BioForm, hållbara och miljövänliga material för vakuumformade produkter i fordon

Public report

Project within Vinnova FFI
Author Andreas Åhrlin, Xinfeng Wei, Thomas Prade
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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.

For more information: www.ffisweden.se

1 Summary

The Bioform project introduced three types of bio-based fillers: 1) cellulosic fiber-based filler/chips, 2) lignin-based filler, and 3) biochar-based filler, with the goal of creating vacuum-formable materials to replace fossil-based plastics with bio-based alternatives. These materials were designed to meet the processability and performance requirements for automotive applications. The project incorporated high bio-based content into Acrylonitrile Butadiene Styrene (ABS), achieving a significant carbon footprint reduction of up to 40%. Testing revealed that long, fiber-shaped fillers were unsuitable for vacuum forming, as they negatively affected formability. However, biochar and lignin-based composites demonstrated good processability for both extrusion and vacuum forming, resulting in the successful production of a miniature roof box prototype.

A thorough evaluation of the material properties showed both benefits and challenges. The composites exhibited a moderate increase in modulus, indicating enhanced stiffness, and a significant improvement in flame retardancy. On the downside, the strength and ductility of the composites were reduced. This reduction was addressed by introducing a compatibilizer to enhance ductility. The developed materials showed strong potential for industrial scalability and recyclability. A vacuum-formed heater cover demonstrator was successfully produced.

2 Sammanfattning på svenska

Ett fordon består delvis av plastkomponenter som är tillverkade av olika plastmaterial och med olika bearbetningsmetoder. Eftersom det mesta av den plast som används för fordonskomponenter är baserad på fossila råvaror såsom råolja eller naturgas, finns det alltid ett visst klimatavtryck förknippat med dessa material. Bland strategierna och lösningarna för att minska klimatavtrycket för plastkomponenter finns återvunna material och resurssmart användning samt biobaserade material. Formsprutning är den dominerande bearbetningsmetoden för fordonskomponenter, varför forskning om hållbara material för fordonskomponenter fokuserar på formsprutning. En annan viktig bearbetningsmetod för tillverkning av fordonskomponenter i stora format och mindre serier är vakuumformning. De material som används för vakuumformning idag kommer till största delen från återvinningsbara polymera material som kommer från fossila råvaror och skiljer sig till viss del från de material som används för formsprutning.

Ett första mål med detta projekt var att hitta potentiella kompositmaterial som är lämpliga för vakuumformning, där biobaserade fyllmedel används och där matrismaterialet innehåller största möjliga mängd biobaserad råvara, vilket i båda fallen bör fungera bra för vakuumformning. Med biobaserade tillsatser med förstärkande egenskaper erhålls en

produkt med lägre klimatpåverkan. Ett andra mål med projektet var att möjliggöra en biobaserad andel på minst 50 % i vakuumformade produkter för fordonsindustrin och en viktminskning av dessa med 20 %. Ett tredje mål var att sänka materialets klimatavtryck med minst 30 % jämfört med konventionella material för vakuumformning.

Projektet syftade till att undersöka och utvärdera termoplastiska material med biobaserade tillsatser avsedda för komponentproduktion genom vakuumformning, för att demonstrera tillämpningen av dessa material för applikationer till kommersiella fordon och kvantifiera det lägre klimatavtrycket jämfört med dagens konventionella material för vakuumformning. Ett av angreppssätten är att biobaserade restprodukter, till exempel lignin från skogsindustrin, används som fyllnadsmaterial. Genom att utveckla dessa nya material och få nödvändig kunskap om deras egenskaper och bearbetning möjliggörs tillämpningen av dessa material i fordonsapplikationer för att möta fordonsindustrins ökade krav på lägre klimatavtryck. Projektet genomfördes med aktörer längs hela värdekedjan från materialtillverkare via komponenttillverkare till slutanvändare.

Bioform-projektet introducerade tre typer av biobaserade fyllmedel: 1) cellulosafiberbaserat fyllmedel/spån, 2) ligninbaserat fyllmedel och 3) biokol-baserat fyllmedel, med målet att skapa vakuumformbara material för att ersätta fossilbaserade plaster med biobaserade alternativ. Dessa material har utformats för att uppfylla kraven på bearbetbarhet och prestanda för fordonstillämpningar. Projektet införlivade upp till mer än 40 viktprocent biobaserat innehåll i akrylnitrilbutadienstyren (ABS), vilket uppnådde en potentiell minskning av koldioxidavtrycket på upp till 40 %. Tester visade att långa, fiberformade fyllmedel dock var olämpliga för vakuumformning, eftersom de påverkade formbarheten negativt. Biokol- och ligninbaserade kompositer visade dock god bearbetbarhet för både extrudering och vakuumformning, vilket resulterade i en framgångsrik produktion av en prototyp av en takbox i miniatyr.

En grundlig utvärdering av materialens egenskaper visade på både fördelar och utmaningar. Kompositerna uppvisade en märkbar ökning av E-modulen, vilket indikerar ökad styvhet, och en signifikant förbättring av flamskyddet, särskilt när biokol och lignin användes tillsammans, på grund av en synergistisk effekt. Till det negativa, minskade kompositernas styrka och duktilitet. Denna minskning åtgärdades genom att introducera en kompatibilisator för att förbättra duktiliteten. De utvecklade materialen visade en stark potential för industriell skalbarhet och återvinningsbarhet. En vakuumformad demonstrator av ett vakuumformat hölje togs fram med goda resultat.

