LCM applied to Auto Shredder Residue (ASR)

Luciano Morselli[1], Alessandro Santini[1], Fabrizio Passarini[1], Ivano Vassura[1], Luca Ciacci[1]

[1]University of Bologna, Dept. Industrial Chemistry and Materials, Viale Risorgimento 4, I-40136 Bologna, Italy

Abstract

Auto Shredder Residue (ASR) is the waste generated from End of Life Vehicles (ELVs) pre-treatment, dismantling, shredding and metals recovery operations. ASR consists of plastics, rubber, textiles, glass, fines, dirt, etc. and many time is contaminated with heavy metals, hydrocarbons and PCBs. ASR is currently landfilled or incinerated but, due to the coming into force of Directive 2000/53/EC, it must be treated aiming at material and energy recovery to reach recycling targets by 2015. This work aims at a sustainable ASR management by using LCA as a decision tool, improved car design and innovative plastic recycling technologies.

Keywords:

Auto Shredder Residue (ASR); Life Cycle Assessment (LCA); Pyrolysis

1 INTRODUCTION

Automotive industry is one of the most resource-consuming sectors of the industrial production [1]. This holds that its products have both a high content of precious materials, such as steel and other non-ferrous metals, and an embedded energetic content, especially in plastics and rubbers.

Consequently, end-of-life-vehicles (ELVs) are a particularly valuable waste stream, amounting to more than 9 million tons per year in Europe, an extent which needs to be properly managed [2].

A correct and efficient management of this kind of waste is thus of great importance in Europe and several other Countries, from environmental, economical and technological points of view.

In Europe, at first fluids and other hazardous components (such as batteries) are mandatory removed. Then, according to the market rules, components may be dismantled and further reused and recycled, if it proves to be profitable. After these operations, hulks are baled and transported to a shredding plant where cars are reduced into pieces. The embodied materials are liberated and then sorted for recycling. Metals account for up to 75% of a vehicle mass and, especially ferrous ones, are very easy and profitable to be sorted, and thus to be recycled. On the contrary, the non-metallic residue, called “car fluff” or “automobile shredder residue” (ASR), is mostly landfilled in Italy, as it happens in many other European Countries [3].

Automobile shredder residue (ASR), the residual fraction of a vehicle obtained after shredder and metal separation steps (named also ‘‘car fluff”), requires a particular attention. ASR is an agglomerate of plastic (19–31%), rubber (20%), textiles and fibre materials (10–42%) and wood (2–5%), which are contaminated with metals (8%), oils (5%), and other substances, some of which may be hazardous (about 10%), e.g., PCB, cadmium and lead [4]. Its composition may vary strongly depending on the shredding input mix (vehicles, white goods and ferrous waste combination) and on the depollution operation carried out.

Since some years, even under the pressure of European Community, through the Directive 2000/53/EC which imposes the achievement of specific targets of recycling and recovery in fixed time periods (at least 80% of recycling and 85% of total recovery, by 2006; at least 85% of recycling and 95% of total recovery, by 2015), different possible ways of ASR valorization have been investigated, both aimed to material recovery (e.g., in cement

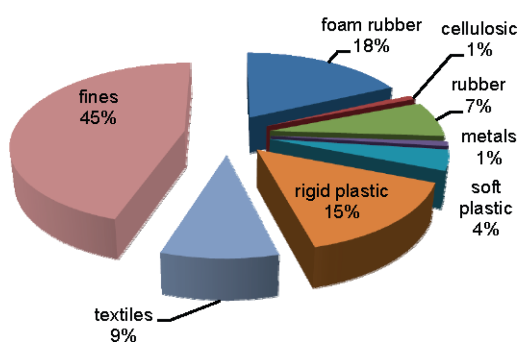

Figure 1: ASR composition analysis results [6].

J. Hesselbach and C. Herrmann (eds.), *Glocalized Solutions for Sustainability in Manufacturing: Proceedings of the 18th CIRP International Conference on Life Cycle Engineering, Technische Universität Braunschweig, Braunschweig, Germany, May 2nd - 4th, 2011*,
DOI 10.1007/978-3-642-19692-8_17, © Springer-Verlag Berlin Heidelberg 2011

concretes), and to energy recovery such as co-combustion in cement works, pyrolysis and/or gasification [4] [5] [6] [7]. The average weight of a vehicle is about 1 ton and 25% of its mass consists of ASR. This corresponds to about 2.5 million tons yearly generated and almost totally landfilled in Europe-25 (with an estimation of 3.5 million tons within 2015), with economical (due to the expenses related to this type of disposal) and environmental problems (associated to the physical–chemical processes of contamination which can occur in this situation).

