Eco-Innovation for Recycling/Remanufacturing Electric Vehicle Engines

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Abstract. Because of climate changes and the increasing cost of raw materials, the mobility will become more and more electric in the future years. It is already the case for automotive and the first electric car from Renault company, "Renault Zoé" appeared in 2009. So the first models are now reaching their End-Of-Life and it is time to consider their dismantling. The traditional recycling industry used for Internal Combustion Engine vehicles is not adapted to electric vehicle powertrains. This study deals with the disassembly of 2 electric powertrains of Renault Zoé vehicle. All the components have been separated, identified, their chemical composition has been determined as well as their potential recyclability. We have highlighted that sometimes, some materials should be substituted by more recyclable others and that some subsets should be redesigned in order to facilitate the disassembly. A strategy to maximize the gain, reduce wastes has been built and some recommendations for the future design of these electric powertrains has been proposed.

Keywords: Recycling · Electric vehicle powertrain · Eco-design

1 Introduction

The goal of e-REVE project (Eco-Innovation for Recycling/Remanufacturing Electric Vehicle Engines) is to find solutions for recycling and add value to the different materials contained inside electric vehicle powertrains. Up to now, because of the specific manufacturing of electric vehicle powertrains it is not possible to use the traditional recycling methods which are currently used for Internal Combustion Engines Vehicles. Some people are worrying about this for some years (Hermine 2014; Rapport RSE Renault 2015) and a team project has been created to bring answers to this challenge. The team is made up of.

MTB Recycling, a world leader in industrial waste management which focuses its activities on three major areas: *recycling*, equipment *manufacturing* and *engineering*.

https://doi.org/10.1007/978-3-031-23615-0_59

RENAULT for its skills in electric vehicles design.
INDRA, automotive recycler which provides a global offer in the End-Of-Life Vehicle (ELV) sector.
ECAM Lyon, an engineering school for its skills in materials characterization.
ICRM, a circular economy consulting company.

At the beginning of the 2000's, several events have made electric engines for vehicles more and more present on the market: atmospheric pollution, depletion of natural resources,… According to European Union proposals "Fit for 55", greenhouse gas emissions must be reduced by 55% by 2030 and 100% by 2035 (compared to 1990), so that Electrical Engines should progressively substitute Internal Combustion Engines for vehicles (see Fig. 1).

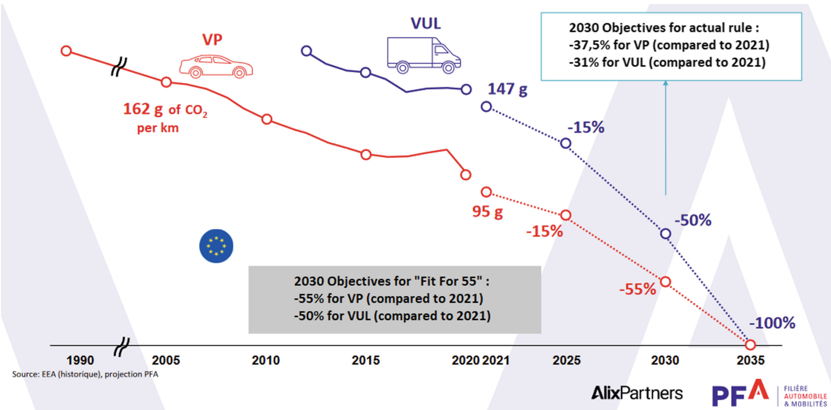

Fig. 1. Evolution perspective for Internal Combustion Engines. (Plate-forme automobile, filière automobile & mobilité 2021)

In 2019, D'Adamo and Rosa published a large literature review (129 references) about the recycling of Electric Vehicles. Most of the references deal with the recycling of batteries which seems to be a key point for numerous laboratories but very few concern the recycling of the different components of electric engines (Bdiwi et al. 2016; Li et al. 2014, 2018; Elwert 2015; Soo et al. 2018; Kibira and Jain 2011). It seems that this global approach for electric Vehicles is still few developed for the moment.

In the first part, this paper will present the Ecodesign approach which is to our point of view a key point to have in mind if a manufactured product is designed for future recycling. Then experimental results are presented and divided in two parts: from a technical point of view with the dismantling of the different subsets and their material analysis but also from an economic point of view because recycling will be developed only if a financial gain is obtained.

2 Ecodesign

The description of the term "eco-design" is given in the standard NF X 30-264 (Management environmental – Aide à la mise en place d'une demarche d'éco-conception 2013). The Mechanical Engineering, Design and Manufacture Department from the Manchester Metropolitan University also published a few years ago (Simon and Dowie 1993) some recommandations about this subject. Before thinking about the different recycling technics for materials from End-Of-Life Vehicles (electric or not), the first point to take into consideration is the disassembly of a manufactured product. That is why the sooner this step is considered, the easier the recycling operations will be and if possible from the design. For a manufactured product, three subsets have been identified: materials, fasteners and connectors and finally the product structure.