Biokompositerna som utvecklats i denna studie utgör ett betydande genombrott för **fordonssektorn** och erbjuder ett hållbart alternativ till konventionella petroleumbaserade material. Med förbättrat **brandskydd**, **mekanisk prestanda** och **miljöfördelar** är dessa biokompositer mycket lämpliga för olika fordonsapplikationer, inklusive **inredningsdetaljer**, **instrumentbrädor**, **dörrpaneler** och **takboxar**.

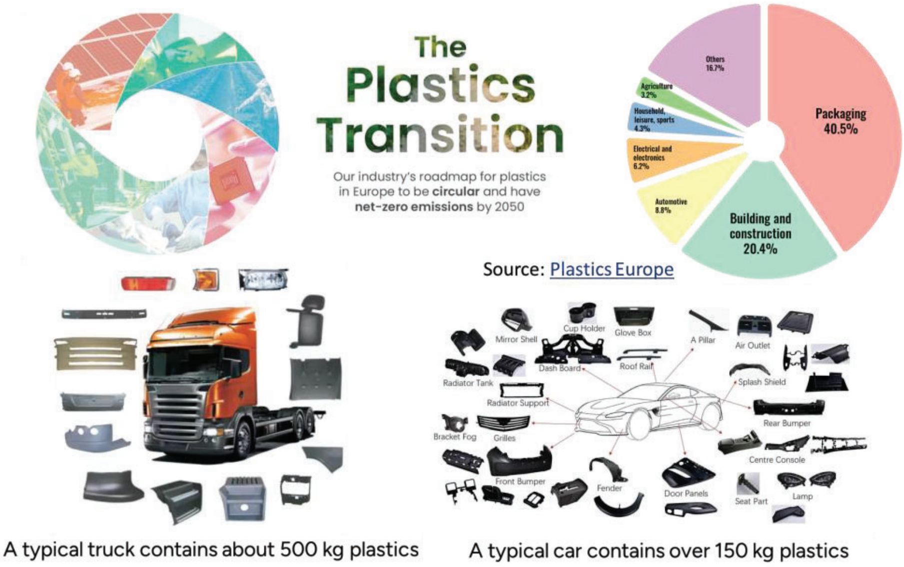
Brandsäkerhet: Den förbättrade flamskyddsförmågan visar att materialen potentiellt skulle kunna användas i fordonskomponenter, särskilt i områden där brandmotstånd är kritiskt.
Mekaniska egenskaper: Materialets ökade märkbart utan betydande kompromiss i bearbetbarhet stöder dess användning i strukturella komponenter för fordon. Dessutom förbättrar introduktionen av kompatibilisatorn duktiliteten och segheten, vilket gör dessa biokompositer mer motståndskraftiga i applikationer som kräver flexibilitet och slagtålighet.
Hållbarhet: Minskningen av koldioxidavtrycket med upp till 40 % positionerar dessa material som en hållbar lösning för att uppfylla bilindustrins hållbarhetsmål, särskilt med strävan att minska utsläppen av växthusgaser och beroendet av fossilbaserade resurser till 2050.
Bearbetbarhet: Den framgångsrika storskaliga produktionen av dessa biokompositer, demonstrerad genom extrudering och vakuumformning, bevisar att materialet enkelt kan integreras i befintliga tillverkningsprocesser, vilket gör det idealiskt för massproduktion inom fordonsindustrin.

Trots goda resultat i projektet, uppnås inte de usprungliga målen helt. Målet att möjliggöra en biobaserad andel på minst 50 % i vakuumformade produkter för fordonsindustrin och en viktminskning av dessa med 20 % uppnås inte. Vi lyckades tillverka en produkt med över 40 % biobaserad andel, vilket är mycket nära det uppsatta målet på 50 %. Men en högre andel biobaserade produkter ledde till svårigheter med sammansättning och oönskad försämring av vissa egenskaper.

3 Background

A vehicle partly consists of plastic components which are manufactured from different plastic materials and through different processing methods. Since most of the plastic used for vehicle components is based on fossil raw materials such as crude oil or natural gas, there is always a negative carbon footprint associated with these materials. Among the strategies and solutions to lower the carbon footprint for plastic components are recycling of materials and resource-smart use such as partial replacement with bio-based materials. Injection molding is the dominant processing method for vehicle components, which is why research into sustainable materials for vehicle components focuses on injection molding. However, another significant processing method for manufacturing automotive components is vacuum forming. The materials used for vacuum forming today mostly come from recyclable polymeric materials originating from fossil raw materials and differ to some extent from the materials used for injection molding.

The project investigated and evaluated thermoplastic materials with bio-based additives intended for component production by vacuum forming, to demonstrate the application of these materials for applications to commercial vehicles and quantify the climate footprint compared to today's conventional materials for vacuum forming. One of the approaches was that bio-based residual products, such as lignin from the forest industry, were used as fillers. By developing these new materials and obtaining the necessary knowledge about their properties and processing, the application of these materials to vehicle applications was made possible in order to meet the automotive industry's increased demand for lower climate footprints. The project was carried out with stakeholders along the entire value chain from material manufacturers via component manufacturers to the end user.



