste and in the end also have an upholstery that was easier to recycle at the end of life, since less different material had been used.
We started with a small brainstorm session to find all different aspects/solutions that together could create the best solution. It would also be interesting to rank them to see which were most feasible to do or would be most valuable for sustainability and circularity. Most likely it would be impossible to use all ideas in one upholstery, but we could probably combine parts of them. Some of the questions we came up with were:

- Is it possible to use less variants of materials in the upholstery?
- Are all materials needed, or can we think differently?
- Can a better material utilization degree be achieved, and the waste minimized in production?
- Does shape, material, number of parts etc need to be changed?

Figure 37 show the topics that were further discussed to refines ideas and continue the work. The workshop continued with more specific details and solutions were found as how certain procedure should be changed. The workshop resulted in several ideas that were realized within the project.

[13] FULLTEXT01.pdf (diva-portal.org)

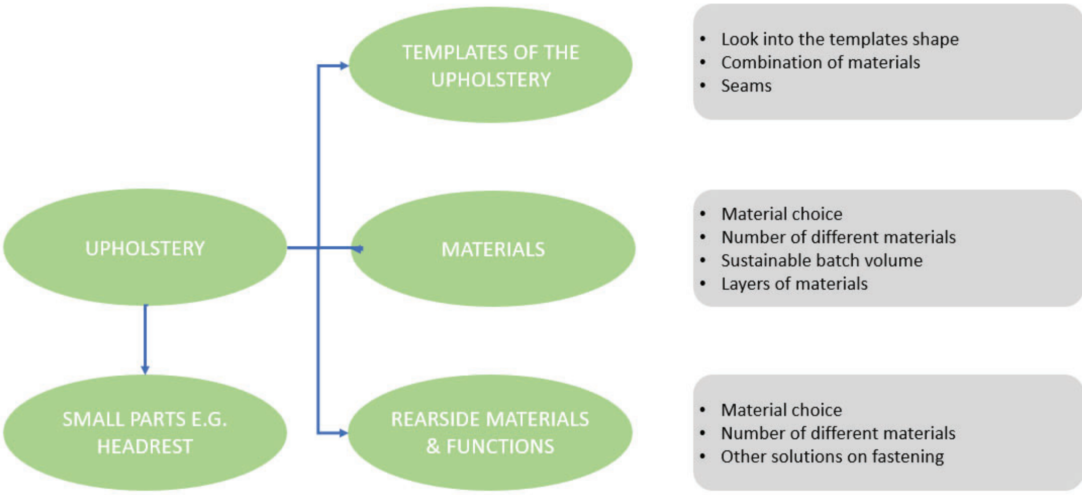

Figure 37. Schematic outcome of a workshop on "Reduction of production waste" for upholstery.

6.5 Exhibition, lectures, workshops and group discussions

The project exhibition was held 14-15 May 2024 in Volvohallen, Gothenburg. 14 May was reserved for exhibition preparations in the morning, followed by a final project meeting. 15 May was reserved for presentations for a more general audience and exhibition of each components presenting results with posters (totally totally 9 posters and 2 screen presentations), samples and items that had been prepared. Project partners exhibited their products a/o processes. Project partner colleagues were invited to take part of the project results.

The presentations focused on summarizing results, partners presenting "Lessons learned" during the project and panel discussion about ELV. Volvo Cars Sustainability Strategy looking to 2040 was presented as well an interesting example a development project at VCC: "Increased recycled content and enabling circularity for carpets".

The photos below represent a very interesting event with good discussions about achieved results and future possibilities.

Figure 38 The SVIS exhibition was held in Volvohallen 14-15 May 2024

Figure 39. Presentation given by VCC.

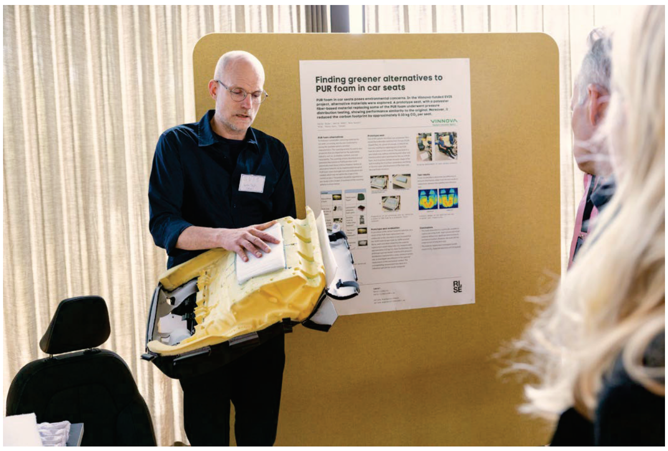

Figure 40. RISE colleague presenting samples as measurements from Seat -alternatives to PUR foam.

