
Frank E. Mark
DOW Europe S.A

Axel Kamprath
Recticel S.A.
ABSTRACT
A more environmentally sound ELV disposal is presently discussed with the European Union directorates, the council of ministers and the European parliament. National plans or already existing legislation are in place in several countries like Germany. PU seating material is one of the key targets by legislators and environmental authorities for dismantling. The reason for dismantling seats is a potential recycling or recovery for the PU seating material as it is one of the large plastic parts and can be relatively easily dismantled. A general broad investigation on the ecological and economical impact of this PU material has not been done as for many other parts like the fuel tank, which are presently considered for dismantling.

EU legislation in preparation is calling for a reduction in landfill from ELV’s from 25% by weight today, to 5% by 2015.

The position of the PU producing industry and the seat molders is presently to define what is the economic impact of dismantling seats to recover the PU cushions. A clear cost base calculation for the various routes to cope with the EU and national quota reducing landfill by 2015 to < 5 % of the vehicle is made for the ELV with regards to the subject of potential PU dismantling.

The two potential routes for PU seating could be either a mandatory dismantling with further use for recycling/recovery operations or a recovery with the rest of the plastics.

The lowest cost option for the disposal of an ELV in the future will be to use the traditional process of shredding. This operation could be followed by taking the automotive shredder residues (ASR) to a fuel substitution operation with or without any further ASR refining. Other favorable routes to deal with the ELV depend on regional circumstances with respect to existing infrastructure of collecting companies, shredders and potential users of today’s or refined ASR. The demonstration of different routes to recycle/recover PU seating materials, the ELV in different geographical areas is part of ISOPA’s and Euro-Moulder’s technical program.

The present quality of SR (shredder residue) does favor this option as fuel substitute, and efforts of the plastics industry are aimed at getting Municipal Solid Waste Combustion recognized as an official recovery route and have sufficient energy recovery capacities throughout Europe. The technical demonstration in large-scale facilities and the relatively lower cost of this route compared to other solutions are the reason. Municipal Solid Waste combustion (MSWC is today seen by most European environmental agencies as an indispensable part of integrated waste management because of the environmental performance of today’s state of the art equipment, but its status as a recovery option for ASR is still in discussion especially in Germany.
Refining of ASR to make a raw material or fuel will not be cost neutral. The price of fuel today is too low to warrant an upgrade to higher quality ASR without subsidy. This additional cost would increase the cost of ELV treatment compared to the previously mentioned route.

The dismantling of PU seating material requires a number of steps until the material is at the gate for a customer to use it as a fuel or raw material. Removal for use as fuel in cement kilns is not cost effective due to the low price of fuels today in the cement producing industry.

Viable chemical recycling routes for mixtures of PU materials from ELV’s seats do not exist at present at sufficiently large scale.

There are ongoing efforts on commercial scale in the Netherlands to dismantle seats. These activities in NL are subsidized by the first owner of the car and the money collected is used for dismantling, collection and mechanical recycling into rebonded foams. In other countries like Germany (D) a discussion within the industry and a request for subsidies is ongoing. Any kind of dismantling operation will require a subsidy to compensate for the loss a dismantler or recycler will occur under today’s economic situation.

Market size for rebonded foam is not large enough in Europe for the amount of dismantled PU foam, as a substitute for scrap PU trims. Other outlets for PU foam like potential regrind into powder and use as filler are being evaluated but are not yet commercial.

1. BACKGROUND

The present legislative developments in the European Union and member states request industry to take a position on producer responsibility and potential take back schemes. The EU ELV draft directive is in the second reading, and one can expect that the legislative process will be finalized this year. The key targets to be met on the recycle and recovery quota are set, whereby the time for implementation is still discussed. The current proposal foresees ELV’s to be reused / recovered from 2006 by 85 % and from 2015 onwards by 95 %. Recycling and reuse targets are 80 % and 90 %, respectively.

A well-balanced approach to sound ecological ELV treatment needs to be backed up by a full cost analysis for the various recycling/recovery options that industry has.

