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ECO-CONSCIOUS DESIGN BASED ON SINGLE COMPONENT POLYMERS FOR SUSTAINABLE SUPPLY MANAGEMENT IN AUTOMOTIVE PRODUCTION

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1. Introduction

Automotive OEMs currently achieve recycling ratios defined by the EU-ELV directive; this will however become increasingly difficult in the near future due to an overall reduction of vehicle weight by increased use of polymer. ELV components with economic value are currently recovered and reused on an ad-hoc basis without central coordination. The majority of ferrous and other metals are shredded and recycled. Residual material, termed Auto Shredder Residue (ASR), consisting of plastics, rubbers, foams, etc., makes up to 30% of the weight of the vehicle. The lack of an economically viable process for segregation and recycling of multi-material polymer parts results in incineration or disposing of on landfills. The European project CONCLORE will develop a sustainable system for manufacturing a 100%-recyclable car interior product, recovering it at the end of the useful life of the vehicle and recycling it either for reuse within the automotive industry or for other applications. Developing a single-component thermoplastic sandwich-structure and utilising Product Embedded Identification (PEID) CONCLORE will guarantee continuous quality of recovered material and define a new state of the art by establishing an advanced recycling model called Controlled Closed Loop Recycling (CCLR), integrating Reverse and Forward Supply Chain Management (SCM) geared towards 100% material recovery.

2. State of the Art

Polymer automotive parts today are usually multi-component structures (i.e. PES and PUR-foam), due to their low cost and advantageous physical properties. However, material recovery of multi-component polymers is very costly and energy intensive as they are composed of a number of mechanically and chemically bonded materials and the separation of different layers is impossible.

State of the art ELV recycling starts with the shredding of the entire vehicle and proceeds to separate different kinds of material (i.e. ferrous from non-ferrous metals). The residual material, up to 30% of the weight of the vehicle, is termed Auto Shredder Residue (ASR) or simply "Fluff". Fluff is composed of 50% polymers as well as rubber, glass and electronic components. The multi-material nature of ASR makes it economically impossible to segregate, recycle and reuse. Fluff is thus usually disposed of by means of incineration (thermal recycling). This practice has a considerable environmental impact in terms of CO_2 emissions and at the same time poses a serious health hazard resulting from toxic substances released by incinerated material. Due to the ongoing trend to reduce the overall vehicle weight by increased use of polymer, as illustrated in figure 1, the amount of residual non-recyclable polymers will also increase.

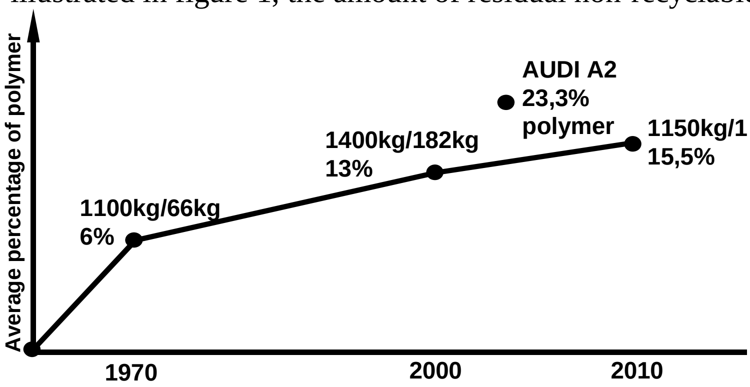

Figure 1. Average percentage of polymer automotive parts [1]

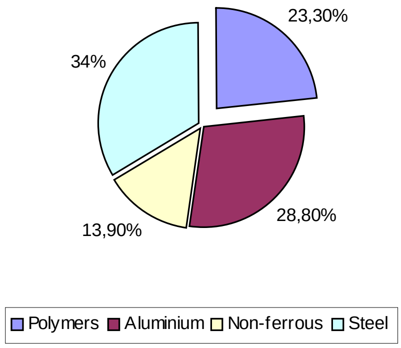

Figure 2. Audi A2 material distribution

Moreover, multi-component structures are generally thermoset and as such are manufactured based on liquid resins. Thermoset binders pose an environmental and health hazard resulting from exposure to volatile organic compounds emitted both during production as well as in the application phase [2]. The California Air Resources Board (CARB), one of the main drivers behind low-emission regulations, has made provisions for a restriction of the total automotive HC-emissions (lightly volatile hydro-carbons) to one quarter of the currently allowed emissions by 2006.

