

Impacts of Non-Traditional Uses of Polyurethane Foam in Automotive Applications at End of Life

Lindsay J. Miller
Univ. of Windsor

Susan Sawyer-Beaulieu and Edwin Tam
Univ of Windsor

ABSTRACT

Polyurethane (PU) foam is used for many automotive applications with the benefits of being lightweight, durable, and resistant to heat and noise. Applications of PU foams are increasing to include non-traditional purposes targeting consumer comfort. An example of this is the use of PU foam between the engine and engine cover of a vehicle for the purpose of noise abatement. This addition will provide a quieter ride for the consumer, however will have associated environmental impacts. The additional weight will cause an increase in fuel consumption and related emissions. More significant impacts may be realized at the end-of-life stage. Recycling PU foams presents several challenges; a lack of market for the recycle, contamination of the foams, and lack of accessibility for removal of the material. PU foam pieces are likely to end up being landfilled after the vehicle is shredded, negating the benefit of choosing this material for its recyclability over another non-recyclable material. PU foams have been credited with contributing to the light weighting of vehicles, however it is important to distinguish between cases where PU foams replace heavier materials and where they are added for comfort. It is also necessary to make manufacturers aware of the gap between what is technically feasible in terms of recycling and what can be practically accomplished with present day technology and markets. As the use of PU foams increase it is imperative to address the obstacles surrounding recycling so that the benefits of these foams can be realized without negative end-of-life impacts.

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INTRODUCTION

Polyurethane (PU) foam has gained widespread use in automotive manufacturing because it is lightweight, shock absorbent, cushions, and protects against heat and noise. Additionally, PU foams are inexpensive and easily can be easily custom moulded. When used to replace heavier materials, they reduce the overall vehicle weight and potentially lower fuel consumption and the accompanying emissions. To date, the primary market for PU foams has been interior applications such as seats, headrests, armrests, bumpers, steering wheels and other soft trim components. Composites such as PU have contributed to lowering the weight of an average car by 200 kg [1]. Furthermore, their ability to be tailor-made reduces scrap material and lowers the overall vehicle cost. PU use in cars has increased dramatically despite other materials, such as metals, being easier to recycle [2].

Applications for PU foam in automotive manufacturing have been expanding to include some non-traditional uses such as adding PU foam for under hood and under body noise, vibration, and harshness (NVH) control. Examples of these

parts include engine covers, hood liners, and wheel well treatments. The Woodbridge Group has launched WhisperTech™ Polyurethane foam enhanced sound absorption for engine bay applications such as engine beauty covers, hood liners, and insulators for fuel rails and air intakes [3]. Additionally, Dow Automotive Systems and GRACO jointly launched a product called BETAFOAM which is a two component PU foam engineered to be applied in vehicle acoustical cavities to improve NVH performance [4].

When heavier materials are replaced with PU foam, significant benefits can be realized during the use phase. Typically, a 10% weight reduction can lead to a 3-7% improvement in fuel efficiency and reduction of emissions [5]. A previous life cycle assessment (LCA) considered the environmental effects of choosing lighter weight vehicle components such as polymer composites over heavier components such as steel [6]. Reducing the vehicle weight by switching from aluminum to polyurethane resin from reaction injection moulding resulted in 57% less CO₂ emissions during the use phase of the engine and a 52% reduction overall when considering the complete

life cycle. In the categories considered in this LCA, the trend appeared to be that the lightweight materials reduced the environmental impacts during the use phase but the environmental impacts increased during the materials and manufacturing phases. Overall, the environmental burden was lower for lightweight materials when considering the complete life cycle [6]. In this study incineration with energy reclamation was assumed as the end-of-life fate of the composites. With this option, the environmental burden associated with the end of life phase contributed less than 1% to the burden of the entire life cycle. An additional study considered how different design options affect environmental performance throughout the life cycle of a vehicle [7]. The results of this study further supported lighter weight vehicles for improved environmental performance even with the assumption of 100% landfilling of plastic parts.

From an LCA perspective, the reduction in emissions during the use phase is often enough to justify negative impacts arising from the end-of-life scenario (i.e., landfilling) for PU foam. Duflo et al. considered the impact of substituting some conventional steel structures for light weight composite materials and concluded that although the manufacture and end of life phase produced greater environmental impacts, the savings during the use phase resulted in a breakeven point of 132,000 km travelled [8]. However, more recently, PU foam is being added, rather than replacing a current part, for reasons largely associated with consumer comfort. In cases such as these, the extra weight of the part, in addition to the end of life scenario can have a negative impact on the overall LCA.

A vehicle that reaches its 'end-of-life' (EOL) - i.e., an end-of-life vehicle (ELV) - is commonly brought to a dismantler where environmentally hazardous fluids and materials are removed and valuable parts are recovered for reuse, remanufacturing and/or recycling. After this stage, what remains of the vehicle, called the vehicle hulk, is typically shredded for metals recovery, along with other metals-rich scrap materials, like construction, renovation and demolition (CRD) scrap and large end-of-life appliances (ELAs) (also known as 'white goods'). Post-shredding, ferrous metals (i.e. carbon steel, cast iron stainless steel) and non-ferrous metals, are separated out from the non-metallic materials typically using a combination of magnetic separation, eddy current separation and air elutriation [9]. What is left after this step, principally non-metallic materials, PU foam included, is termed shredder residue (SR) and is typically landfilled [9,10]. Presently, approximately 80% of a vehicle, principally metals, is recycled at the end-of-life stage, whereas the remaining 20%, mostly non-metals, ends up as automotive-derived SR or ASR [9].