A technical analysis of the various options for plastics in the residue from shredders (SR) has been done and uses a multiple level: technology, ecology, cost, market availability and public acceptance sector approach (1).

The analysis done below applies a true full cost approach with respect to German conditions. Countries in central Europe e.g. the Netherlands have somewhat similar economic and market conditions. But other countries are completely different with almost no infrastructure in the MSWC sector like e.g. Spain and Italy. A country specific analysis has therefore to be followed.

In figure 1, ELV Treatment Scheme Today the cost of the total chain has to be looked at with all steps included. This is shown in figure 1, starting with collection, treatment of the ELV, dismantling, recycling, shredding and other recovery operations.
Figure 2. ELV Treatment in the Future

Figure 2 shows the ELV treatment in the future whereby one has to differentiate between typically practiced operation in the market and best available technique (BAT) in the industry. The BAT technology becomes standard once the EU and national regulations become enforced in the market.

The element of subsidy from whatever source (either first owner or last owner), or a totally free market operation without additional money for the higher environmental cost, has not been agreed on in the European community. In this context it is important to note that subsidies by national governments are today already in place to reduce European-wide high unemployment figures. Work places are today subsidized by various national governments leading to unrealistic low labor cost for the dismantling operation. In addition the impact on the market of large volumes of materials from ELVs dismantling is not known.

2. ELV TREATMENT TODAY

2.1. COLLECTION – Most cars at the end of life are delivered either to the car dealers, where old cars are traded for new ones, or they may be delivered directly to an officially recognized dismantler.

How much goes back to the car dealers depends on the OEM’s marketing / incentives.

In recent years several OEMs like Opel and Ford had slogans such as “old versus new ones” to sell more cars. These campaigns over several years in Germany brought a significant number of ELVs into the hand of contract car dealers. Most of these cars went afterwards to contract dismantlers in order to make sure that cars get scrapped as these campaigns were subsidized car sales. Opel and Ford did support up to 3000 DM/ELV for new car sales. The cost of the subsidy was split 50/50 between the OEM and the dealer. At normal times when no sales discount are given contract dealers receive only a minor amount of their cars back, i.e 3-5 %.

2.2. DISMANTLER – Under today’s existing and up-coming legislation, dismantling embraces a number of important steps: depollution and removal of parts for reuse. But the term dismantler does not describe today’s operation entirely as very little dismantling takes place except in certain countries. In the future the activity may expand to removal of parts for material recycling depending on the European and national legislation.

The “depollution step” is very time consuming due to the lack of equipment for this operation and due to current car design. The future design of parts and car units will take the removal of residual liquids such as gasoline, motor oil, anti freeze, brake fluids, window cleaners etc into account. This results today into high labor cost and to relatively high amount of liquids, which are still left in the car. The labor required is about two hours. The cost of disposal for these liquids, which have to be kept separately, will increase in future leading to higher costs.

The depollution cost will vary in Europe due to the difference in labor cost, disposal laws and environmental permits for these operations. Today’s cost level ranges between 150 and 200 DM/ELV in Germany, where no subsidy exists. Increased certification need due to the enforcement of the ELV legislation may push this cost up. The present situation in Germany and in many other countries, where there is no external funding from the consumer, does not allow any part removal, which is not cost effective. Therefore only batteries and well functioning spare parts are removed, which are either sold directly or retooled.
by specialized companies or even by the OEMs.

Figure 3. ELV Treatment Cost: Dismantler

Figure 3 shows the profitability range for dismantlers and should be understood in the following way: if a dealer or dismantler pays to the end-user 300 DM/ELV, and if he can in minimum realize 800 DM/t sales of parts from this ELV he will make a small profit. The cost of depollution accounts to 150 DM and the revenue for the hulk sale is today 50 DM/ELV. If he pays even more than 300 or realizes only less than 800 DM/ELV he is loosing money.

This case shows that staying in business with higher cost of compliance due to increased fixed cost becomes even more difficult. The revenue from parts sale today and in the future is and will remain the driving force for the dismantler. The present situation is that many cars with components suitable for dismantling are going into export either east, west or south. This export is fueling competition among the dismantlers to get cars for disassembly. Dismantling of plastic parts at that level of cost versus revenue is out of question.