Automotive parts from ELVs valuable enough to be dismantled and recycled are at the moment recovered and reused on an ad-hoc basis without central direction or regulation. The majority of ferrous and other metals remaining within the ELV are shredded and recycled in various industries.

To face this problem, CONCLORE focuses on parts which are based on foam (Melaminresin or PUR), cotton based felt or glasfibre-felts. Both felt-systems consist of shares of duroplastic binders. The foam-systems show good behaviour regarding the air sound absorption and have low material densities. On the other hand these materials are expensive and can not be economically recycled. Parts based on phenolic-cotton-felt show a good air-sound-absorption behaviour. They typically have a weight of up to 1200g/m² in order to achieve the required mechanical stability. Furthermore, as duroplastic materials their recycling properties are also not sufficient, as material recycling is not possible.

The EU End-of-Life Vehicle (ELV) directive (2000/53EC) was issued by the European Commission to address pollution resulting from vehicles that have reached the end of their useful life, also known as End of Life Vehicles (ELV). Its aim is to reduce more than 9 million tons of waste generated by over 12 million cars that become ELVs each year. This directive defines requirements encouraging re-use, recycling and other forms of material recovery from ELV parts. Furthermore it strictly regulates usage of hazardous substances.

Figure 3. Current examples of fibre reinforced material applications

The ELV directive defines that the reuse and recovery of materials shall be increased to a minimum of:

⇒ 85% by 2006 by an average weight per vehicle and year (80% of reuse and recycling)

⇒ 95% by 2015 by an average weight per vehicle and year (85% of reuse and recycling)

The initial recycling ratio of 85% foreseen by the ELV directive can currently be fulfilled by most manufactures. Keeping up with the quota, however will become more and more difficult, due to the increased application of polymers. A higher polymer ratio will become increasingly important as it helps save fuel by lowering the overall vehicle weight. This trend will lead to a lower percentage of metal parts as polymer percentage increases from a current average of 13% to a projected average of 15,5% in 2010. The Audi A2 as "best of class" in lightweight design already shows a polymer percentage of 23% today. The state of the art low sustainability open supply chain is illustrated by Figure 4.