Source: Plastics Europe

A typical truck contains about 500 kg plastics

A typical car contains over 150 kg plastics

Fig. 1. Background of the plastic transition and the use of plastics in automobiles.

4 Purpose, research questions and method

It is a challenge to produce composite materials that are suitable for vacuum forming. If we succeed in this, the competitive advantages are very large and the possibilities for taking a big step towards bio-based resource-efficient products are enormous. Today, there are very few known reports where fillers were used in vacuum formed parts. The reason is most likely that it is a challenge to produce such products. Vacuum forming involves stretching the material in a molten/softened state. In order for pores not to occur in the material due to the rigid filler releasing from the polymer matrix during deformation, strong bonds are required between filler and matrix. The height of innovation here means that a system was developed where the rigid filler obtains sufficient bonding to the matrix so that pores are not formed. In the project, we tested several parallel hypotheses for sufficient bonding, which include chemical modification of the filler to make the surface mimic the matrix material, chemical bonding between filler and matrix (added coupling agent) and use of compatibilizer (material that resembles both the surface chemistry of the filler and the chemistry of the matrix material). The latter formed a physical bond between filler and matrix. All these methods are well proven in other manufacturing techniques, but not yet for vacuum forming, which thus presented an additional challenge. Vacuum forming is one of the most attractive methods for large parts (> 1 m^2) where the batch sizes cannot justify the more expensive tooling required in, for example, injection molding. A strong trend in the automotive industry is a more differentiated product portfolio. This leads to lower batch sizes and then vacuum forming is a suitable manufacturing method with a competitive price/performance combination.

In the project, we aimed to answer a number of research questions; Which filler is best suited for vacuum forming? Can pores be avoided through an optimized compatibility between matrix and filler (surface modification/compatibilization)? Can the vacuum process be modified to facilitate the manufacture of composite materials? How can it be ensured that the products and waste materials are possible to recycle?

5 Objective

The goal of this project was to find potential composite materials that are suitable for vacuum forming, where bio-based fillers are used and where the matrix material contains the largest possible amount of bio-based raw material, that should still work well for vacuum forming. With bio-based reinforcing fillers, a product with a lower climate impact is obtained. The goal of the project is to enable a bio-based share of at least 50% in vacuum formed products for the automotive industry and a weight reduction of these by 20%. The goal is also to lower the carbon footprint of the material by at least 30% compared to conventional materials for vacuum forming.

6 Results and Deliverables

6.1 ABS filled with biochar and/or lignin

Introduction: The global push toward sustainability and reducing greenhouse gas emissions by 2050 has led to a focus on developing bio-based materials to replace petroleum-based plastics. Acrylonitrile butadiene styrene (ABS), commonly used in automotive applications, can be enhanced through the incorporation of bio-based fillers such as lignin and biochar, reducing its carbon footprint and enhancing flame retardancy. Both biochar, derived from the pyrolysis of organic materials, and lignin, a byproduct of the paper industry, offer unique properties such as improved stiffness and fire resistance, making them ideal for use in biocomposites.

Materials and Methods: ABS was mixed with lignin and biochar to create biocomposites. The process involved various production steps and a demonstrator was produced. Tests were conducted to assess mechanical properties, thermal stability, and flame retardancy.

Results:

- The combination of lignin and biochar somewhat improved the material's flame resistance.
- The stiffness of the composites improved, though there were some trade-offs in other properties.
- Lignin affected thermal stability, while biochar had a relatively smaller impact.
- The composites processed well, indicating some potential for industrial applications.
- The use of bio-based materials led to a certain reduction in climate impact.

Conclusion: The combination of lignin and biochar in ABS improved sustainability, flame retardancy, and stiffness, though there were some trade-offs in strength and thermal stability.

6.2 ABS filled with lignin modified with compatibilizer

Introduction: Bio-based fillers like lignin improve sustainability in polymers but reduce ductility. A compatibilizer was added to ABS/lignin blends to enhance ductility without compromising mechanical properties. This study examined the mechanical performance and environmental impact of these biocomposites.

Materials and Methods: ABS was blended with lignin and a compatibilizer (5% and 10%), processed via extrusion and molding. Mechanical properties and global warming potential were assessed.

Results:

- The compatibilizer improved strain at break and toughness.
- Stiffness remained stable, though tensile strength decreased with higher lignin content.
- Carbon emissions were reduced with bio-based materials.

Conclusion: The compatibilizer significantly improved ductility and toughness in ABS/lignin blends, with reduced climate footprint, making these composites suitable for industrial applications.

6.3 Demonstration

The large-scale production and processing of the ABS/lignin/compatibilizer biocomposite materials were successfully demonstrated in collaboration with multiple industry partners. First, **Lignin Industries AB** compounded over 500 kg of the biocomposite material using an industrial-scale twin-screw extruder. This large batch production confirmed that the materials maintained good processability at an industrial level, a critical factor for commercial applications.

Following compounding, **Röchling**, a supplier for Autoform, extruded the material into 5 mm thick sheets, showcasing the scalability of the extrusion process. These sheets were then supplied to **Autoform**, where they were shaped into various vehicle components using vacuum forming. The vacuum forming process proceeded smoothly, with no defects or issues in the material's performance, indicating that the biocomposites retained the necessary thermal stability and mechanical integrity for automotive applications.