It is estimated that about 15 to 25 weight-% of the ELV (approximately 200 kg) is reused in this way (2,3). The estimates vary widely because of the lack of reliable data. It is important to define this amount better in quantity due to the required legislative quota for reuse of parts included in the recycling quota.

2.3. SHREDDER – The shredder operation is the classical way to process the ELV. After dismantling, the remaining part, about 75 to 85 % by weight of the ELV is sold to shredders for further processing. The shredder companies have mostly contracts with several dismantling companies to secure supplies for their operation. They pay at present (1999) in Germany around 50 - 90 DM/ hulk (4). They also pay the transport to the shredder site, which is sometimes a rather high share (30 %) of their total cost.

The shredder cost operation was modeled using results from a study done by Arthur D. Little for APC (5). The model input parameters have been chosen for Europe with typical German labor cost of 40 DM/h (manual) and 60 DM/h (technical) and ASR landfill disposal cost of 150 DM/t. These input values are on the low side of the current market level. The result of this cost modeling shows the difficult position shredder operators are currently facing with a gross margin of 20 DM/hulk.

Because of that, more than 40 % of the ELV or the hulks are going today to export. These exports result into capacity utilization rates of only 50 to 70 % throughout the remaining shredder industry in Germany. Higher operation cost and longer pay back times for the investment are the result.

The revenue of the shredder for the steel, iron and non-ferrous streams is changing very much when comparing today’s prices within a time frame of the last 10 years. Average prices have been used for the calculations ranging around 220 DM/t steel and 380 DM/t for non-ferrous metal mixture. Published list prices can be found in the journals for secondary materials with 110 $ /t at the gate of the shredder in Germany (6).

The transport cost included in the calculation is based on 180 km, which may be high for the typical density within Germany at present. There are about 50 shredders in Germany, which averages to
a smaller distance between each shredder. This also leads to the conclusion that individual shredders have a much smaller protected area they control.

Having separated the metal fraction of the shredded hulk, about 200 kg of SR remains at the shredder site. The total SR volume in Europe sums up to about a minimum of 1.5 million tons per year out of 6.7 million ELVs in Europe and about 200 ktons out of 1.3 million ELVs in Germany.

Most of the SR today is brought to landfill sites. The disposal cost varies significantly from country to country. Therefore, many ELVs and hulks go east and west to Holland, where lower disposal fees exist. Sensitivity analysis shows that if the disposal landfill fee for ASR is increased the relative ratios of transport and disposal do change rather dramatically.

The overall conclusion regarding the cost situation of the shredders in Germany is such that the business today has pay back times of 15 to 20 years in best cases. The fact that most shredders have been built 15 and more years ago does change this picture to a different cost analysis without capital charges. The capital charges were in the base case calculation around 30% of the total cost for the shredders. Without capital charges profitability increases, but it does not leave opportunity for reinvestments and makes the business not sustainable.

2.4. ENERGY RECOVERY OF SR & PU – There are many potential recovery operations for SR but only a single one is used today, which is recovery in MSWC. The European term for WTE (Waste To Energy) is EFW (Energy from Waste) and means state of the art combustion of municipal solid waste on the traditional grate fired boilers to generate medium pressure steam (40 bar). The recovered energy is used to drive a turbine for electricity generation or use medium to low pressure steam in district heating and industrial processes. The extent to which SR goes into energy recovery facilities is till today very small <70 ktons in Europe. PU, however, contributes significantly due to its high caloric value to make energy recovery of SR valuable.

Other potential processes are such where fuel substitution through SR can take place. It is also of interest to understand the potential energy recovery or feedstock-recycling route for dismantled parts separated materials like polyurethane (PU) from car seat cushions. Therefore the two routes are considered here further.

