# Brandsäkra inredningsdetaljer för bussar

**Publik rapport**


Författare: Angelika Bachinger, Anna Sandinge, Kalle Andrén, Gustav Andtbacka
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FFI Fordonsstrategisk Forskning och Innovation
VINNOVA Energimyndigheten TRAFIKVERKET FKG VOLVO SCANIA VOLVO

# Innehållsförteckning

# 1 Sammanfattning

Projektet syftade till att utveckla hållbara lösningar för förbättrad brandsäkerhet i bussinteriören som kan möta förväntade hårdare brandkrav. Nuvarande interiöra paneler för bussar är gjorda av akrylnitril-butadien-styren (ABS) plast, som är mycket brännbara och bidrar till brandspridning. Konventionella lösningar för att minska brandbenägenheten hos ABS-paneler baseras på giftiga tillsatser (bromerade flamskyddsmedel), ökning av tjockleken på panelerna eller användning av dyrare plaster med högre densitet (PC/ABS). Det aktuella projektet ämnade vända den trenden genom att tillhandahålla ny hållbar lättviktsteknik för bussinteriöra material som uppfyller de förväntade brandkraven samt tillverkarnas och slutanvändarnas krav på bearbetbarhet, kostnad, miljöpåverkan och prestanda.

Projektet kunde framgångsrikt identifiera de mest lovande halogenfria flamskyddsmedlen för businteriöra delar avseende kostnad, brandsäkerhet, mekanisk prestanda och toxicitet. En systematisk utvärdering av olika kombinationer av dessa flamskyddsmedel samt synergistiska tillsatser gjordes och resultat jämfördes med kommersiellt tillgängliga alternativ (bromerad FR ABS och FR PC/ABS). Det visade sig att relevanta halogenerade FR för ABS finns på listan Substitute-it-Now av ChemSec på grund av PBT-egenskaper (beständiga, bioackumulerande och toxiska). Dessutom uppvisar halogenerade material hög rökproduktion och röktoxicitet. PC/ABS-system å andra sidan är dyra och uppvisar nackdelar vad gäller bearbetning. Systemen som studerats inom projektet visar låg toxicitet, är kostnadseffektiva och har potential att effektivt skydda ABS-produkter mot brand. Dessutom kunde projektet visa att den mekaniska prestandan och bearbetningsegenskaperna hos det utvecklade materialet är lämpliga för den avsedda tillämpningen. Även om Charpy-slaghållfastheten är drastiskt reducerad, kunde konsortiet genom en slagseghetstestning på tunna plattor visa att denna mer relevanta slagprestanda liknar ren ABS vid energier upp till plastisk deformation.

En del av resultaten har publicerats för att Volvo och andra företag ska kunna välja och optimera det mest hållbara alternativet utifrån de specifika kraven (när de är formulerade). Ytterligare spridning för att överföra kunskapen till såväl regleringsorgan som relevanta branscher planeras. Dessutom, på grund av en försening i utformningen av nya krav, utvärderade projektet olika lösningar för att möta de nuvarande brandkraven (Reg.118) avseende deras hållbarhet och tekniska och ekonomiska genomförbarhet.

# 2 Executive summary in English

The project aimed at providing sustainable solutions for improved fire safety in the bus interior that can meet expected tougher fire regulations. Current interior panels for buses are made of acrylonitrile-butadiene-styrene (ABS) resin, which is highly flammable. Conventional solutions to reduce the flammability of ABS panels rely on addition of toxic additives (brominated flame-retardants), increasing the thickness of the panels, or using heavier and more expensive plastics (PC/ABS). The current project aimed to reverse that trend by providing new sustainable lightweight technologies for bus interior materials that meet the expected fire regulations as well as manufacturers' and end-users' requirements regarding processability, cost, environmental impact and performance.