This work aims at applying LCM to automotive sector, in particular to car fluff recycling. S*creening* LCA results are followed by laboratory-scale experiments of both plastic sorting and thermochemical conversion, which are the two most promising ASR recycling technologies. Expected results are mainly both to understand technical feasibility and "state of the art" of the most sustainable ASR recycling technologies and both to integrate this know-how into new vehicles design.

2 ASR CHARACTERIZATION

2.1 ASR Composition analysis

In order to recycle materials contained into ASR it is necessary to know its composition and recyclables share. Thus, a composition analysis was performed on the fluff samples in order to study ASR for future thermo-chemical and separation trials [5].

As it can be easily observed in figure 1, fines (0–20 mm fraction) represent almost a half of the total sample. For the fine fraction, a thorough composition analysis cannot be performed, because of the very small size of the materials included. Anyway, it is possible to identify glass pieces, plastics and metals, blended together with dust and dirt.

The remaining fluff mainly consists of polymers, up to 45%, such as polyurethane (foam rubber), plastics and rubbers. Textiles accounts for about 10% on the total and together with polyurethane foam (PUF) are strictly related to car seats and carpeting.

2.2 Chemical-physical analysis

ASR revealed a rough 30% of ashes, LHV equal to 13.8 kJ/kg and heavy metals such as As, Cr, Mn, Ni, and Pb exceeding Italian RDF law limits [6]. These parameters will be taken into account during LCA study.

3 LCA AS DECISION TOOL

Life Cycle Assessment was applied in this study as a scientific approach aimed to characterize and quantify environmental damages and impacts resulting from different ASR management methods: 1) landfill, 2) nonFe metals recovery, 3) incineration, 4) plastic sorting&recycling plus residue incineration and 5) gasification. Methodology, assumptions and scenarios are fully reported in reference [7].

The results show that industrial processes aimed at matter recovery are not only a necessary solution to fit European recycling and recovery targets for ELVs, but also the options that can obtain greater environmental benefits compared to present practices. Furthermore:

(i) ASR landfilling is the worst scenario due to the direct impacts resulting from the disposal of polluted and hazardous waste as such ASR commonly appears, without any treatment aimed at energy or material recovery; thus, it results in a net loss of material. However, the nonferrous metals fraction recovery carried out commonly by most shredders at present allows a reduction of environmental loads, even if strictly for resources consumption.

(ii) ASR co-combustion in incinerator would allow a decrease in damages related to plastics landfilling, and further benefits related to energy recovery processes, like waste volume reduction and organic pollutants destruction. In spite of the advantage resulting from the opportunity to operate in co-combustion with MSW (at the rate of 5%, any significant variations in outputs were not observed), ASR incineration should not be considered as a long-term alternative to landfill since this end-of-life strategy do not allow the achievement of 85% recycling target fixed by the European Community.

(iii) In terms of environmental impact, better results characterize post-shredder technologies modeled by scenarios 4 and 5, with a little advantage for "feedstock recycling". It is

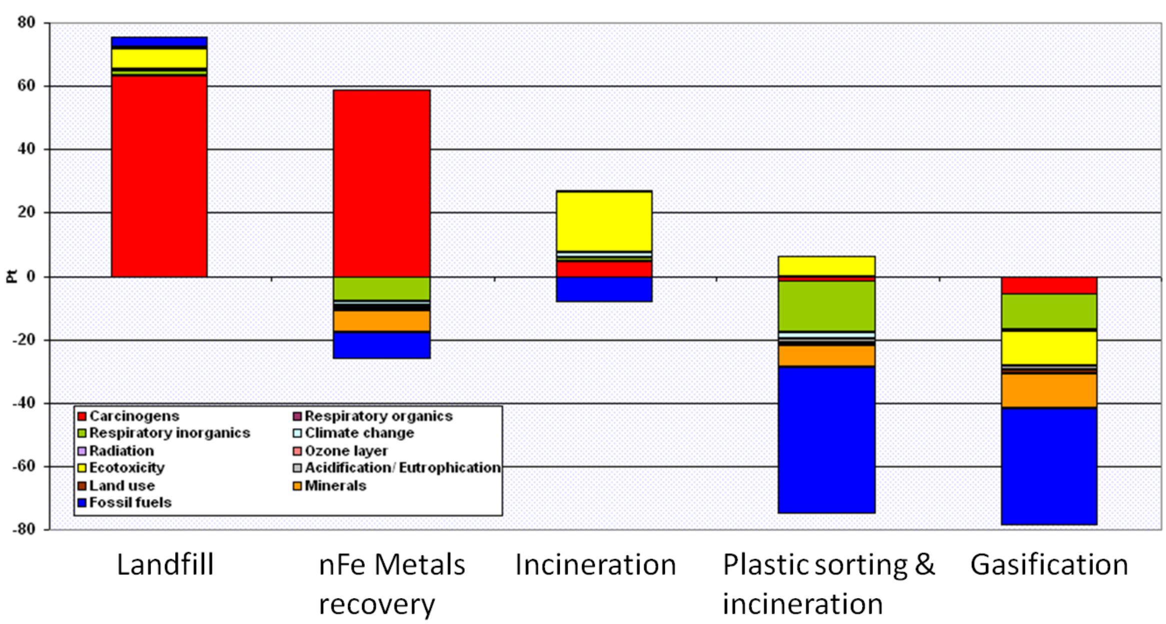

Figure 2: LCA results [7].