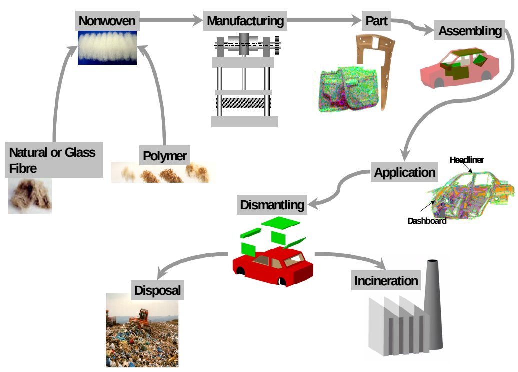

Figure 4. State of the Art Recycling

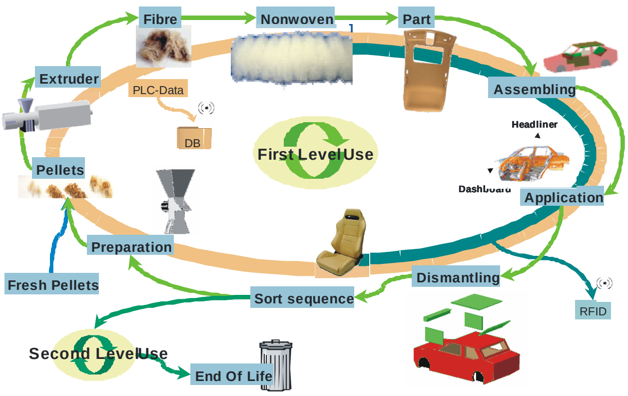

Figure 5. Controlled Closed Loop Recycling

CONCLORE innovation will help close the loop and achieve practical and cost-effective automotive part production out of material recovered from recycled ELVs by establishing an advanced recycling model geared towards 100% material recovery and continuous quality reprocessing of automotive polymer parts. The proposed Controlled Closed Loop (CCLR) will integrate Reverse and Forward Supply Chain Management (SCM) and Product Life-cycle Management (PLM) into a Sustainable Supply Management (SSM) loop using PEID for tracking & tracing. The CCLR will have a positive impact on the sustainable use of energy and raw materials in industrial production by enabling the cost-effective use of recycled materials for sophisticated products. The CCLR will be achieved based on the following CONCLORE innovation:

- 100% recyclable multilayered sandwich structure based on single-component material for environmentally friendly production
- A Controlled Closed Loop in the global automotive lifecycle for cost-effective recycling and sustainable production
- This loop will connect forward supply chain management with reverse supply chain management based on PEID integration in automotive interior parts.
- Classification framework for dismantling and sorting of single component automotive parts and decision support for recipe configuration for continuous quality production

3. Conclore approach

CONCLORE aims to achieve a sustainable solution by substituting multi-component structures through single-component thermoplastic sandwich-structures for production of automotive polymer parts. The proposed sandwich-structure will be composed of a number of layers of non-woven thermoplastic fibres.

A promising material for single-component parts is PET or in special cases PP. PET and PP are two well-known widely used materials which are today already being recycled on a large scale, e.g. PET as single-use or refundable-deposit bottles. Preliminary studies conducted by the consortium on manufacturing headliners based on PET and PP, have shown the feasibility of using both materials for single-component automotive parts. Moreover, consistent with the good recycling properties of PET, trials have shown that it is technically possible to process PET-headliners 100% once again into fibres.

In order to close the loop and achieve practical and cost-effective automotive part production out of material recovered from recycled ELVs, recovered material of continuous quality is necessary. Due to the physical and chemical properties of polymers the quality of the material can degrade over a long time-period such as the usage period of the average automotive. A car part on average will be exposed to a number of environmental conditions during its lifetime. Changing humidity levels, heating and cooling cycles and exposure to contaminants are amongst some of the variables with the potential to affect the material used in the part and can consequently have an impact on the quality of the material recovered through recycling.

Even though polymer material of degraded quality can still be recycled it no longer has the physical properties characteristic of virgin material. Consequently, continuous quality in material recovered from recycled parts can only be achieved through the removal of contaminants and processing that takes the degradation through external factors into account. Achieving continuous quality in material recovered from recycled polymer parts thus depends on accurate information on the actual properties of the recovered material. CONCLORE will derive this information gathered using Product Embedded Identification (PEID) devices (mostly RFID tags) integrated into automotive parts. In addition, CONCLORE proposes the dismantling of individual polymer parts before shredding. This approach allows for a radical advancement of state of the art in recycling and continuous quality reprocessing based on the use of PEID in combination with advanced sensors and planning functionality to allow for automated identification, sorting, classification, and routing during dismantling.