Concerning the materials, the requirements are:

Minimize the number of different materials.
In case of subsets difficult to disassembly, use the same material.
In case of polymer materials, make the symbols visible.
Favor recyclable materials.
Clearly identify dangerous parts if present to put aside quickly.

Concerning fasteners and connectors, the requirements are:

Minimize the number of fasteners.
Easy access fasteners.
Fasteners should be disassembly with standard tools, if not it should be easily breakable.
Avoid adhesive junction between 2 parts which are incompatible with recycling.
Minimize length and number of connection cables.

Concerning the product structure, the requirements are:

Minimize the number of parts.
Realize a design as modular as possible with separated functions.
Easy access for parts which have a high value regarding recycling.
Aggregate non-recyclable parts at the same place, easy to remove.
Avoid filled polymers.

The way of dismantling and recycling End-Of-Life Vehicles has been described by several authors (Hao et al. 2017; Pan and Li 2020; Zhou et al. 2019). The first step consist on separating the different subsets and salvage all the fluids and toxic or dangerous products (oil, batteries, brake fluid, engine coolant,…). All the components in good condition which can easily be sold are put aside (tires, mirrors, body parts,…). Non-metallic parts which have their own recycling channel are sorted out (glass, rubber, plastics,…). The remainder is then milled and form what is called "Automotive Shredded Residue" (ASR). These ASR are either landfilled or sorted for recycling.

The benefit of a manual disassembly prior an automatic grinding is the recovery rate of materials for recycling. According to a Swedish study (Tasala Gradin et al.

2013), an automatic grinding lead to a result for recycling materials of only 73% but 85% if a manual disassembly is realized before. Anyway, a manual disassembly is time consuming: as an example, it took more than 6h for three operators to dismantle a "Volkswagen Vista" vehicle (Tian and Chan 2016). The ratio cost/benefit of recycled materials should be taken into account.

3 Experimental Results

Our work focused on both understanding the technical and economic elements. The challenge was to enable short loop reuse of different materials from electric vehicle powertrains.

3.1 Technical Point of View

The different subsets of an electric powertrain are presented on Fig. 2. The main components are: wire harnesses (1), electrical gear motor, electric power unit and junction box (2). Each subset has been completely disassembled but to maximize the recovery of the different materials (especially strategic materials) and respond to a short loop challenge, a manual disassembly is necessary.

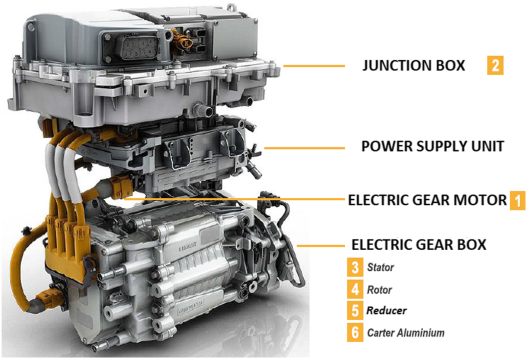

Fig. 2. Description of the different subsets of an electric powertrain (Renault) (Grimaud 2018).

As an example a complete disassembly of a junction box is presented on Fig. 3.

It was also fundamental to involve an important sorting during this disassembly in order to think precisely about the rest of the process for each organ (see Fig. 4).

Then, for each component, its composition has been determined by different chemical analysis (IR Spectroscopy, Glow-Discharge Optical Emission Spectrometry, Energy Dispersive Spectroscopy) depending on its shape, size, materials family,… As an example, the composition of some containing copper parts is given in Table 1; most of them are almost pure copper or copper alloys with some tin (bronze).

Fig. 3. Junction box after complete disassembly.

Fig. 4. Wire harnesses (left) and screws and bolts (right)

Table 1. Composition of containing copper parts (GDOES analysis).

	Cu	Sn	Sb	As	Co
Part identification	Mass percentage				
1	99.97	0.01	0.02	0.03	0.01
2	99.97	0.01	0.01	0.03	0.01
3	99.67	0.34	–	–	–
4	99.69	0.31	–	–	–
5	98.51	1.49	–	–	–
6	98.75	1.25	–	–	–
7	99.42	0.58	–	–	–
8	99.34	0.66	–	–	–
9	99.23	2.77	–	–	–

3.2 Economic Point of View

The constitution of the three main families of powertrains from a "Renault Fluence" vehicle is presented in Table 2. The major difference concerns the content of copper which is very much higher in case of electric powertrain.