Although PU foams are recyclable, there are substantial challenges: the majority of these foam pieces are landfilled at the end of life stage. Recycling options for PU foams include mechanical, chemical, and feedstock recycling, as well as incineration for energy recovery. The first major obstacle to recycling PU foams is that they would have to be separated at the dismantling stage prior to shredding. Whether or not parts are separated for recycling during dismantling depends on the

market value of the parts, the accessibility of the parts containing the PU foam and on the labour costs to remove the parts [11]. The dismantler will not remove and segregate the PU foam unless it is economically advantageous to do so, as is the case with tires. Some PU foam-containing parts are not readily accessible. For example, structural PU foam injected into automotive unibody structures (for stiffening of chassis components) will not be economically recoverable by dismantling. The next obstacle is that these foams may become contaminated with oils and fluids from the use phase, depending on the location of the PU foam parts. PU foam parts located in the engine compartment, for example, commonly become contaminated with oils, and therefore would require costly cleaning and treatment prior to being recycled. This clean-up is often not technically feasible, economically valuable, or ecologically desirable. Even if this path were to be pursued, it could pose a risk to the final customer as residual contamination may affect the properties of the foam, for example, if used for rebonding [12]. Lastly, there is a lack of market for PU recycle. PU foams are most commonly 'down cycled' since recycling PU back to their original purpose require higher densities and typically results in reduced physical properties.

Due to the obstacles associated with recycling PU foams, the major benefit of using lightweight plastics and foams lies in the product use phase [13]. However, as the use of plastics and foam materials in vehicles increases, there may be significant consequences from the lack of viable recovery options at vehicle end-of-life phase if markets do not become available for these materials. Passarini et al. have already concluded that the increasing use of polyurethane foams will have a significant impact on the quality and quantity of ASR [10].

Clearly, if manufacturers are to select preferred environmental materials, then they need to understand the fate of these materials at the end of life stage. This paper presents a case study that highlights the challenges that are faced by manufacturers when selecting materials for their applications, and examines the gap between what is technically possible and what is practically possible in terms of recovery at the end of a vehicle's life.

CASE STUDY

Automotive manufacturers are faced with the dilemma to decrease the weight of their vehicles in order to reduce fuel consumption and CO₂ emissions, while at the same time improving the vehicles functionality, comfort, and appeal to consumers. This contradiction is demonstrated by the engine of the vehicle. Engine 'beauty covers' are typically added to surround the engine itself and add to the aesthetic appeal under the hood. More recently, insulation has also been added between the engine and the engine cover to alleviate some of the engine noise, therefore providing a quieter ride for the driver and passengers. Although this improves the comfort level of the vehicle, it also comes with an increased weight. This case study addresses one manufacturer's concern with

choosing possible materials for this purpose, and the environmental tradeoffs of choosing one material combination over another in terms of the use phase versus the end-of-life phase of the vehicle.

Methods

To assess the environmental impacts of the different materials available for engine covers, four scenarios were considered:

- Scenario 1: Plastic engine cover alone ([Figure 1](#))
- Scenario 2: Plastic cover + shoddy material as insulator ([Figure 1](#) + [Figure 2](#))
- Scenario 3: Plastic cover + polyurethane foam as insulator ([Figure 3a](#) & [3b](#))
- Scenario 4: Painted foam polyurethane without plastic component ([Figure 4](#)).



Figure 1. Plastic engine cover (scenario 1).



Figure 2. Shoddy material as insulator between engine and engine cover (scenario 2).



Figure 3a. Plastic cover plus polyurethane foam as insulator (side by side) (scenario 3).

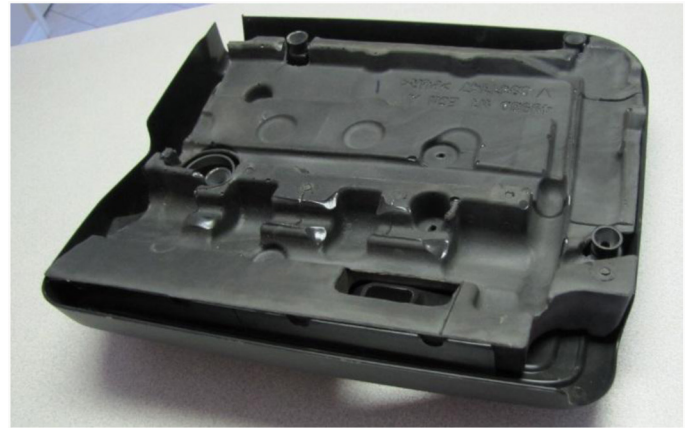


Figure 3b. Plastic cover plus polyurethane foam as insulator (assembled together) (scenario 3).



Figure 4. Painted polyurethane engine cover (scenario 4).

In all cases, the PU foam is of the methylene diphenyl diisocyanate (MDI) formulation.

For the use phase, fuel consumption and CO₂ emissions were used as indicators of environmental performance. Since these parts represent a small portion of a vehicle, values of these indicators were provided on a national scale as well as for an individual vehicle. The national scale represents the scenario if everyone in the country pursued the same option and allows for differences that may seem negligible on an individual vehicle basis to be visualized on a larger scale.

For the end-of-use phase, the weight of the component part dominated the environmental comparisons because, based on current markets, it is likely that these parts would be landfilled. Therefore, the environmental indicators that were used in this assessment were the amount of space these components would take up in the landfill at the end of their useful life, as well as fuel consumption and CO₂ emissions from transportation of these parts from a dismantler to a landfill.