Figure 41 RISE colleague discussing results with visitors


Figure 42. Samples of recycled textile from various steps in the process.

The following lectures were given during the project:

Lecture 1: Recycling plastics and textiles
Lecture 2: LCA
Lecture 3: Quality assurance of recycled plastics
Lecture 4: Chemical recycling of plastics and textiles
Lecture 5: Volvo Strategy regarding sustainability
Lecture 6: Sustainable materials – consumer view
Lecture 7: Plastics recycling - Regulations and Standards
Lecture 8: LCA Part 2
Lecture 9: Proposed ELV Directive

Lecture 10: Circular business models
Lecture 11: Current and future perspective on how to recycle plastics

Workshop 1-4: One workshop for each component; Instrument panel, Seat-Upholstry, Carpet and Pillar
Workshop 5: Textile waste recycling (starting from Seat-Upholstry)
Workshop 6: New seat design
Workshop 7: Requirements for recycled/sustainable materials
Workshop 8: Requirements No 2.

Group discussions at project meetings:

- Design for disassembly – groups discussed different components
- Products from textile waste other than sound absorbents
- Future seat concepts
- Recycling of laminated textiles and/or PU foam:
- Pathways of upholstery waste into plastic components
- One-polymer solutions for plastic components
- What do you wish for the remaining project?
- Ideas for new projects (after SVIS)

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	x	The “Handbook” containing results and experiences from the project will be shared among the partners and it will be used as further reference as how to work toward the objectives of resource efficiency and collaboration within the value chain. RISE is publishing a “Story” on ri.se that will describe the benefits of the project with interviews of project partners The project results will be presented at a webinar arranged by “Klimatledande Processindustri” in October 2024.
Be passed on to other advanced technological development projects	X	Increased competence of individuals will be the main way to forward results, ideas and way of working, into new projects.
Be passed on to product development projects	x	Increased competence of individuals will be the main way to forward results, ideas and way of working, into new projects.
Introduced on the market	x	Some partners are close to opening new production planned for zero waste. Others are planning recycling experiments as a continuation of the collaboration that has been established.
Used in investigations / regulatory / licensing / political decisions		

7.2 Publications

Nilsson Karin M.: “Chemical Recycling of All-Polyester Vehicle Interior Solutions - Investigating the Recyclability of PET and PBT Mixes, Including a Polyester Based Vehicle Interior Flooring Solution by Glycolysis”, Chalmers University of technology, 2023.

Hansson Charlie and Larsson Oscar: “Recycling and upgrading of glass fiber reinforced polypropylene composites”, Chalmers University of Technology 2022

Wennerstrand Esther: “Recycling of Textile and Plastic from an Interior Vehicle Component”, KTH Royal Institute of Technology School of Engineering Science in Chemistry, Biotechnology and Health Department of Fibre and Polymer Technology 2021

8.Conclusions and future research

As short conclusions have been given for each component throughout chapter 7, this chapter will focus on overall conclusions related to future research and the need for increased sustainability in the automotive industry.

- **Collaboration within the value chain:**
  Discussions during workshops have repeatedly shown that partners sharing experiences have been "eye-opening". An example is a subcontractor describing certain features in the interior design that cause 90% waste while 10% of the material used became product. Knowing this would possibly make the OEM consider removing such features.
  Another example was suggestions coming up during discussions about how recycled material can be introduced in products. It was suggested that subcontractors may present recycled alternatives to be followed by a discussion about requirements, instead of regarding requirements to being carved in stone.

  The fact that time has been set aside for workshops focusing on sustainability and recycling have given the opportunity for creative ideas to be shared. This would not have happened, had not the project meant reserving time for the topic. This is an important learning for the future. Partners also share that they have a new way of thinking when it comes to how resources are handled, if materials can be reused or recycled and if a material can have a second life.

- **Real reduction of production waste:**
  The most successful examples of reduction of production waste have been made possible due to good planning and short geographical distances. The fact that transportation is a cost both regarding costs and emissions is an important hinder for resource efficiency.

- **Lack of value chains for recycling:**
  The concept of "One-polymer solution" is a good starting point when it comes to design for recycling. However, even though good results have been achieved in the project for components that have been re-designed (carpet) or experiments performed (instrument panel, seat-upholstry), there is a lack of recycling infrastructure to really increase the materials' utilization. The different scenarios described for the carpet are interesting examples. If the carpets were dismantled, it would be possible to chemically recycle the material with a high quality product allowing for closed loop recycling. Another alternative would be a much more advance handling of the plastic and textile fraction after shredding ELV. The lack of specific recycling processes is probably the biggest hindrance for a more resource efficient use of material when it comes to interior vehicle components.

9.Participating parties and contact persons

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