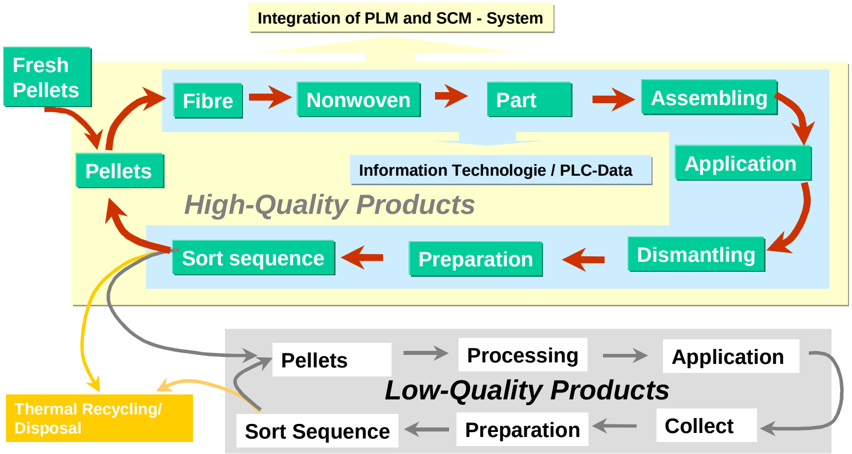

Figure 6. The Controlled Closed Loop Recycling

As demonstrated in Figure 6, CONCLORE will define a new state of the art by establishing an advanced recycling model called the Controlled Closed Loop Recycling (CCLR) geared towards 100% material recovery and remanufacturing of automotive polymer parts. CCLR will form a loop integrating Reverse and Forward Supply Chain Management (SCM) into a Sustainable Supply Management (SSM) loop using PEID for tracking & tracing. The CCLR will have a positive impact on the sustainable use of energy and raw materials in industrial production by enabling the cost-effective use of recycled materials for sophisticated products.

CONCLORE innovation within the forward supply chain will focus on a higher recycling ratio by processing a blend of virgin material and materials of disassembled ELVs reintegrated back into the production process after recovery. CONCLORE innovation in the reverse supply chain focuses on intelligent dismantling, classification and sorting in order to achieve high recycling ratios and cost reduction regarding dismantled material, based on its characteristics.

3.1. CONCLORE objectives

To achieve the goals of the project, the consortium of CONCLORE has identified the following objectives:

A closed loop in the global automotive lifecycle for cost-effective recycling and sustainable production

CONCLORE innovation within the forward supply chain will focus on a higher recycling ratio by processing a blend of virgin material and materials of disassembled ELVs reintegrated back into the production process after recycling. Material flows at floor level will have to be reviewed and adapted. To achieve continuous product quality, recipe adaptation is foreseen in order to cope with varying properties of the material. CONCLORE innovation in the reverse supply chain focuses on intelligent dismantling, classification and sorting in order to achieve high recycling ratios of the dismantled material, based on its characteristics.

Fully recyclable multilayered sandwich structure based on single-component material for environmentally friendly production

Achieving the objectives of the ELV directive and recycling 95% of vehicles through the development of the composition of a one-component multi-layer sandwich-structure for 100% recyclable interior parts. The single-component interior part can be made up of different types of non-wovens, utilising a sandwich construction. The functionality of this solution will be demonstrated on a dash insulator. The goal is to achieve acoustic, mechanic properties and resistance to heat and solvents (water, oil, fuel, etc.) comparable to the current used multi-component materials. To minimise the production related waste the current production pathways have to be switched to the use single-component sandwich roll-good materials. Currently there is no existing process chain to produce the intended one-component multi-layer part.

PEID supported dismantling and sorting process

CONCLORE aims to enhance reliability and minimise operation costs by automating dismantling and sorting through incorporation of Product Embedded Identification (PEID) i.e. Radio Frequency Identification (RFID) tags in automotive interior products during production in a closed loop. Of particular interest is the automated processing of material containing various types of colourings (i.e. particles or chemicals).

Automated decision support in the recycling value chain

An advanced Supply Chain Planning model based on the CCLR concepts and requirements will be researched and developed in order to automate decision making across the recycling value chain involving all the partners. Advanced functionality such as wireless inventory tracking, material characteristics and quality control monitoring, material classification and sorting, will form the core of the Supply Chain Planning system.