interesting to compare results even on the recycling and recovery rates gained by those scenarios: both allow the attainment of European targets, but scenario 4 reaches a higher recycling score than the other, competing with the other strategy in being considered the best solution. Hence, identifying the best way to treat ASR waste may be quite difficult even as a consequence of the frequent variations that occur in ASR composition.

Thermochemical plastics conversion and mechanical plastics recycling revealed to be the best environmental solution due mainly to the production of either chemicals (or polymers) and energy which compensates environmental impacts related to disposal with avoided impact coming from the production of goods. Consequently, we decided to study ASR pretreatment and thermochemical conversion via pyrolysis in order to separate and recovery polymers and chemicals from ASR.

4 HYDRO-MECHANICAL ASR PRETREATMENT

At first, ASR has been sieved by means of a 20 mm sieve, obtaining a fine and a coarse sample. Fine, coarse and raw ASR samples have been then floated with a lab-scale equipment with d=1.4 kg/l aiming at polymers separation from the non-organic residue. ASR floating/sinking ratio is 40/60 for coarse fraction and raw samples while it is 25/75 for fines, revealing fines to contain the heaviest materials: metals, heavy rubber, glass and soil.

After that, the floating fraction has been floated again with water in order to separate polyolefin, PP and PE (according to figure 3).

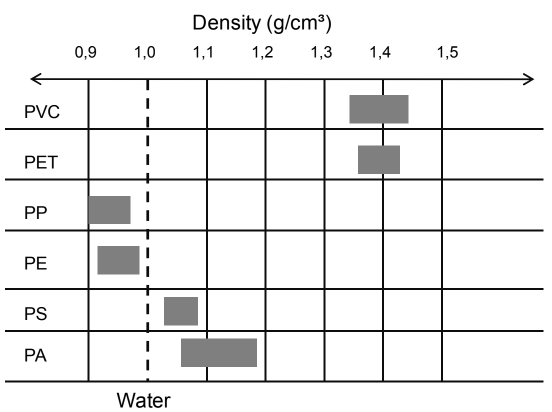

Figure 3: density distribution in selected plastics [8].

Polyolefin fraction amounts to a rough 8% of the total ASR mass while plastics with 1 < d< 1.4 kgl/l represent 11% of the ASR raw sample. Further separated poliolefines mechanical recycling trials are still going on in order to understand if this poliolefines mixture can be successfully palletized and re-extruded (as it was in scenario 4, chapter 3). The main benefits of this practice are plastics landfill avoidance and replacement of crude-derived virgin poliolefines with up to 50% recycled materials.

5 PYROLYSIS TRIAL

Thermochemical plastic conversion into hydrocarbons-rich oils is a very promising process in plastics waste management. Aiming at feedstock recycling, different sorted plastic fraction created in chapter 4 have undergone a pyrolysis process.

5.1 Pyrolysis reactor

Floated ASR samples were loaded in the pyrolysis reactor under a constant nitrogen flow. The reactor was then heated and, at cracking temperature, volatiles compound created were carried out of the reactor by the N_2 flow and condensed in two coolers. Uncondensed gases were collected in a gas sampling bag and analyzed. Once cooled down, reactor was opened and solid char residues taken out and weighted. Liquids were weighted and characterized as well by GC-MS.

5.2 Pyrolysis results

Results show that raw ASR sample has a total conversion (meaning gas + liquid yield) of 22%. Floating samples with d<1.4 kg/l rise total conversion to almost 60%.

Moreover, polyolefin alone reach 90% conversion with low liquid viscosity and optimal refining potential. Pyrolysis oil chain length is influenced by waste input. The goal is to achieve light compound for chemical recycling.

Polyolefins oil consist of: 16% molecules with more than 14 carbon atoms, olefins and paraffins represents a rough 25% while aromatics only 5%. Unknown compounds are quite high, 35%, but further GC-MS analysis will be carried out in the next future. If compared to mixed plastics oil, the poliolefines one looks much more suitable for further refining due to reduced viscosity and shorter hydrocarbons chain.