The project could successfully identify the most promising halogen-free flame-retardants for ABS in bus interior applications regarding cost, fire and mechanical performance and toxicity. A systematic evaluation of various combinations of these flame-retardants as well as synergistic additives was performed and compared to commercially available alternatives (brominated FR ABS and FR PC/ABS). It was found that relevant halogenated FRs for ABS are on the Substitute-it-Now list by ChemSec due to PBT (persistent, bio-accumulative and toxic) properties. Moreover, halogenated materials exhibit high smoke production and smoke toxicity. PC/ABS systems on the other hand are expensive and exhibit disadvantages regarding processing. The systems studied at RISE show low toxicity, are cost-efficient and have potential to effectively protect ABS products against fire. Moreover, the mechanical performance and processing properties of the developed halogen-free FR systems could be proven to be interesting for the aimed application. Even though the Charpy impact strength is drastically reduced, it could be shown by impact testing on thin plates that this more relevant impact performance is similar to pure ABS at energies up to plastic deformation ~~and suitable for the aimed application also at higher deformations~~. Some of the results have been published to enable Volvo and other companies to choose and optimize the most sustainable option based on the specific requirements (once formulated). Further dissemination to transfer the knowledge to the regulative body as well as relevant industries is planned. Moreover, due to a delay in the formulation of new requirements, the project also evaluated different solutions to meet the current regulations (Reg.118) regarding their sustainability and techno-economic feasibility.

# 3 Bakgrund

Due to several tourist bus accidents in France and Germany during 2016/2017 involving numerous deaths, European road safety authorities have decided to tighten the requirements on interior fire arrest and toxicity for buses. Already the current regulations are extremely difficult to meet with available technology and materials and even tighter rules were expected to be formulated in 2019 and introduced in 2023.
Current solutions to meet the recently introduced fire regulations require the addition of environmentally detrimental additives, at the same time as materials with high density are used and the thickness of the structures is increased. The project aimed to reverse that trend by providing new sustainable lightweight technologies for bus interior materials that meet the expected fire regulations as well as manufacturers' and end-users' requirements regarding processability, cost, environmental impact and performance.

Current interior panels for buses are made of acrylonitrile-butadiene-styrene (ABS) resin. Without flame retardants (FRs), ABS can be easily set on fire with a small ignition source, like a lighter, match, electric failure or mechanical overheating. Smoke will be generated when ABS is burning; furthermore, ABS will continue to burn after removal of the ignition source. In order to meet the recently introduced requirements, additives are currently incorporated in buses interior panels that pose environmental risks and problems. ABS has also been replaced with a PC/ABS blend, which increases the density. In addition, the thickness of the panels was increased to meet the current requirements, thus increasing the amount of material by 20% on existing details. Looking at a whole bus, the weight increases by about 60 kg per vehicle. The increased panel thickness also leads to longer process times and higher energy consumption during the forming process. All in all, the current solution involves environmentally detrimental additives and leads to thicker, heavier and more expensive items than before. There are currently no materials that are suitable for vacuum forming that meet the requirements for fire, weight, cost and performance. Some manufacturers incorporate halogens into their materials which is not an alternative for Volvo Buses, as those additives have been shown to be environmentally detrimental and toxic.
The current project aimed to reverse that trend by providing new sustainable lightweight technologies for bus interior materials that meet the expected fire regulations as well as manufacturers' and end-users' requirements regarding processability, cost, environmental impact and performance.

# 4 Syfte, forskningsfrågor och metod

The present initiative aimed to provide a technology for bus interior panels that allows not only to meet the current requirements regarding fire safety, but also anticipated future regulations at the same time as reducing the environmental impact and avoid toxic substances such as halogens throughout the value chain. The proposed project focused mainly on short term solutions (sustainable, non-toxic additives for ABS), in order to provide a technology that can be introduced within 2-3 years.
A comprehensive review of the market and literature regarding flame-retardants (FRs), and especially halogen-free FRs, for ABS and PC/ABS was compiled as a first step, along with the definition of requirements for the aimed bus interior material.
Based on the conclusions from the literature and market review, experiments were designed to evaluate the most promising FR systems for the aimed application. The experiments were conducted in several stages to identify (i) the most promising individual FRs (ii) promising (synergistic) combinations of FRs and (iii) the influence of additional synergists. In a final step, the mechanical performance was improved by impact modifiers and coupling agents. The materials were characterized regarding their toxicity and environmental impact, mechanical performance (impact, tensile) and fire performance (flame spread, heat release, smoke production, smoke toxicity)