Classification framework for dismantling and sorting single component multilayer polymer automotive parts

To realise the sorting, recycling and reintegration of used polymer materials for the reintegration into the productions process it is mandatory to define classification rules and properties, which allow sorting of components of ELVs especially regarding their suitability for the use in different high quality applications. To capture and provide all information necessary to ensure continuous quality of the recycled material in the controlled closed loop recycling system and to minimise the risk of contamination, furthermore a system platform, software tools and a sorting process basing on the classification system, have to be developed. Of particular importance is the automated processing of material containing contaminants such as colourings and the development of methods for the production of new parts out of this material (i.e. based on the extraction of colourings).

Decision support for recipe configuration

The production of automotive parts requires a continuous quality of material. Reprocessing of recovered material into new products requires a way to guarantee a certain quality of the material in spite of any material degradation occurring during its use. To ensure the quality of the recycled material a decision support system to adapt production parameters will be researched and developed.

3.2. Product Design

The parts the project focuses on are at the moment based on foam (Melaminresin or PUR), cotton based felt or glasfibre-felts. Both felt-systems consist of shares of duroplastic binders. The foam-systems show a good behaviour regarding the air sound absorption and have low material densities, but are these materials are expensive and can not economically be recycled. Parts based on phenolic-cotton-felt show a good air-sound-absorption behaviour. They have typically higher weights (up to 1200g/m²) to reach the mechanical stability. As a duroplastic material the recycling properties are also not sufficient because a material recycling is not possible.

The innovation related to this project is an optimised combination of different laminated dry laid non-wovens. These different non-wovens all have to be made of one single polymer e.g. PET to ensure the recycling capabilities. Furthermore the project will develop a solution that will fulfil the demands to weight, stiffness, acoustics properties, flammability and solvent resistance, which are achieved by currently solutions like PUR foam, fibre glass or textile waste for example.

It is expected that it will be necessary to develop different types of non-wovens where the single material (layer) fulfils different of the above-mentioned specifications. The next step of the manufacturing process will be to join or laminate the different materials together and thereby creating a composite, which fulfils the overall specifications. For the development of parts based on felt-material, the system supplier needs to define the shares and in addition the detailed specifications of the used fibres likewise:

- Bi-component fibre (fibre thickness, fibre length, specification)
- PES fibre (fibre thickness, fibre length, specification)
- Special acoustic fibres (hollow, micro fibre, etc.)

Today it is possible to laminate different non-wovens together in a second process. The classical PUR solution this is typically flame laminated, but solutions to laminate different types of textiles hereunder non wovens are also on the market today – these types of lamination (calendaring and flad-bed lamination) are primarily used in connection with face fabric for trim parts in general or e.g. seats. This second and extra process is of course increasing the cost level of the end product.

The intended solution will, as mentioned above, be a sandwich construction and therefore consist of different layers. It will therefore also be necessary to use laminating as a part of the manufacturing process. Existing procedures for laminating have to be adapted and enhanced to optimise the manufacturing process.

The choice of the exemplary component for an engine part component like an outer dash insulator was made due to their high impact on the exterior and interior noise level of vehicles. Furthermore, the currently used solutions lack in comparison regarding flammability, solvent resistance and stiffness under temperature, which are important properties. Additionally, the project aim is to reduce the emissions occurring during manufacturing and utilisation of a car interior part.

The requirements for automotive parts differ extremely depending on their intended application. To structure the requirements of all polymer parts of a car concerning recyclabilty they will be clustered, e.g. interior, exterior, structural parts, visible and non-visible parts. The resulting Requirement Cluster will be the basis for the material recycling scenario.

For the classification, sorting and recipe configuration the intended application for the recycled material is needed for cost-effective and utility oriented reprocessing of the dismantled material.

