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Unleashing the power of secondary materials: A strategic research and innovation agenda for effective material recycling in a circular Europe



Strategic Research & Innovation Agenda

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Executive summary

To be written later

1 Secondary raw materials research and innovation for a competitive Europe and a circular economy

To pave the way towards a circular economy and a more resource efficient society with less environmental impacts all sectors and various actors need to contribute. The European Union's economy loses a significant amount of potential secondary raw materials in current waste streams, due to inefficient collection, sorting and recycling.

In 2013, total waste generation in the EU amounted to approximately 2.5 billion tons of which 1.6 billion tons were not reused or recycled (European Commission, 2015a). Also, a considerable part of the recycling is downcycling, to lower quality material. At the same time the EU imports 20 percent of total natural resources extracted globally (ref). With an increasing competition on raw materials and the ambition of becoming more independent and self-sufficient there is a need for developing increased opportunities for secondary material (more material and of higher quality) as well as to keep the loops within the EU, when possible and effective.

In recent years, an improving awareness of waste management issues at EU level and the striving for a more circular economy has led to an increased focus on the waste part of the value chains, both politically and in terms of research and innovation. The Circular Economy Package and the Roadmap to a Resource Efficient Europe are initiatives reflecting this new focus. The Circular Economy Package approved by the European Commission consists of an EU Action Plan for the Circular Economy that establishes a concrete and ambitious programme of action, with measures covering the whole material and product cycle: from production and consumption to waste management and the market for secondary raw materials (European Commission 2016a). The agenda will support the ambitions of the Circular Economy Package as well as the Roadmap to a Resource Efficient Europe by presenting research and innovation actions focusing material recycling related to three important waste streams, being end-of-life vehicles (ELV), waste electric and electronic equipment (WEEE) and plastic packaging waste (PPW).

1.1 Vision - Unleashing the power of secondary materials

This agenda envisions a circular economy in Europe by the year 2030 where high degree of material recycling from ELV, WEEE and PPW is achieved and where recycled material is used as input material for high grade applications.

This is achieved through technological solutions, supported by societal measures, infrastructure, transnational collaboration and by new, sustainable business models based on circular economy thinking.

1.2 Purpose

The purpose of the agenda is to form a basis for future EU research and innovation actions that acts on the needs critical to boost material recycling, prevent the loss of valuable materials recovered from ELV, WEEE and PPW and stimulate the market for these materials. The purpose of the agenda is also to strengthen the links between research funding programmes across EU.

1.3 Scope

The agenda addresses research and innovation (R&I) crucial for the implementation of the circular economy concept in relation to the targeted waste streams of end-of-life vehicles (ELV), waste electric and electronic equipment (WEEE) and plastic packaging waste (PPW). The goal is to improve material recycling from waste and stimulate the secondary raw materials market, with an emphasis on metals and plastics. The three value chains resulting in waste streams of ELV, WEEE and PPW are providing good examples on challenges of implementing the circular economy concept. Cars and electric and electronic equipment are increasingly complex products and the material compositions are rapidly changing. The waste streams from these product groups are considerable. PPW is the largest waste stream from plastic use and the waste streams are continuously increasing.

The agenda focuses on one specific step in the waste hierarchy, being material recycling, with the ambition of maintaining the value of materials recovered and providing a market for it. This is only one piece of many needed for the overall jigsaw puzzle of a circular economy and for moving towards a near zero waste Europe. In line with the waste hierarchy, prevention, minimisation and reuse of waste should be prioritised over material recycling. Still, there is a need for ensuring that waste that does arise is recycled in the most efficient way, which is the scope of the agenda.

In terms of current policies related to materials, resources and circular economy the agenda fits in well, due to the fact that these initiatives points to higher collection and recycling rates as one of several key factors to stimulate a circular economy.

With the emphasis on material recycling, the agenda scope is covering collection, sorting and material recycling of waste. Emphasis is put on technological issues, but also market, policy and design issues have been considered in order to support the achievement of the vision.

The main target group of the agenda is EU and national level policy makers with a focus on research and innovation. Time horizon is 2030 for achieving goals resulting from this agenda.

The agenda is a collaborative effort involving recyclers, producers, sector organisations, public authorities and academia with an overarching goal to strengthen the European industry in taking the lead for a more material efficient future.

Current material recycling of ELV, WEEE and PPW

This section will be in a "text box" in the final version of the agenda, and not part of the general "text flow".