2.4.1 Energy Recovery in Production of cement or lime – The lack of demonstrated operational capability to use PU foams from seating does not mean that this operation in cement kilns cannot be considered for our cost estimation. The quality of the seating material would certainly meet the specification requirements for fuels in the cement industry (8,9). Pretreatment cost is important to consider for the cement route. Estimated pre-treatment costs for shredding seat foam to 5-10 cm pieces is ranging from 200 to 400 DM/t, which includes a simple ferrous metal detector and removal system. This material size is then small enough for so called secondary firing as fuel replacement. Primary flame fuel substitution requires smaller (<2 cm) fluff and does not seem worthwhile for the present market situation, because cement producers do not have lower gate fees for primary fuel versus secondary fuel replacement. Today this might only be ecologically favored.

Figure 5. ELV Treatment Cost: ASR Refining for Sales

The present gate fees in the market are around 200 DM/t for MPW (mixed plastics packaging waste) in the steel industry. The cement industry requests in the range of 50 DM/t up to 200 DM/t depending on the amounts delivered, the quality of fuel and the physical form bales or fluff delivered. Overall the present gate fee in the market for baled material free delivered is ranging around 100 to 200 DM/t and covers their cost to prepare the fuel to their specifications on size, homogeneity etc.
The cost of the cement route for the PU can be looked at favorably due to the lack of special pre-treatment costs compared to the steel industry. The cement industry can be hence a good customer for PU seating materials.

2.4.2 Recovery in MSWC – Municipal solid waste combustion (MSWC) is a widely used technology in Europe to dispose of household and small industry wastes as well as commercial waste. Its use today in various European countries ranges very widely from ca. 80 % in Denmark and Switzerland to as low as 5 % of total MSW presently in the UK. Market data and a technical assessment of the state of the art MSW combustors are available (10,11) and the aspects of plastics have been closely investigated very much in detail (12,13,14). The advancement of gas cleaning with respect to gaseous emissions is very high compared to the past and to other industries like cement and steel. The current EU directive for MSWC enforces this high environmental performance standard.

The co-firing of dismantled PU material in MSWC is looked at by legislators today as inferior to other material recycling or recovery routes eg. cement. Life Cycle analysis (LCA) for MPW have shown that state of the art high efficient MSWC can compete with chemical recycling and the use as reducing agents in blast-furnaces (15). A high efficient MSWC with year round energy demand is comparable to a power plant or a co-generation plant.

This route does not require any pre-treatment of waste. Baled seats foam material can be dropped into the bunker as they are delivered from the dismantler after baling wires are cut. Different technical demonstrations with large amounts of PU materials have been done. These materials are very close in quality to the seating material. No technical operational, emission related problems are to be foreseen for these high PU content combustion tests. The nature of MSWC operation is such that materials are mixed by the crane to use higher calorific materials like PU with wet low calorific materials like household waste to achieve stable and good combustion conditions with high burn out.

The cost of MSWC varies significantly from country to country, and similarly, the capacity and availability of MSWC. The gate fees today in the market in Germany, Switzerland, the Netherlands and the UK are shown for example in figure 6. These gate fee prices are compared to the gate fees taken by landfill operators. It is obvious that landfill costs are generally lower than those for MSW combustion. This situation is due to different environmental standards, which will prevail till 2005 in central European countries.

3. PU CUSHION DISMANTLING

For the recovery option of PU seating materials two cases A and B can be considered.

A: The dismantling of PU seat material only, whereby the cover textiles and plastics are removed. Large metallic parts inside the seat module are removed as well whereas small steel wires may remain inside the foam cushion. It is assumed that these small amounts of metals are not subject to concern to the cement production, as tires are today used in the secondary firing with the steel cord being left inside the tire.

B: The second case considered in this cost estimation assumes a total dismantling and full separation of the other non PU materials from the PU to make the material suitable for further size reduction into small PU fluff or densified fluff.