With data regarding recycling requirements it is possible to assess the additional effort, required to meet the requirements of the application area. One aim is the combination of the requirement cluster data base of OEMs with the sorting stage for fast and flexible sorting depending on the intended application in the next polymer life cycle. A more practical approach would be the collection of defined amounts of dismantled and sorted material with similar material properties and then reprocessing material with a continuous quality, like it is done in the PET-bottle recycling.

3.3. PDM and PEID integration

The embedding of PEID into automotive parts will have beneficial effects for the Supply Chain Management and the dismantling and recycling of the ELV. Incorporating RFID will improve inventory visibility and monitoring, allow for more accurate decision making and enhanced accessibility of product data. Especially the latter will have significant impact on dismantling and recycling. Currently data about polymers are stored, but this data is not accessible for recycling. The identification of single automotive parts after dismantling is not feasible. Tracing a part to its original manufacturer and retrieving information about its actual composition is not realisable. Through incorporating this information directly into to the part, the necessary data will not only be available when dismantling an ELV, but it will be immediately available, to allow for real time sorting and economical recycling.

This is a prerequisite to create the envisioned Controlled Closed Loop for cost-effective recycling and sustainable production to transform used products into new products and/or materials that can be recycled without harming the environment.

To realise an economic viable solution for recycling, the retrieval of automotive parts has to be considered. Since the size of an automotive part and the time needed for dismantling correlate, as shown in Figure 7, parts with suitable accessibility and weight have to be identified and selected.

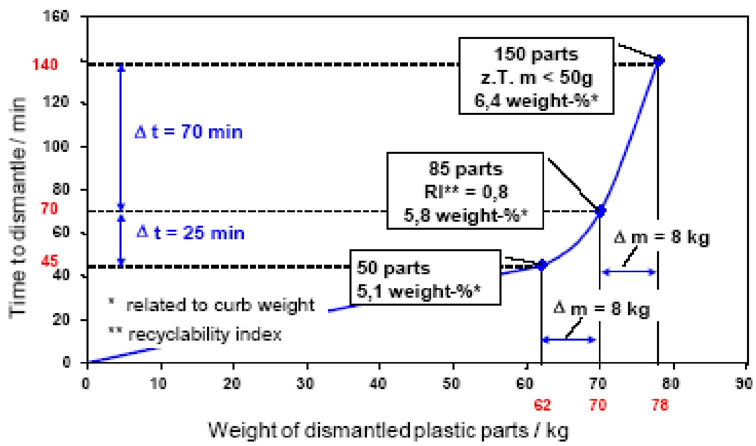

Figure 7. Dismantling of plastic components in end-of-life vehicles [3]

To enable the identification of these parts PEID will used. In particular Radio Frequency Identification (RFID) is expected to meet the requirements regarding economic viability and data stability during the lifetime of a vehicle. As this technology is already gaining good traction in different areas of supply chain management, such as warehouse management and inventory control, it offers promising capabilities. Especially the fact, that RFID-tags can be identified with a reader only requiring a close approximation but no direct contact, is a prerequisite to enable an automated dismantling process in which single parts can easily be identified and located.

The intended device will be used to store data on the material composition. This data will provide the dismantler of the ELV in real time with information about the polymer used in the automotive part and enable a segregation of different plastic materials into the appropriate recycling stream. Additionally dismantling information, e.g. part position or required tools for dismantling, could also be enclosed on the RFID. This information will support the dismantling process to achieve a reduction of time required for dismantling.

3.4. Dismantling

The lack of an economically viable material recycling process can be attributes to costs and quality of the recycled material. Since automation technologies for dismantling and sorting are not realised up to today, costs for manual dismantling are still high and the quality of the material can only be assessed through material evaluation tests. Therefore dismantlers just retrieve reusable parts normally. The reuse of polymer or even steel parts is not feasible, since there is no market for these materials. Currently interior parts are made of fibre reinforced materials which are not suitable for material recycling. Only for a few applications are high-end polymers and single-material-parts used, like filter boxes or battery holders. Solutions based on mono-material-compositions, like developed in CONLCORE, will increase in future, aided through the restrictions of the ELV-Directive. CONLCORE will investigate solutions for cost-effective dismantling using robotics and recycling of Mono-Material-Polymer-parts.