The success of both the extrusion and vacuum forming processes demonstrates the versatility and reliability of the ABS/lignin/compatibilizer material for large-scale manufacturing. The seamless integration of this biocomposite into established industrial workflows validates its potential for use in automotive applications, particularly in vehicle components where flame retardancy, stiffness, and environmental sustainability are key concerns. This successful trial paves the way for broader adoption of bio-based materials in the automotive sector.

Fig. 2. The demonstration processes.

7 Carbon footprint assessment

7.1 Methodology

The carbon footprint of the materials, processes and final product was assess in terms of greenhouse gas (GHG) emissions from the production and end-of-life carbon release, following life cycle assessment methodology (ISO 2006). The assessment was carried out based on the components used in material composition and corresponding emission data. Furthermore, the impact of material choice for the applied processes was compared for the tested materials with biofiller and the corresponding reference material, i.e. the neat fossil matrix material.

Production system boundaries

The production system for the suggested new materials was investigated in a set of subsections to provide a sufficient level of detail. These subsections include 1) raw material composition, 2) sheet extrusion, product manufacture and 4) the extended production chain (Fig. 3).

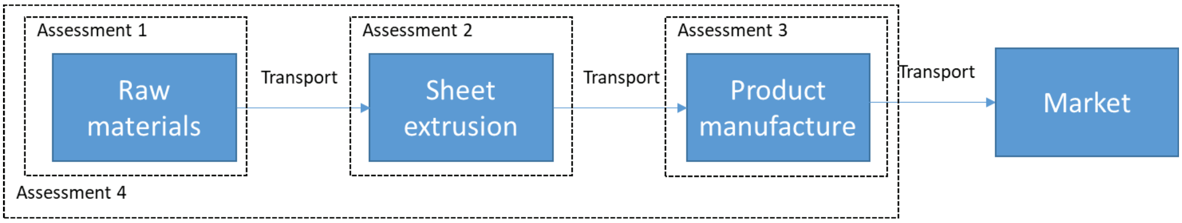


Fig. 3. System boundaries for the assessments carried out in the present study.

For assessment of the sheet extrusion (assessment 2), product manufacture (assessment 3) and extended production chain (assessment 4), differences in material density were accounted for. For the assessment of the extended production chain (assessment 4), also mass flows for the reference material and the ABS-lignin blend were established based on internal material recycling proportions.

7.2 Assessment 1 – material composition

Two sets of material blends were tested in terms of their global warming potential (GWP). Firstly, the carbon footprint of the blends of ABS, lignin and biochar was assessed as greenhouse gas (GHG) emissions from their production and end-of-life carbon release via combustion, simulating end-of-life treatment as waste incineration (**Table 1**). For these materials blends only assessment 1 was carried out. Secondly, for a ABS-lignin material blend (70/30) with 10% impact modifier (**Table 1**), also the full production line was simulated, i.e. sheets extrusion (assessment 2), product manufacture (assessment 3) and for the whole production chain (assessment 4). This composition was chosen to show how the carbon footprint of plastics can change if fossil components are replaced by biobased materials. The formulation represents a theoretical approach.

Table 1. Emission factors for components used in the production and the end-of-life combustion of the tested blends. Only fossil carbon was accounted for.

Compound	**GWP, production** **[g CO_2e/kg]**	**GWP, combustion** **[g CO_2e/kg]**	**Source**
Material components			
Acrylonitrile butadiene styrene (ABS)[a], high	4650	3128	Ecoinvent 3.10, market for ABS copolymer, global
Acrylonitrile butadiene styrene (ABS)[a], low	2690	3128	PlasticsEurope (2023)
Lignin (Renol®)	870	0	Lignin Industries (2021)
Biochar	112	0	Paulsson (2020)
Impact modifier	3779	2200	
Packing materials			
Wooden pallet	13402	0	Ecoinvent 3.10, market for EUR-flat pallet
Plastic Wrap, LDPE	2967	3143	Ecoinvent 3.10, LDPE granulate + market for extrusion
Paper wrapping	1040	0	Ecoinvent 3.10, market for kraft paper

[a] Combustion emissions based on a fossil carbon content of 85,3%.

7.3 Assessment 2 – Sheet extrusion

A scaled-up processed was assumed: For the production of sheets, raw materials are supplied and stored before sheet extrusion and further processing (Fig. 4). Excess material is cut from the sheets, and then after milling internally recycled into the raw material supply. Here also excess material from the product manufacturer is recycled. In this case addition additives are used. Transport within the process is carried out by electrical forklift.