3.1 LOGISTICS OF DISMANTLED PU CUSHIONS – Reuse or material recycling of PU from ELV seats requires – besides the disassembly step – important logistic
efforts. In order to make an estimation of these additional logistic cost, three scenarios have been considered:

I. Each dismantler has invested in his own baling press and compresses the PU cushions before transportation to the recycler

II. The dismantler collects PU cushions in containers and transports them to a nearby baling center

III. Uncompressed transport of PU cushions from dismantler to recyclers

It is assumed that there are about 1,000 dismantlers with legal license in a country like Germany, which fulfill all the technical and environmental requirements. We assume in this study further 30 baling centers and 4 final destinations (e.g. rebonded foam plants or cement kilns).

The average distance between dismantlers will be around 50 km. Average distance between dismantlers and the baling center will be about 200 km and the distance between baling center resp. dismantler to the final destination will be 600 km.

In this calculation we estimate 2 Mio cars to be dismantled per year with in total 8 Mio front seat plus front back-rest cushions and 4 Mio rear seat plus rear back-rest cushions. In an uncompressed state this represents a total volume of 320,000 m³ polyurethane foam having a total weight of about 14,000 metric tons (average density of seat cushions about 45 kg/m³ = 2.8 pcf). The calculations are based on an average transportation cost of 2.5 DM/km for a 40 m³ size truck.

Thus, each of the 1,000 dismantlers will have to handle about 320 m³ or 14 tons PU per year.

**Scenario I:**

Dismantler transports baled PU to final destination:

Depending on the capacity and size of the baling press, these 14 tons will be compressed to 200 to 700 bales. Transportation cost will be between 0.90 to 1.95 DM/kg PU. In total (including the baling process itself) the costs will sum up to 1.10 to 2.20 DM/kg PU. It has to be mentioned here that the capacity of even the small baling press chosen is only used at a level of maximum 10 % (in a one-shift production).

**Scenario II:**

Dismantler transports unbaled PU cushions in containers to baling center and from there to the final destination:

Assumption: there might be 30 baling centers in Germany. Each baling center will thus have to handle 470 tons PU per year.

The 320 m³ PU foam per dismantler and year will require between 20 and 25 transports to the baling center (distance about 200 km). These costs sum up to 0.75 to 1.00 DM/kg PU.

Each baling center has to bale 470 tons PU per year. The baling center can afford bigger presses than any individual dismantler. Thus, about 2,000 bales of 250 kg each have to be transported to the final destination (average distance 600 km). The total transportation cost incl. baling itself sums up to 0.40 to 0.50 DM/kg.

The total logistic costs of scenario II will be between 1.15 and 1.50 DM/kg PU foam.

**Scenario III:**

Dismantler transports unbaled PU to final destination:

As one can imagine this is the most expensive solution: in this case the logistic costs are between 2.10 and 2.80 DM/kg PU. Figure 7 shows the logistic cost in an overview:
3.2 RECYCLING – Two different routes of recycling in the context of the European legislation have been considered (7). The material recycling such as straight mechanical recycling of PU into other applications or the recycling as chemical feedstocks such as polyol or synthesis gas.

I. Mechanical recycling into rebonded foam

II. Chemical recycling:
    • Glycolysis
    • Reduction of iron ore in steel industry

The extent of recycling for dismantled parts is rather limited today in Europe. The countries where small amounts of plastics and PU are removed are limited to the Netherlands and Italy. Auto Recycling Netherlands (ARN) has selected seats as one item that is dismantled. The amount of PU generated in 1998 was published with about 2200 t. The material is collected in special trucks equipped with a transportable baling unit to reduce transportation cost and sent to recycling companies.

Mechanical recycling:

Flexible bonded foam – The production of flexible bonded foam represents by far the most important technology of mechanical recycling. More than 40,000 tons of bonded foam have been produced in Europe (out of industrial waste) in 1999 whereof more than half is dedicated to flooring applications. Another 60 000 tons of material trim foam (production waste) are sent to the USA for carpet underlay. For an additional expected amount of approximately 70,000 - 80,000 t/a foam from ELVs, however, even that market is definitely not large enough.