End of life vehicles, ELV

Around 14 million passenger cars were taken into use within the EU in 2013 (Eurostat, 2013). During the same year about 6.3 million passenger cars were scrapped (Eurostat, 2016a). The material content in passenger cars varies depending on type of car, age and propulsion system etc. Today's vehicles consist in about 75 percent of metals with steel and iron contributing to more than 50 percent of the vehicles weight; non-ferrous metals such as aluminium, copper, zinc and magnesium make up for the remaining share. Growing use of electronics has led to increased use of critical raw materials and precious metals. The non-metals constitute about 25 percent of the vehicle's weight of which plastics, rubber and glass are the most frequently used materials. Europe's automotive sector uses about 4 million tonnes plastics (8.6 percent of the total plastic demand) per year (Plastic Europe, 2015). The most frequently used plastics within the automotive industry is polypropylene (PP), followed by polyurethane (PUR) and polyethylene (PE).

Waste electrical and electronic equipment, WEEE

In 2012 an estimated 9.5 million tonnes of electrical and electronic equipment (EEE) was put on the market within the EU (Eurostat, 2016b). During the same time period the corresponding amounts of WEEE was discarded by consumers, businesses and governmental agencies throughout Europe (European commission, 2014). Large household appliances (refrigerators, washing machines etc.) are the largest product category by weight representing more than half of the WEEE generated. WEEE is a very heterogeneous waste stream in terms of material composition which varies widely between the different subcategories. Examples of materials which can be found in WEEE include (Hagelüken, Corti et.al 2010): base metals, precious metals, and rare earth elements (REEs). Furthermore, engineering plastics and other organics, hazardous substances, such as brominated flame retardants, lead, beryllium, arsenic and other materials, such as glass and ceramics can be found.

Of the 9.5 million tonnes of WEEE collected in 2012, 3.3 million tonnes were reported by Member States as being collected and recycled, 2.2 million tonnes were mixed with metals scrap and another 0.8 million tonnes were estimated to end up in the waste bin (European commission, 2014). The collection rate for WEEE is in general much higher in the northern and western parts of Europe compared to the eastern and southern parts.

Plastic packaging waste, PPW

Packaging applications are the largest application sector for the plastics industry, representing about 40 percent of the total plastics demand in Europe (Plastic Europe, 2015). This corresponds to an annual amount of 19 million tonnes. PE, PP and polyethylene terephthalate (PET) are the three dominant polymer types for plastic packaging. In 2014, about 26 million (Plastic Europe, 2015) tonnes of post-consumer plastics were generated of which 16 million (63 percent) tonnes were plastic packaging (Hesting, Faninger et.al 2015).

Of the total plastic waste amounts generated in 2014 (26 million tonnes), 30 percent was material recycled, 40 percent was sent to energy recovery and the remaining 30 percent was landfilled (Plastic Europe, 2015). The collection rate of plastics differs throughout Europe where southern and eastern parts of Europe in general have a lower recycling rate compared to the western and northern parts (Plastic Europe, 2015). Due to technical as well as economic bottlenecks the recycling yield is on average 73 percent (Hestin, Faninger, et.al, 2015), where the losses in the recycling process of 27 percent are sent for energy recovery or landfilling. The recycled materials are used in a vast variety of products, generally with limited requirements of the mechanical properties for the final application.

For the plastics waste in general there has been a steady increase of plastic waste to material recycling and energy recovery at the expense of landfilling. Even though landfilling of plastic waste has decreased it still remains the dominant treatment method in the eastern and southern parts of Europe. Countries in the northern parts of Europe have practically no landfilling of plastic waste, the introduction of the landfill ban of organic/combustible waste being the main reason.

2 Towards the vision – Research and innovation themes

To reach the vision of high level material recycling from ELV, WEEE and PPW, there are five major research and innovation themes and related actions which should be prioritized. For each theme the main challenges for each of the three studied waste streams have been identified and relevant research and innovation actions defined.

- **Effective collection and monitoring**

Effective collection concerns having appropriate and easily available as well as cost effective collection systems for which user behaviour has been taken into consideration as well. For most of the waste streams well-functioning source separation is a crucial part of the collection system both with respect to the amounts and the quality of the collected materials/products. ***Effective monitoring relates to having common methods for measuring the overall performance*** such as recycling rate (based on outputs) for different value chains in order to create transparency and credibility for stakeholders. In addition, this will support the maintaining of valuable resources within the EU.