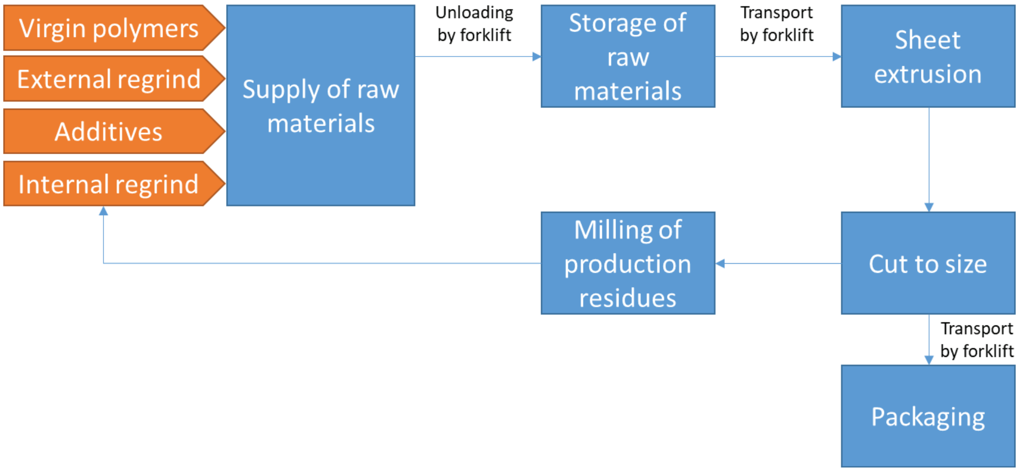


Fig. 4. Process schematics for production of extrusion sheets.

Energy consumption was assumed to amount to 1,3 kWh per kg of material entering the process originated from extrusion, supply of compressed air, charging of the electrical forklifts and milling of the excess material from sheet production. Of the extruded material, 30% were assumed to be access material that – after cutting the final sheets – were recycled internally. Packaging required 0,04 kg/kg product wooden pallet, 0,002 kg/kg product wrapping plastic and 0,001 kg/kg product wrapping paper.
Transport of materials accounted for truck transport requirements of 412 kg*km for the reference material ABS and 571 kg*km for the ABS-lignin blend. The latter also required 2000 kg*km shipping transport. Emission from transport assumed use of a EURO6 lorry emitting 0,151 kg CO_2e//t/km (Ecoinvent 3.10).

7.4 Assessment 3 – Product manufacture

A scaled-up processed was assumed: The product manufacture takes place in another facility than the sheet extrusion. The manufacturing steps include 1) drying of the material, 2) vacuum-forming of the product, 3) cutting of excess material (Fig. 5). From here the shape product will continue to be finalized, however, since this is not assumed to be any different from the reference material/product, its assessment was excluded her.

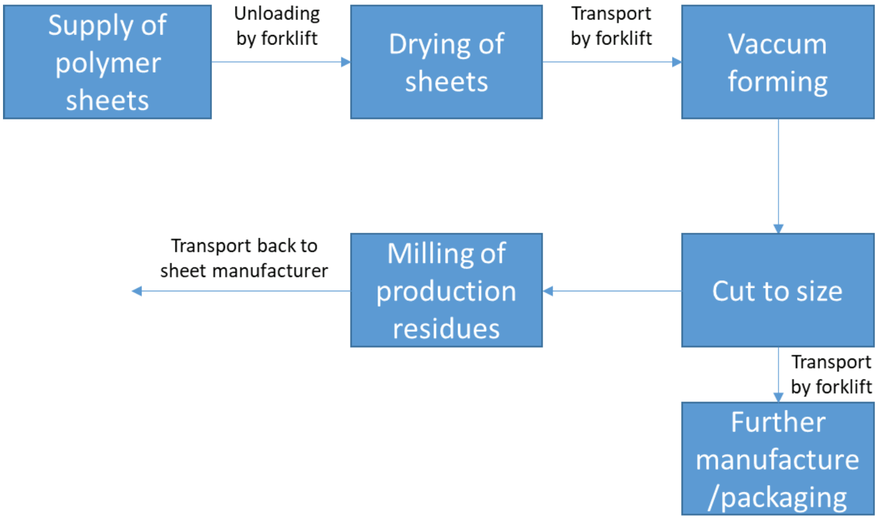


Figure 5. Process schematics for manufacture of final the product.

Energy consumption was estimated based on measurements made when the ABS and ABS-lignin sheets were used to manufacture the model product. For the drying step, the sheets are transported to a drying room. The sheets are heated from 20 to 75°C and kept at this temperature for 96 hours. Assumed heat capacity was 1,2 kJ/kg/K for neat ABS (reference), while for the ABS-lignin the heat capacity was estimated for a composition of 70% ABS (1,2 kJ/kg/K), 20% lignin (Renol) (1,342 kJ/kg/K) and 10% impact modifier (0,468 kJ/kg/K), resulting in a slightly lower heat capacity of 1,155 kJ/kg/K. Due to a higher density of the ABS-lignin material, 2,7% more material are needed for the final product. Energy consumption was estimated based on the energy require to heat up the material and energy losses during the drying process, which amounted to approx. 10% of the total energy consumption in this production stage.

In vacuum forming, energy consumption was estimated based on a base effect (7 kW), effect for heating of the material (40 kW) and effect for cooling of the product (10 kW). While the reference material was heated to 210°C, the ABS-lignin sheets were processed at 180°C. This reduced the time for a process cycle of heating (110 s), forming (55 s) and cooling (35 s) for ABS of 200 seconds to 180 seconds for ABS-lignin (97, 48 and 35 s, respectively).

Cutting of the formed product was assumed to be the same for ABS and ABS-lignin, with a cutting speed of 6 m/min, 2,141 m/product cutting length and an energy consumption of 0,224 kWh per meter of cutting.

The excess material removed by cutting was then assumed to be milled to granulate to be returned to the producer of the material sheets. Energy consumption was assumed to be 0,05 kWh per kg of material processed. The average Swedish carbon intensity of electricity production of 9 g CO_2/kWh was used as emission factor in the carbon footprint assessment (EEA 2024).