The market price level for baled PU to be used for rebonded foam applications fluctuates very much when looking at historical figures, from 0.40 to 1.20 DM/kg. Future predictions on the price level are very difficult and depend on the market supply and demand balance for the flexible PU scrap market. The price estimates used for this study assume a general consolidation in the supply demand balance similar to today with a trend to have less export from Europe to the US than today. The price level for baled PU assumed for the bonded foam production will range from zero to 0.8 DM/kg to be paid by the recycler for the dismantled PU seating material.

Regrind/Powdering – The use of pulverized PU material as filler is another potential option from a commercial point of view.

The concept of using flexible PU foam after milling to 60 to 120 microns particles in new hot and cold molded foams has been extensively researched by several parties. Equipment building companies in NA and Europe have developed the necessary equipment for the mixing and dosing equipment (7).

Grinding economics vary as a function of volumes produced and equipment used, from c.a 0.65 to 1.20 DM/kg. A 10 % loading with PU powder in a new foam cushion seems to be technically viable. Loadings of 15 % might be possible in slabstock PU foams which represent a market about 7 times larger than car seat molded foams. Such foams are used for mattresses and upholstered furniture, but also for rear car seats and fabric lining for seat covers and roofing in cars. Other applications of such PU powder could be considered.

Chemical recycling:

Glycolysis – In Germany some initiative exists from OEMs to test that PU recycling potential. The OEM most active in the market is BMW for their instrument panel. The overview on PU specific recycling technologies is given in (7). Glycolysis is the simplest chemical operation and
results into different polyols depending on the type of PU and of glycol used. According to EWvK, former BAYER, BASF and HOECHST joint research institute in Germany, the cost of these recycle polyols are of similar prices as virgin materials ranging from 1.85 to 1.60 DM/t for DPG and DEG base respectively. This kind of recycle polyl, however, is only suitable to produce rigid PU foams and therefore not suitable for seat production. The total volume of those polyols from ELV seat cushions would sum up to about 200,000 tons per year. Due to their chemical nature those polyols can only be used in rigid foams. This market, however, is by far not big enough to take up that amount additionally.

Recycling in the steel industry – The use of PU seating is potentially possible from the experience made with plastics from packaging (MPW). But it has been always made clear by the steel (pig iron furnace) operators that they like to get high grade value fuels with high carbon and hydrogen values. PU seating material has a heat value of around 27 GJ/t. This route is being seriously considered in Japan and also studied in North America (22). The relatively high gate fee and the additional treatment cost compared to the energy recovery route processes should however make this route less attractive from an economic point of view.

4. COMPARISON OF TRADITIONAL AND POTENTIAL FUTURE ELV HANDLING:

The two important parameters, quality of foam and cost to get this quality, are considered here for a comparison.

4.1 QUALITY COMPARISON PU SEATING MATERIAL – The quality of PU seating material has not been assessed in the past. Industry has investigated the influence of shredder treatment on the polymer fraction in SR with the objectives to use the materials for recycling purposes and to value the contribution of polymers to the SR mixture with respect to contaminants and hazardous components. The PU seating material has been analyzed as part of the SR mixture in Switzerland and Germany.

- The contamination of the PU seating material is rather high as found out by specific foam analysis. The total amount of heavy metals is rather high and above 1000 ppm for As, Cr, Co, Cu, Mn, Ni, Pb, V, Sb and Sn of the regulated heavy metals in various European Emission laws.
- The foam might be washed or even dissolved in special solvents as described in (21). But it is not proven that a considerable clean up of the foam fraction is technically feasible at large industrial scale, economically viable and ecologically desirable.
- The foam quality of dismantled PU seating material has been analyzed in three European countries: The Netherlands, Italy and France by ISOPA and Euro-Moulders. Large scale dismantling takes place in the market in NL and I, which allowed sizable amounts of around 10 t of PU foam to be processed for this purpose.