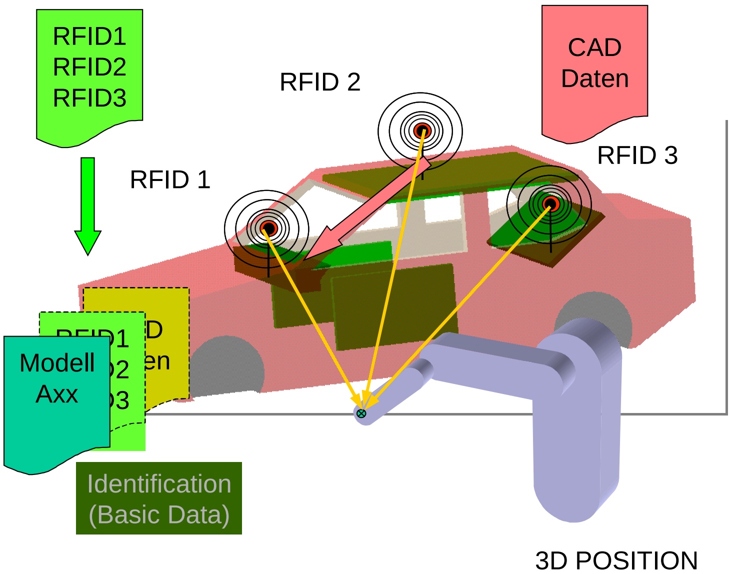

Figure 8. Scheme of Triangulation-principle for easy disamntling

The use of robots in the dismantling environment require a flexible and easy programming interface, since the solution will face a great variety of used cars and low-skilled staff. This makes it difficult using standard control solutions for dismantling. One solution could be the introduction of triangulation for parts via the integrated RFID. The RFID will be read by a transponder system installed in three defined points in the dismantling cell. The idea of triangulation is scanning three position vectors of a part concerning the tool center point of the robot. The position will automatically be transformed into a trajectory for the kinematic manipulation of the robot. This requires just a minimum of programming at the dismantling cell through the staff. Another proposed solution is retrieving information about the position of a part from its RFID. This would require a standard reference point in the dismantling cell which has to be defined for each car model. Additionally, CAD-data could be used to extract the position and to avoid collisions between robot manipulator and car installations. The required data could be provided by the OEM, in respect of confidentiality of such information.

After dismantling parts have to be sorted and reprocessed concerning the required quality. Sorting will be done depending on the evaluated material condition. CONCLORE will develop a new method for an easy and fast sorting algorithm. Material Classification after sorting for next life cycle application will be done based on the requirements of the intended application. Alternatively, material will be reprocessed first with controlled quality and after processing proposed for feasible applications. This will be supported by a decision framework with abilities to support all relevant aspects of the reverse supply chain.

3.5. CONCLORE Architecture

Based on initial efforts the participants of CONCLORE, involving major players from the automotive value chain, a first overall architecture of the CONCLORE system was developed. As depicted in 9, the CONCLORE SSCM loop encompasses SCM components that control the dismantling of automotive parts and their introduction back into the production cycle, from PET recycling and production facilities to manufacturer of automotive parts.