as well as their anticipated cost. The most promising FR system was evaluated regarding its processability by manufacturing of a demonstrator in an industrial environment. Fire testing of the demonstrator made from the developed halogen-free FR ABS compared to a demonstrator in pure ABS was then performed to validate the results.
The anticipated new regulations were not formulated during the project time (originally anticipated end of 2019). Therefore, Volvo needed to investigate solutions to fulfil the current regulations that came into force during 2020. A new activity was therefore introduced in the project: Evaluation of the sustainability and techno-economic feasibility of different approaches to meet the current regulations (Reg.118-02), which are in force for all new registrations since 2020. Two approaches were compared:

- Flame-retarded materials available on the market versus
- Re-design of components and tools to meet the requirements with currently used non-flame-retarded ABS.

# 5 Mål

Lightweight technology is strategically important for Swedish future competitiveness. The project contributes to the overall FFI objectives by promoting collaboration between Volvo Buses, the Tier1 supplier (and SME) Andrénplast and the research institute RISE. The aim was to develop more lightweight interior parts solutions using material with improved fire performance. The option is otherwise to continue the route with even heavier and more expensive parts to meet the future fire performance regulations. The project ambition was to reverse that trend. The project is important in order to verify the material performance and gain experience. The material solutions needed to be proven out, from a high-volume thermoforming perspective in a supplier end-user collaboration. A secondary effect is that the project results can be straightforwardly transferred to other industries in which fire-retardant parts are required.
In relation to the program, the project aimed at the overarching goals of enabling the ability to produce new components with new materials having minimal environmental impact. It is also relevant for the target of resource efficiency in production for reduced environmental impact and increased market competitiveness. The project aims to reduce CO2 emissions by creating a process that enables new materials to be formed that cuts the weight by 20% compared to the current option. The main part of the work in the proposed project is focussed on short term implementation (2-4 years) since there is a very strong market incentive to introduce new solutions.
During the course of the project, the project goal has shifted somewhat, as the expected regulations were delayed. As the requirements for fire and toxicity were not defined, the material could not be optimized towards the requirements. Instead, the project goal shifted and was divided into two parts:
1. Create knowledge about the potential of halogen-free FRs for ABS compared to halogenated FRs for future reference.
2. Evaluation of the sustainability and techno-economic feasibility of different solutions to meet the current regulations (in force since 2020).

# 6 Resultat och måluppfyllelse

The formulation of the regulation was not available at the start of the project. However, based on the current regulation as well as indications about the coming regulation, it was possible to (i) identify potential systems based on a literature review (reported in Deliverable 1), (ii) screen out flame-retardants (FR) with poor performance (reported in Deliverable 2&3) and (iii) provide a systematic evaluation of sustainable FR systems in collaboration with a parallel project funded by the Swedish Center for Chemical Substitution [1].
The planned optimization of the material system towards the new regulation was not possible within the project, as the formulation of the new regulation is delayed and is not available to date. After a project freeze of 1 year, the consortium decided that it was not feasible to keep waiting for the new regulation. Instead, the focus of the project was split into two parts:
1. Evaluation of the feasibility of halogen-free FR ABS for likely future regulations and comparison to halogenated alternatives. This was achieved by modification of the systems developed in [1] for improved impact performance (reported in Deliverable 2&3). The best recipe was successfully demonstrated by demonstrator manufacturing in an industrial environment (reported in Deliverable 4). It could be shown that the developed FR system for ABS exhibits low toxicity and environmental impact, low cost, as well as superior heat release and smoke properties

[1] *A. Bachinger et al. Journal of Applied Polymer Science, 2022, 139/13, 51861. DOI: 10.1002/app.51861*

compared to halogenated FRs. Depending on the detailed requirements for fire and toxicity as well as mechanical performance, small adjustments of the recipe may be necessary (the required information could be provided in [1]). Original concerns regarding a significant deterioration of the impact performance of ABS with halogen-free FRs could be relieved by evaluation of the impact performance in a more relevant impact scenario. However, the impact performance still needs to be optimized and evaluated towards specific requirements when the new regulation is available: optimization of the material towards the required fire and mechanical performance needs to be done simultaneously as any adjustments of the recipe to optimize one parameter will influence the other.
2. Evaluation of the sustainability and techno-economic feasibility of different approaches to meet the current regulations (Reg.118-02), which are in force for all new registrations since 2020 (reported in Deliverable 4). Two approaches were compared:

    2.1 Flame-retarded materials available on the market versus
    2.2. Re-design of components and tools to meet the requirements with currently used non-flame-retarded ABS.