A comparison of the average analytical results from the ELV PU foam dismantled and the SR PU foam is given below:

<table>
<thead>
<tr>
<th></th>
<th>PU Foam Dismantled</th>
<th>PU Foam in SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hu</td>
<td>25.6</td>
<td>16.7</td>
</tr>
<tr>
<td>Ash</td>
<td>0.9</td>
<td>21.3</td>
</tr>
<tr>
<td>Cl</td>
<td>0.11</td>
<td>0.91</td>
</tr>
<tr>
<td>Hg</td>
<td>&lt;0.1*</td>
<td>0.8</td>
</tr>
<tr>
<td>Tl, Cd</td>
<td>&lt;1.0*</td>
<td>1.2</td>
</tr>
<tr>
<td>As to Sn</td>
<td>200</td>
<td>1200</td>
</tr>
<tr>
<td>Zn</td>
<td>50</td>
<td>5340</td>
</tr>
</tbody>
</table>

* < means below detectable limit.

The end of life characteristics of dismantled PU foam are extremely different and significantly better than foam from ASR’s. This is not surprising as the PU foam absorbs a large amount of heavy metals and other components still present in the ELV when its goes through the shredder. The contamination of the SR foam with other constituents is extremely high and makes any kind of cleaning costly and carries a high risk for the final customer of this PU foam from SR for e.g. rebonding.
4.2 COST COMPARISON PU SEATING MATERIAL – A comparison of different cost elements involved to get these two different PU qualities is shown below. Today’s free market disposal system for ELV may change drastically in the near future due to legislative pressure and possible law enforcement for sound ELV treatment. The development of ELV disposal cost will bring higher costs for the total chain. The hierarchy of solutions on the cost base is clearly indicated in figure 8.

Figure 8. ELV Treatment cost today

Co-combustion of plastics within the ASR is the preferred option from a cost point of view for all plastic materials. Many recent large scale controlled tests (16,17) and ongoing operations in countries like Switzerland, Germany and Sweden have demonstrated the technically mature stage of this recovery route for PU in SR (18). This option has been supported through environmental data (19) for the Nordic countries. It has been shown with a combined environmental parameter study like the ELU (Environmental Load Unit) that co-combustion of SR, which contains all the PU foam ranks similar to dismantling of plastic parts. Only very few other LCA based analysis are presently available.

Enough environmental arguments about the sound concept are available especially on the subject of solid residue usage and potential risk (20). These data show that SR energy recovery route in MSWC is acknowledged as a recovery route. The refining of the bulk ASR as raw material or fuel may be a competitive option at future market prices.

Figure 8 shows graphically the ranges for the individual cost elements of dismantled PU seating foam as well total cost of dismantled PU seating material in showing ranges for the individual cost elements. The ranges are due to local circumstances, differences in transportation cost, different pre-treatment requirements to name only a few important drivers for the overall cost. The total overall cost for the rebond case will add up to about 1.90 DM/kg to 4.50 DM/kg depending on the parameters. The total chain cost for the PU/filler application is estimated to a range from 2.90 DM/kg to 5.60 DM/kg. Total cost for the cement route sums up to 1.60 DM/kg to 3.40 DM/kg PU. Revenues from material sales of shredded PU or milled powder as well as any kind of gate is not shown and need to be considered for the total assessment. Market value for the floc or powder material will relate to price development of trim foam.

Other alternatives may be sustainable only with long term subsidies.

5. CONCLUSIONS

The discussion around the dismantling of plastic parts for further reuse and recycle needs a diligent analysis of environmental, economical and market impacts. The decision on the best possible use for large parts like PU seat cushions needs a broad investigation about alternative routes to MSWC, such as the ones discussed in the paper, which are not commercial today.

A general consideration in Europe on the possible dismantling of PU seating material is not possible as this depends on prevailing conditions in the various countries such as the country legislation, the ELV collection area and the location of the recycling plants. The general waste management guidelines such as proximity principles, self sustainability and use of existing infrastructure apply for decision on best practice.

The differences between various countries in infrastructures, shredders and dismantling operations, existing recycling industry and recovery operations such as in cement kilns and in blast furnaces as well as waste-to-energy facilities is so important that many different ELV recycling / recovery schemes will develop, which will lead to a wide variety of uses for end of life vehicle PU seating material.
ACKNOWLEDGEMENTS
The work has been greatly supported by the two industry associations ISOPA and Euro-Moulders.
The opinions expressed are those of the authors and not necessarily those of The Dow Chemical Company and Recticel SA.