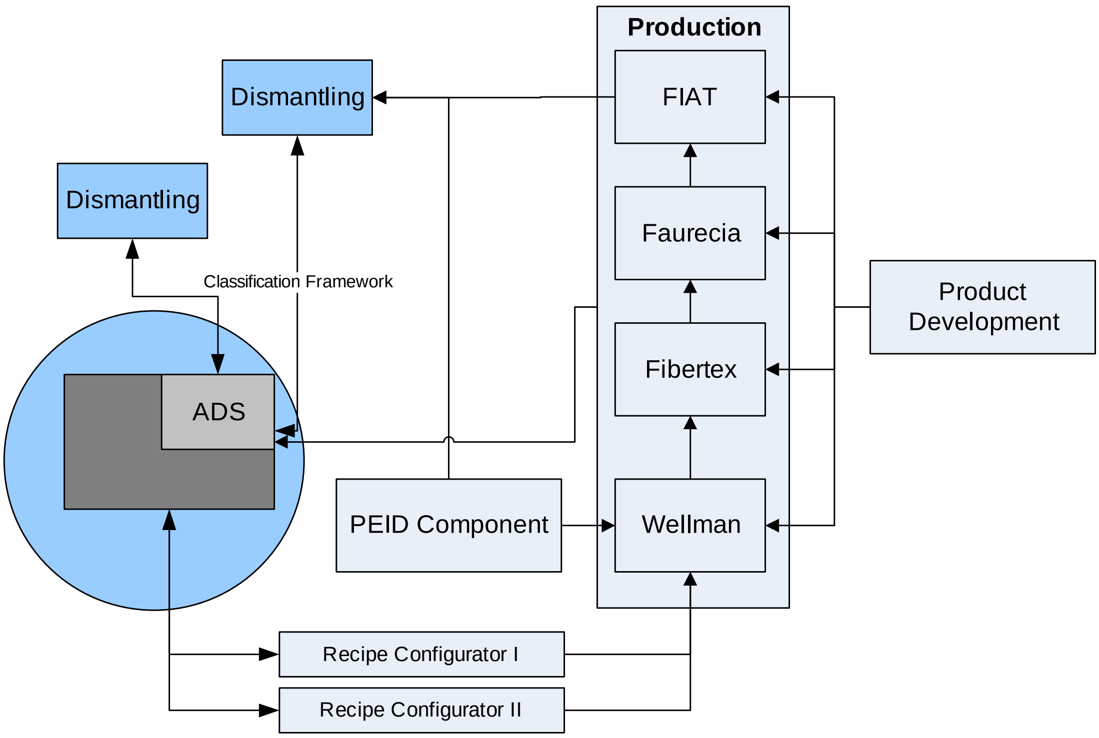

Figure 9. Overall Architecture

CONCLORE will define an advanced Sustainable Supply Management Chain model, including a Reverse Supply Chain for recycling automotive interior components, through dismantling instead of shredding. Therefore a new PLM-architecture will be developed which includes different SCM- and PDM-frameworks. Furthermore, including the Product information stored in the PEID, and the information transfer between all life-cycle stages, the SSCM-Model plays an important role for the idea of CONCLORE, the controlled closed loop recycling, to enhance the quality and acceptance of recycled materials for high-level-applications. Of particular importance are therefore issues identified which are prerequisites for economic recycling. One of these issues is easy dismantling and the use of single-component materials, since even minimal contaminations with other polymers can have a dramatic effect on the recyclability of PET. Multi-component materials are therefore not suitable for recycling. Also the separation of various layers of different polymers is economically not feasible.

Another important issue is the value of dismantled parts and recovered material itself. Only high value materials are economically feasible for recycling, due to that fact that in order to create a market, the amount of material collected from ELVs has to surpass a certain threshold to be economically interesting. That is why CONCLORE has chosen PET as material of choice for substituting currently established multi-component automotive parts to create a sustainable Controlled Closed Loop in the global automotive lifecycle for cost-effective recycling and sustainable production of automotive parts.

4. Conclusions

CONCLORE will define a new state of the art by establishing an advanced recycling model called the Controlled Closed Loop Recycling (CCLR) geared towards 100% material recovery and remanufacturing of automotive polymer parts. CCLR will form a loop integrating Reverse and Forward Supply Chain Management (SCM) into a Sustainable Supply Management (SSM) loop using PEID. The CCLR will have a positive impact on the sustainable use of energy and raw materials in industrial production by enabling the cost-effective use of recycled materials for sophisticated products.

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