The project has created valuable knowledge regarding lightweight technologies with minimal environmental impact and improved fire performance and contributes therefore directly towards FFIs goal to provide and demonstrate solutions to make road transport sustainable and safe.

# 7 Spridning och publicering

## 7.1 Kunskaps- och resultatspridning

| Hur har/planeras projektresultatet att användas och spridas? | Markera med X | Kommentar |
|---|---|---|
| Öka kunskapen inom området | x | Spridning inom konsortiet genom rapporter och presentationer. Utanför konsortiet genom publikation [1] |
| Föras vidare till andra avancerade tekniska utvecklingsprojekt | x | När krav är formulerade kommer fortsättning att diskuteras, beroende på kraven kan det bli tekniska utvecklingsprojekt eller produktutvecklingsprojekt |
| Föras vidare till produktutvecklingsprojekt | x | |
| Introduceras på marknaden | | |
| Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut | x | Resultaten kan påverka beslut om kraven, då dem visar för första gången hållbara material som kan möta höga krav på flamspridning och rökutveckling samtidigt. |

## 7.2 Publikationer

- A. Bachinger et al. Journal of Applied Polymer Science, 2022, 139/13, 51861. DOI: 10.1002/app.51861
- A. Sandinge et al. Evaluation of smoke gas toxicity and smoke density of bus interior materials. Fire and Materials. Manuscript accepted, not yet published.
- Confidential reports:
    - SICOMP report CR20-016_Fire retardants for ABS and PC/ABS_Deliverable 1
    - SICOMP report CR20-017_Guidelines to sustainable fire protection
    - SICOMP report CR22-004_FRIPs D2&3_Evaluation of Fire-retardant systems in ABS
    - SICOMP report CR22-005_FRIPs D4_Re-design of bus interior parts for Reg.118.02 and demonstration

# 8 Slutsatser och fortsatt forskning

Table 1 provides a comparison of most important studied material classes regarding the identified requirements.

Table 1: Comparison of different material systems regarding requirements

| Approach | Charpy Impact | Thin plate Impact | Flame spread | Heat release | Smoke production | Cost | Toxicity |
|---|---|---|---|---|---|---|---|
| **Halogenated FR** | Good | Good | Best | Poor | Poor | Good | High |
| **Commercial halogen-free FR** | Fair | - | Fair | Fair | Fair | Fair | - |
| **Studied systems SubC** | Poor | Good | Good | Good | Good | Low | Low |
| **Best Benchmark (PC/ABS)** | Best | - | Good | Best | Best | High | Fair |

- Phosphorus-based flame-retardant (PFR) systems as studied in the project provide the best affordable option regarding smoke and toxicity as well as peak heat release rate.
- The best performing PFR systems (PFR/PFR combination and PFR/PFR/synergist combinations) among a wide variety of systems were identified [1].
- PFR systems induce a drastic reduction of the Charpy impact performance of ABS, which can be improved to some extent by impact modifiers.

- The ‘thin-plate’ impact behavior of the developed system is similar to pure ABS at deformations up to about 7 mm, after which plastic deformation (buckle) is detected for both materials.

The project results provide a suitable knowledge base for future product development projects which will be needed upon formulation/implementation of new harsher requirements for fire and smoke toxicity in buses.

# 9 Deltagande parter och kontaktpersoner


- RISE:
  - Department for polymers, fibers and composites: Angelika Bachinger (angelika.bachinger@ri.se)
  - Department for fire technology: Anna Sandinge (anna.sandinge@ri.se)
- Volvo Bussar AB: Gustav Andtbacka (gustav.andtbacka@volvo.com)
- Andrénplast: Kalle Andrén (kalle.andren@andrenplast.se)