REFERENCES
2. F. Wallau, A.J. 11/97, Situation of ELV dismantlers in Germany, pages 42-45
4. F. Wallau, A.J. 9/97, Situation of Shredders in Germany, pages 46-50
5. APC Project P-12, American Plastics Council, Arthur D. Little, January 10, 1994.
7. ISOPA, European Isocyanate Producers Association, Fact Sheets on options in practice, rebonded flexible foam, densification/grinding, adhesive pressing and particle bonding, compression moulding, regrind/powdering, chemolyis, etc.,...
12. Frank E. Mark, APME TEC brochure, Energy recovery through co-combustion of MPW and MSW, June 1994
13. Frank E. Mark, APME TEC brochure, effects of MPW addition on solid residues and chlorinated organics, December 1994
14. J. Vehlow and Frank e. Mark, APME TEC brochure, co-combustion of building and construction foams with MSW, 1996
17. IGEA, Foundation for Environmental Sound Car Disposal, CH-3000 Bern, P.O. 5232, Switzerland
18. Volvo Car Cooperation, S-40508 Goeteborg, ECRIS Project: REFORSK Institute, Sweden
21. SALYP, Recycling of ASR, Salyp nv, 8900 Ieper, Belgium
22. ARC '99 ,Michael M. Fisher, APC , USA

DEFINITIONS, ACRONYMS, ABBREVIATIONS

ASR: Automotive shredder residue
MPW: Mixed plastics packaging waste
SR: Shredder residue
ELVs: End of Life Vehicles
ATTACHMENT I: COST COMPARISON TABLE

Cost estimates in DM/kg PU were done for the three potential routes to use dismantled seats and the PU foam from this operation for cement fuel substitution, re bonding applications replacing production trim scrap as well as powdered PU for potential future filler applications. I and II means low and high estimate respectively!

<table>
<thead>
<tr>
<th></th>
<th>Dismantling incl. separation</th>
<th>Baling + Transport</th>
<th>Storage</th>
<th>Washing</th>
<th>Shredding or Grinding</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td></td>
</tr>
<tr>
<td>PU/Cement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>0,20</td>
<td>1,20</td>
<td>0,10</td>
<td>-</td>
<td>0,10</td>
<td>1,60</td>
</tr>
<tr>
<td>II</td>
<td>0,80</td>
<td>2,20</td>
<td>0,20</td>
<td>-</td>
<td>0,20</td>
<td>3,40</td>
</tr>
<tr>
<td>PU/Rebond</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>0,40</td>
<td>1,20</td>
<td>0,10</td>
<td>-</td>
<td>0,20</td>
<td>1,90</td>
</tr>
<tr>
<td>II</td>
<td>1,30</td>
<td>2,20</td>
<td>0,20</td>
<td>0,40</td>
<td>0,40</td>
<td>4,50</td>
</tr>
<tr>
<td>PU/Filler</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>0,40</td>
<td>1,20</td>
<td>0,10</td>
<td>-</td>
<td>1,20</td>
<td>2,90</td>
</tr>
<tr>
<td>II</td>
<td>1,30</td>
<td>2,20</td>
<td>0,20</td>
<td>0,40</td>
<td>1,50</td>
<td>5,60</td>
</tr>
</tbody>
</table>

Assumptions made:
(1) time to dismantle PU from ELV, including separation of metals and textiles from PU, foam should be metal free
(2) small baling press at the dismantler (15-20 kg/bale) or baling center with high capacity baling press (250 kg/bale); transport cost are based on trucking rate of 1500 DM/day of a maximum 20 tons or 50 m³
(3) storage cost are low due to outside-ambient conditions, several stages of storage are possible or needed
(4) due to lack of experience could the washing step only be estimated very roughly
(5) shredding step to produce PU flocks at a rate of maximum 800 kg/hr with knife mill type; grinding step to about 100 micron suitable equipment like slow rotating twin roll mill, strongly influenced by particle size prices are relevant to 50 % of virgin production scrap price