7.5 Assessment 4 – Production line comparison

For the final assessment of the extended production chain, emissions originating from the material production, sheet extrusion and product manufacture were summarized based on the mass flows for the reference material and the ABS-lignin blend at the included production stages. Emissions were calculated for a model product and the functional unit was set to one product unit.

7.6 Results and discussion

Mass balance

The amount of material ending up in the final product is often only minor proportion of the material transported during the production process. Due to internal recycling for excess material during both sheet production and product manufacture, considerable amounts of additional material need to be transported per functional unit. Due to a difference in material density, the ABS-lignin-based product was approx. 3% heavier compared to the reference material-based product.

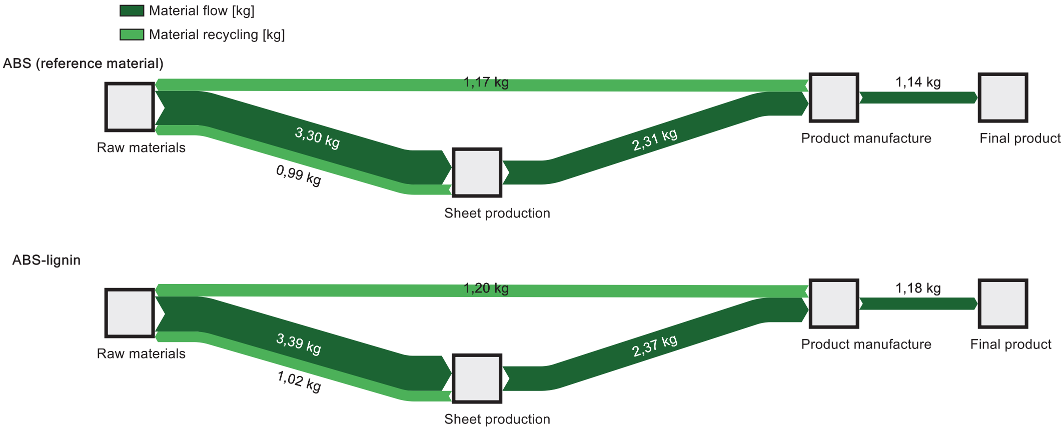


Figure 6. Mass flows for the ABS and ABS-lignin material-based products.

Assessment 2 – Sheet extrusion

Emissions for the sheet extrusion process per kilogram of sheet material were relatively low compared to emissions originating from material composition (Fig. 7). The main difference in process emissions between the reference material ABS and the ABS-lignin blend caused by relatively high transportation emissions for the lignin component and the impact modifier. Material transport accounted for 76 and 86% of the sheet production process for ABS and ABS-lignin, respectively.

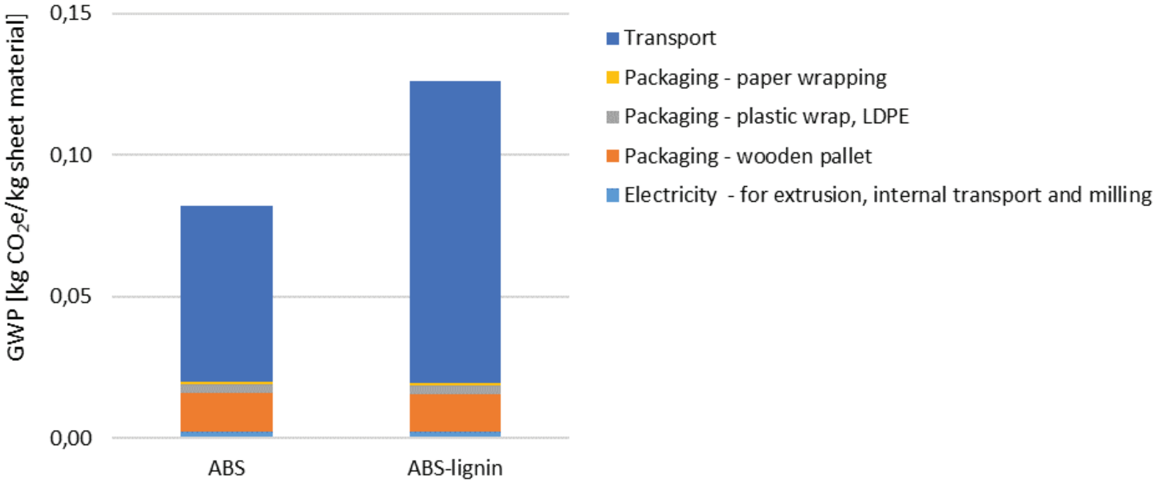


Figure 7. Global warming potential (GWP) of sheet production process operations, packaging and transport for the reference material and the ABS-lignin material.

Assessment 3 – Product manufacture

Emissions for the product manufacture processes were relatively low compared to emissions originating from material composition (Fig. 8). Despite a higher heat capacity and material density, the advantage of a lower temperature in vacuum-forming and corresponding shorter processing cycles resulted in a 8% lower carbon footprint for the ABS-lignin material.