6 FEEDBACK TO VEHICLES ECO-DESIGN

DfR and DfD are tools belonging to the set of techniques named Design for Environment (DfE), aimed at the reduction of impacts deriving from EOL treatment and at the maximum product recycling and recovery. These tools can provide better product recyclability, determining the conditions for an increased added value, in a life cycle perspective. Thus, the design of each component must be performed by choosing recyclable or renewable materials, without toxic or hazardous substances, mono-material or composite parts of a high compatibility with recycling processes, low energy consumption materials, according to a life cycle concept. Furthermore, complex products (as automobiles) must be designed in order to simplify as much as possible assembly and disassembly operations, resulting in significant advantages from easiness and quickness standpoints. It can be reminded that actually disassembly is still far to be considered as a reversal of the assembly, thus next years DfD techniques should carefully consider joining parts, structure priority and the correct product dismantling sequence, to reduce disassembly costs, increasing effectiveness, limiting the time employed.

Focusing on the recycling and recovery rates claimed by ELVs Directive for year 2015, it appears fundamental to improve recovery processes for non-metallic fraction. Intuitively, the increase in removal efficiency for these materials from ELVs, combined with a required spread of markets for secondary products, will allow the achievement of EC targets and economical profits for the stakeholders involved. Equally important will be the choice of materials employed in vehicle design, since the use of mono-materials and composites with high separation efficiency from vehicle waste, is a nodal point towards a sustainable ELVs management.

In a previous work we applied *design for dismantling* (DfD) guidelines to a car seat [9]. This allows reducing dismantling time to one third whit respect to the baseline model. Applying now also *design for recycling* (DfR) guidelines, it means that different families of plastics would be substituted by polyolefins, characterized by higher sorting and recycling easiness, when technically feasible.

7 CONCLUSIONS

Life-cycle-oriented products development describes the process of systematic consideration and optimization of a product's technical, economic and ecological characteristics and effects during the entire life cycle, within the frame of the product development process. The goal is to meet the requirements of an Extended Product Responsibility (EPR) by using the scope for decision-making during the product development to realize a maximum product benefit for costumers and producers during the life cycle and to minimize its economic, ecologic and social cost risks.

During 2009 Italian ELVs recycling rate (Rr) was 80.6% [10]. Thus, ASR represents a rough 20% of a vehicle mass since no further treatments are currently carried out on ASR in Italy. So far, in order to reach 85% Recycling rate in 2015, it is necessary to recycle at least 25% of ASR mass. Plastics floatation and pyrolysis may lead to a rough 30% yield that, by summing up residual 5-6% metals in the heavy sinking residue, may lead to a total 35% ASR recycling, corresponding to 88% final Rr. ASR floatation and pyrolysis are feasible but further research are necessary for improving both separation efficiency and refining pyrolysis oil.

8 REFERENCES

[1] Jody, B.J., Daniels, E.J., (2006): End of-Life Vehicle Recycling: The State of the Art of Resource Recovery from Shredder Residue, Energy Systems Division, Argonne National Laboratory.

[2] EC, (2000): Directive 2000/53/EC of the European parliament and of the council of 18 September 2000 on end-of life vehicles—commission statements. Off. J. Eur. Comm. L269, 0034-0043 (Brussels).

[3] Santini A., Morselli L., Passarini F., Vassura I., Di Carlo S., Bonino F., (2010a): End-of-Life Vehicles management. Italian material and energy recovery efficiency, Waste Manage, in press.

[4] Srogi, K., (2008): An overview of current processes for the thermochemical treatment of automobile shredder residue. Clean Technol. Environ. Policy 10, 235–244.

[5] Boughton, B., Horvath, A., (2006): Environmental assessment of shredder residue management. Resour. Conserv. Recycl. 47, 1–25.

[6] Morselli L, Santini A, Passarini F, Vassura I (2010): Automotive shredder residue (ASR) characterization for a valuable management. Waste Management, in press.

[7] Ciacci L., Morselli L., Passarini F., Santini A., Vassura I. (2010): A comparison among different Automotive Shredder Residue treatment processes, Int J LCA.

[8] La Mantia, F. (2002): Handbook of plastics recycling, Rapra Technology, Shrewsbury UK.

[9] Santini A., Morselli L., Passarini F., Vassura I., Herrmann, C., Luger, T. (2010): Assessment of Ecodesign potential in reaching new recycling targets, Resources, Conservation and Recycling, 54, 1128-1134.

[10] GHK/Bios (2006): A study to examine the benefits of the End of Life Vehicles Directive and the cost and benefits of a revision of the 2015 targets for recycling, re-use and recovery under the ELV Directive. Final Report to DG Environment, Birmingham.