- **Optimised sorting and recycling technologies**

For optimised recycling of materials, the realization of effective and flexible sorting and recycling techniques which are adapted to process discarded products entering the end-of-life chain are necessary. Losses are minimised and recycling efficiency is high, i.e. a high functional recycling where individual occurring materials and their characteristics are maintained and utilized in the manufacture of new products.

- **Well-functioning market**

Well-functioning market and economy concerns the ***accomplishment of an effective and established market including innovative business models for recycled materials*** which can compete with virgin raw materials as well as landfilling and energy recovery.

- **Effective policies and legislation**

Efficient policies and legislation are needed to stimulate material recycling and the secondary utilization of them. This also concerns harmonized legislation and policies and enforcement of them to create fair conditions throughout the EU, and preferably throughout the world.

- **Sustainable product design**

Sustainable product design concerns ***developing products for which the end-of-life treatment has been accounted for already at the product design phase,*** as well as ***the use of secondary materials in the products***. This will result in high recycling efficiency with minimum losses in the recycling chain but also enable high grade applications for recycled materials. Important aspects to consider include for example the choice of materials and how the materials are combined, identifiability and accessibility of hazardous parts, components and fasteners etc.

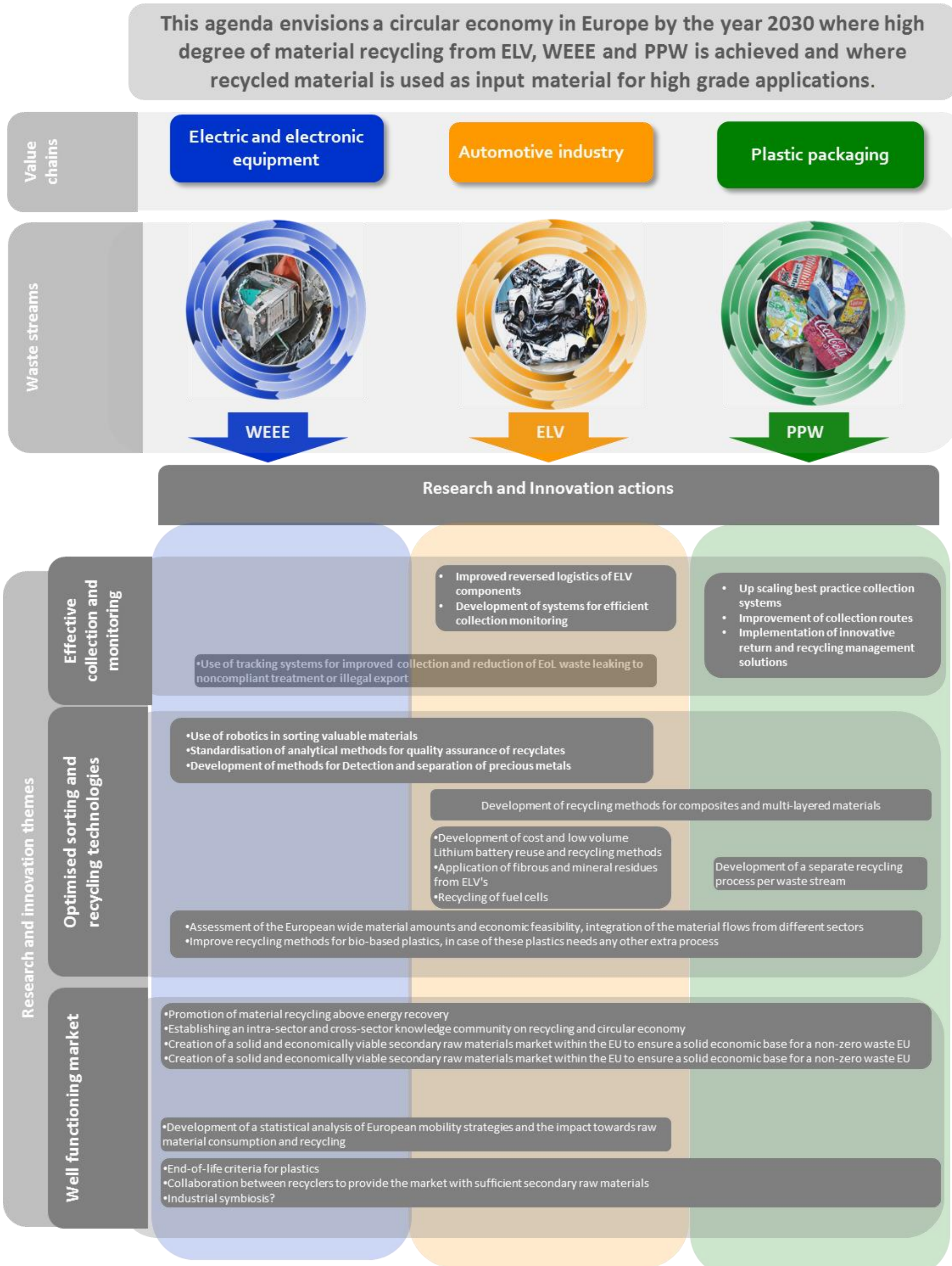

Figure 1. Structure of the research and innovation agenda. **(This figure will be updated as all R&I actions are set and the agenda is to be finalised, for now it just indicates how the structure will be presented).**

3 Research and innovation actions needed

This chapter presents the key research and innovation (R&I) actions needed to address the challenges identified for each research and innovation theme. Altogether they will contribute to reach the vision of high level material recycling from ELV, WEEE and PPW. The actions address the identified challenges which are presented in detail in chapter 4. Figure 2 presents aspects used to describe each of the proposed research and innovation actions.

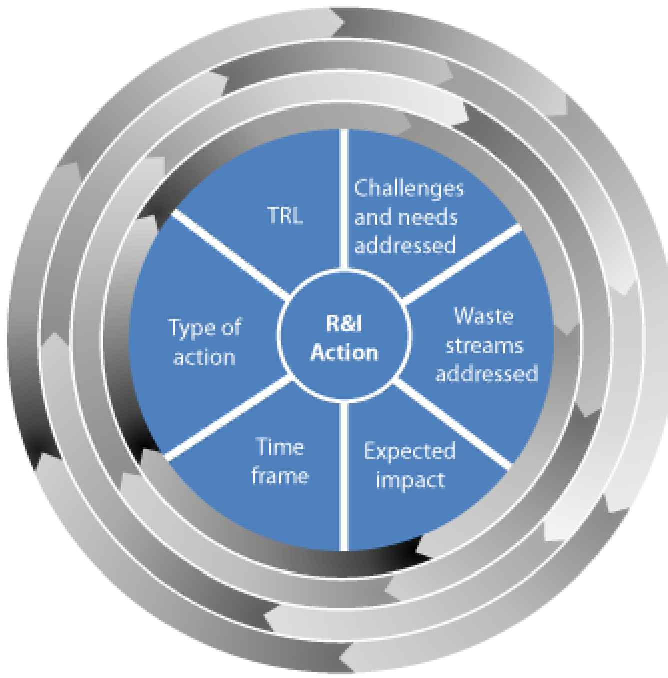