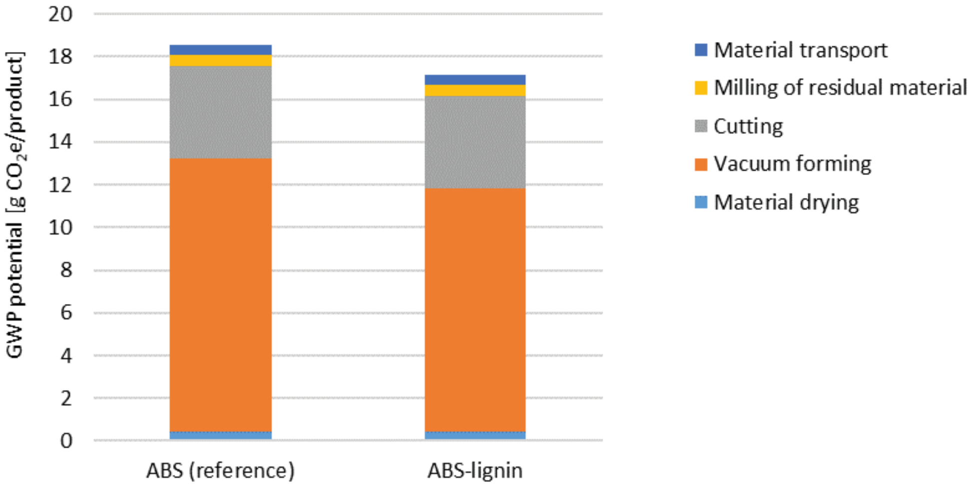


Figure 8. Global warming potential (GWP) of product manufacture and material transport for the reference material and the ABS-lignin material.

Assessment 4 – Production line comparison

Emissions related to the choice of material dominated the total emissions from the extended production chain with 95 and 92% of the total emissions for the ABS reference and the ABS-lignin blend, respectively. In total, the ABS-lignin material demonstrated a 15% reduction of GHG emissions compare to the reference material.

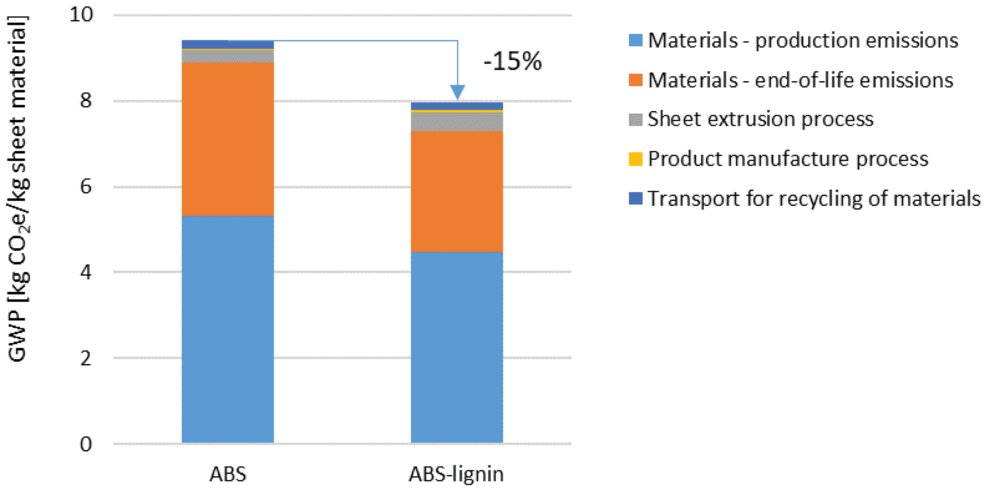


Figure 9. Global warming potential (GWP) of the extended production chain for the reference material and the ABS-lignin material. The end-of-life emissions are given for a scenario where the product is incinerated for energy recovery.

While internal material recycling during sheet production only added emissions for material milling and additional extrusion, internal recycling during product manufacture also added to the emissions for sheet and recycled material transportation. However, these are still marginal in comparison to the overall GWP impact.

7.7 Conclusions

Material choice is the key to reduce climate impact from plastic materials. Processes for material and product manufacture are only representing a minor part of the overall emissions. Another way to cut emissions is to recycle material, not only internally, but also post-consumer, with a high reduction potential of around 1,5 kg CO_2e per recycled product for the first cycle.

A future project should therefore investigate how well new materials can be recycled and what impact the additional recycling operation would add to the carbon footprint.

From these studies we manage to fulfil following objectives:

- ✓ **Suitable Bio-Based Fillers Identified**: Biochar and lignin were found to be the most suitable bio-based fillers for vacuum-forming materials.
- ✓ **Phase-Out of Cellulosic Fiber-Based Filler**: The cellulosic fiber-based filler/chips were phased out due to poor processability for vacuum forming.
- ✓ **High Biofiller Content Achieved**: The project successfully developed biocomposites with above 40% bio-based fillers, significantly reducing the use of fossil-based components.
- ✓ **Significant Carbon Footprint Reduction**: The incorporation of bio-based fillers resulted in a huge reduction in the carbon footprint.
- ✓ **Material Development**: The project developed biocomposites with a reduced carbon footprint while maintaining excellent properties, including processability, stiffness, and flame retardancy.
- ✓ **Compatibility Improvements**: Methods to enhance the compatibility between bio-based fillers and the polymer matrix were developed.
- ✓ **Scalability Confirmed**: The developed materials demonstrated easy scalability for industrial production, with successful vacuum-formed prototypes.
- ✓ **Scientific Contribution**: The project's outcomes yielded two manuscripts—one ready for submission and another under preparation.
- ✓ **Commercial Development**: The project led to the creation of a commercial ABS/lignin grade by Lignin Industries AB.
- ✓ **Industry Recognition**: Autoform highly graded the materials for vacuum forming, and SCANIA recognized their significant potential for use in their trucks.