As the mineral resources concerning this metal are limited, its price is continuously increasing that is why it is more and more interesting to salvage it.

Furthermore, as shown on Fig. 5, economic gains are exponential when quality approaches 100%, that is why the chemical composition of each part is important to be known in order to avoid mixture of different alloys.

Table 2. Constitution of different powertrains (Grimaud 2018).

	Petrol engine	Diesel engine	Electric engine
Powertrain (kg)	141	141	113
Aluminum (kg)	24.6	25.5	32.8
Copper (kg)	0.6	0.7	15.9
Steel (kg)	102.9	106.6	48
Others (kg) (polymers. …)	12.8	14.2	15.7

The possible gains are a balance between the costs (essentially workforce + energy) and the material recovery. The dismantling of the first powertrain was a complete discovery for our team so that the necessary time to find the right tool (screwdriver, spanner, grinder,..), the right procedure was quite long. However, the duration to reach each component has been measured.

After this first experience, a second electric powertrain (Renault Zoé Vehicle) has been disassembled with an optimized duration and it took approximately 95 min for 2 operators.

Then a complete table was realized. This table contains for each component, its weight, its composition, the price per kg of this material if recycled and the necessary duration to collect it. With the help of this table, it has been possible to draw the diagram presented on Fig. 6.

We can notice that after only 32% of the total disassembly duration (95 min), already 65% of the possible gain is obtained. Of course, it is possible to obtain a higher gain but a balance between the gain and the necessary time to get it should be deeper studied.

4 Conclusion

After this work, the exact composition of each component of an electric powertrain and the necessary time to collect it are known. Some of them can be reuse (screw, connectors, wires,…), some others can be sold for recycling (steel, copper, aluminum, polymers,…). This study allowed us to realize that the partial dismantling then the treatment of different fractions of GMPe makes it to obtain at the same time a suitable

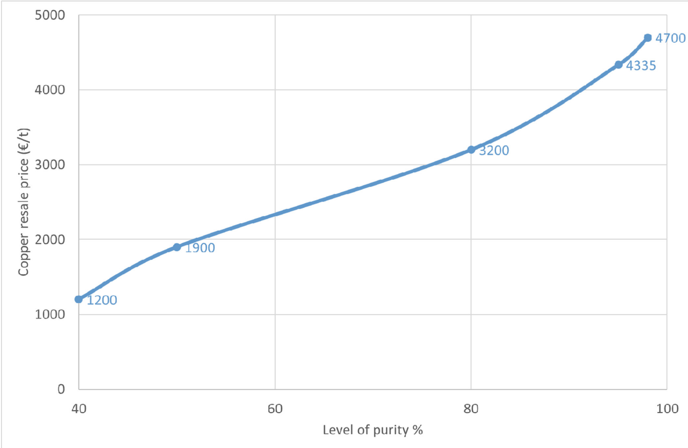

Fig. 5. Data from the London Metal Exchange (October 2018)

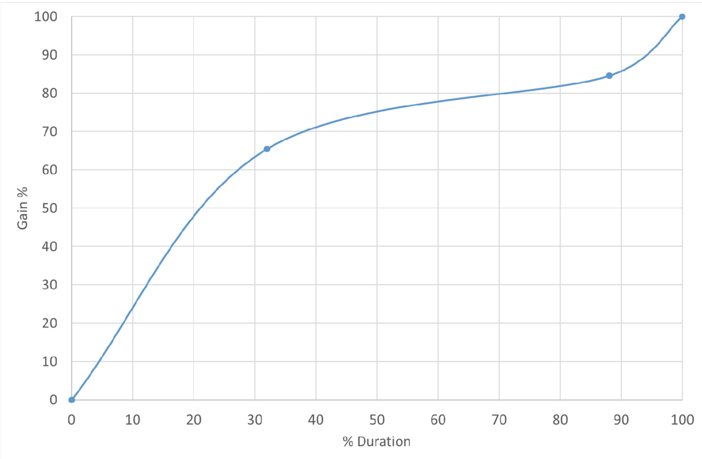

Fig. 6. Evolution of the possible gain versus time.

economic profitability with a final machine valuation over 700 €/t. At this material value, it is necessary to subtract all the processing costs. We have highlighted that sometimes, some materials should be substituted by more recyclable others and that some subsets should be redesigned in order to facilitate the disassembly. In the next years, electric vehicles will be more and more present (the first ones are already reaching their End-Of-Life) so that it is necessary to follow these recommendations, as soon as the design for cost saving and reduce future wastes.

Acknowledgements. The authors wish to thank BPI France which has partially supported this work.

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