Figure 2. Aspects to describe each proposed research and innovation action. TRL level is the technology readiness level, which indicates the maturity i.e. how close to commercialization a technology is. The TRL has a scale from 1 to 9 with 9 being the most mature technology.

Description of the R&I topic and the needs it addresses as well as the challenges for each topic are presented, as well as expected impacts which relates to what positive impacts are foreseen after the suggested research and innovation topic has been performed and possibly commercialized and implemented on a large scale, depending on topic.

The time frame means an estimate of the time required before the results of the research and innovation action can be introduced in society and on the market. When relevant the technical readiness level (TRL) is presented, which indicates the maturity i.e. how close to commercialization a technology is. The TRL has a scale from 1 to 9 with 9 being the most mature technology.

Table 1 below presents different types of actions based on the typology used in Horizon 2020.

Table 1. Types of of research and innovation actions (based on Horizon 2020).

Type of action	Code	Aim
Research & Innovation Action	RIA	collaborative research projects
Innovation Action	IA	produce plans & arrangements or designs for new, altered or improved products, processes or services
Coordination & Support Action	SCA	accompanying measures (standardisation, dissemination, policy dialogues etc.) no research
SME Instrument	SME	combination of demonstration activities (testing, prototyping, …), market replication
Fast Track to Innovation	FTI	produce plans & arrangements or designs for new, altered or improved products, processes or services
ERA-NETs	ERA-NET	coordinate research efforts of participating MS/AC in the field described & implement joint transnational call for proposals with EU co-funding
Pre-Commercial Procurement	PCP	enable the public sector as a technologically demanding buyer to encourage research, development and validation of breakthrough solutions in areas of public interest
Public Procurement of Innovative Solutions	PPI	enable trans-national buyer groups of procurers to share the risks of acting as early adopters of innovative goods or services which are not yet available on a large-scale commercial basis

3.1 Effective collection and monitoring

Table 2 presents an overview of research and innovation actions proposed for research theme Effective collection and monitoring.