Deviations

The goal to enable a bio-based share of at least 50% in vacuum formed products for the automotive industry and a weight reduction of these by 20% was not achieved. We did manage to fabricate materials with more than 40% bio-based share, which is very close to the set goal of 50%. But higher bio-based share led to difficulties of compounding and unwanted loss in properties.

8 Dissemination and publications

8.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	
Be passed on to other advanced technological development projects		
Be passed on to product development projects	X	
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

8.2 Publications

Bjurström, A. et.al., Synergistic Enhancement of Flame Retardancy and Carbon Footprint Reduction in ABS Biocomposites through Combined Use of Lignin and Biochar. Manuscript, submitted (2024).

Wei, X. et.al., ABS/Lignin blends with reduced carbon footprint and balanced properties for vacuum forming. Manuscript, under preparation (2024).

Oral presentation at the SuPRA conference organized by Scania.

9 Conclusions and future research

Conclusions

The biocomposites developed in this study present a significant breakthrough for the **automotive sector**, offering a sustainable alternative to conventional petroleum-based materials. With enhanced **fire retardancy**, **mechanical performance**, and **environmental benefits**, these biocomposites are highly suitable for various automotive applications, including **interior trims**, exterior parts, **dashboards**, **door panels**, and **roof boxes**.

Fire Safety: The improved flame retardancy ensures that these materials meet the stringent safety requirements for automotive components, particularly in areas where fire resistance is critical.

Mechanical Properties: The increased stiffness of the material without significant compromise in processability supports its use in automotive structural components. Additionally, the introduction of the compatibilizer enhances the ductility and toughness, making these biocomposites more resilient in applications requiring flexibility and impact resistance.

Sustainability: The reduction in the carbon footprint positions these materials as a viable solution to meet the automotive industry's sustainability goals, particularly with the push toward reducing greenhouse gas emissions and reliance on fossil-based resources by 2050.
Processability: The successful large-scale production of these biocomposites, demonstrated through extrusion and vacuum forming, proves that the material can be easily integrated into existing manufacturing processes, making it ideal for mass production in the automotive industry.

Future Research Directions

While this study has shown significant promise, further research is needed to fully optimize these biocomposites for broader automotive and industrial applications:

1. **Enhancing Impact Resistance**: Future work should focus on improving the impact toughness of the biocomposites. The reduction in notched impact toughness, although still sufficient for certain applications, could be optimized to expand the use of these materials in high-impact areas such as bumpers or structural components.
2. **Exploring Other Bio-Based Fillers**: To further increase the bio-based content and improve material performance, future studies could explore other renewable fillers such as cellulose nanofibers or natural fibers. These fillers might offer additional improvements in mechanical properties, biodegradability, and cost-effectiveness.
3. **Long-Term Durability and Environmental Resistance**: While the materials have shown good processability and mechanical performance, long-term durability under various environmental conditions such as UV exposure, temperature fluctuations, and moisture needs to be assessed to ensure their suitability for outdoor automotive components.
4. **Optimization for Specific Automotive Applications**: Tailoring the composition of these biocomposites for specific automotive applications (e.g., lightweighting for electric vehicles) could help optimize performance for targeted uses, such as improving fuel efficiency and reducing vehicle emissions through lighter materials.
5. **Multilayer sheets**: Material with lignin content, are naturally brown (without any color additives). In order to get materials sheets in various colors and finishes, multilayer extrusion with an ABS/Lignin base with top layers of e.g. neat ABS could be tested. This could also be a way to increase the total biobased content in the material sheets.
6. **Recyclabilty**: The recyclability of the materials needs to be further analyzed. Can the material be handled in a normal thermoplastic stream, or is a new stream for this material needed.

By addressing these research areas, the biocomposites can be further refined to meet the evolving needs of the automotive industry, supporting the sector’s goals of increased sustainability, safety, and performance.

10 Participating parties and contact persons

The steering group consisted of one person from each project party (Daniel Helgesson, Autoform, Mikael Hedenqvist KTH, Lars Jerpdal, Scania, Thomas Roulin, Lignin Industries and Thomas Prade, SLU. The group handled result follow-up and any deviations.

The project's main project manager is Daniel Helgesson, Autoform, and the project was carried out practically as described in the AP. Part project manager at Autoform was Anna Matsson. Part project leaders at KTH were Xinfeng Wei and Mikael Hedenqvist. Lars Jerpdal and Stefan Bruder were sub-project managers at Scania, Ella Norén and Thomas Roulin were sub-project managers at Lignin Industries and Thomas Prade was project manager at SLU. Project meetings with the aforementioned participants were held once every two months.

Main Contact persons

1. Andreas Åhrlin, andreas.ahrlin@autoform.se , Autoform i Malung AB, 782 33 Malung, Sweden
2. Mikael Hedenqvist, mikaelhe@kth.se Department of Fibre and Polymer Technology, KTH Royal Institute of Technology, Stockholm 10044, Sweden;