Table 2. Overview of key research and innovation actions related to effective collection and monitoring.

Section	Research and innovation action	Relevant waste streams	Type of action	Time frame
3.1.1	Investigation and design for improved collection systems	PPW	RIA, CSA	5-10 years
3.1.2	Improved reversed logistics of ELV components	ELV	RIA	5-10 years
3.1.3	Development of systems for efficient monitoring	WEE, ELV	RIA	0-5 years

3.1.1 Investigation and design for improved collection systems

For the secondary raw materials sector a proper collection of waste is a pre-condition for optimal recovery of materials from waste, which varies across the EU, Member States and their local governments who apply many different waste collection systems from co-mingled collection systems to separate collection. Decision-makers need more information about the overall performance of different systems, including their economic performance, and a better understanding of the conditions that are necessary for shifting to alternative, better-performing waste collection systems.

For packaging waste, appropriate systems for separate collection are required in order to increase the quantity of homogeneous plastic material entering the plastic recycling value chain. Several materials from the collected mixed fraction can be separated at the sorting and recycling facilities, but not all. It is important to emphasise the significance of recycling of PPW assuring that a minimum amount ends up in the municipal waste. Additionally the effectivity of the collection systems should be improved: to what extent do collection systems contribute to the goals of a circular economy? For improving the effectivity of collection systems the operations in the collection and recycling scheme should be adapted to the requirements from recyclate users as much as possible. It is at this point difficult to set a best practise collection system over the whole EU due to inconsistency in waste management practices in different member states. The design of innovative collection systems must focus on making it easy to sort the materials in a correct way.

Introduction of new materials on the market demands a novel approach for collection and separation of these waste fractions. Different plastic fractions need to be collected according to material properties (degradable, reinforced etc.). This also requires possibility for the consumers to identify the material and know how to separate the different products.

This action should address in particular:

- Investigate the best solutions for collection systems in the different member states
- Design of collection bins that promote easy separation by type of material or application
- Incorporate measures in the collection systems to meet the requirements of recyclate users

Expected impact: Optimisation of the collection of PPW will facilitate material recycling consequently decreasing or eliminating the fraction ending up in landfills and incineration. The quantity and quality of secondary plastic material that can reach the market will increase, without increased downcycling. Recommendation of best solutions for collection systems should allow Member States or regions to improve their performance to the level of the currently best performing Member States in the EU.

Relevant waste streams: PPW

Type of action: RIA and CSA

Time frame: 5-10 years

3.1.2 Improved reversed logistics of ELV components

As more complex and lightweight materials are introduced because of electrification, stricter emission regulations, improved fuel consumption during use and comfort demands etc. an extended dismantling in terms of number of parts and components of ELVs is expected. Generating more dismantled parts calls for efficient logistic management solutions (reversed logistics) between the dismantling facilities and the subsequent end-of-life treatment facilities for respective parts. Compared to traditional logistics reverse logistics is generally more complex. This due to high costs compared to the transported value as well as an uncertainty in demand and supply. For lightweight materials such as plastics and composites low filling rates is another challenge as they are bulky and thus take up a lot of space during transport.

This research and innovation action should address in particular:

- How to increase the low filling rate for bulky materials
- Possible cooperation and coordination with other waste streams such as PPW and WEEE.

Expected impact: An improved reversed logistics will decrease the costs related to the transport of parts and components as well as reduce environmental impact due to transport.

Relevant waste streams: ELV

Type of action: RIA

Time frame: 5-10 years

3.1.3 Development of systems for efficient monitoring

Improved knowledge of the material streams entering the system in different parts of the recycling chain would be important for estimating realized recycling rates and the availability of recycled materials in the future. Linking of the monitoring and tracking solutions to a real-time data managements system enables exploitation of the monitoring data for optimisation of the collection and recycling systems. At the moment, there is a lack of statistics of different materials entering the value chains. New systems and/or solutions for efficient monitoring and data transfer and creating statistical data of the recycled material flows would be needed. This could include for example benchmarking existing systems from different waste streams and using new technologies for tracking purposes.

Expected impact: Comparable statistical data from different countries is needed for evaluating actual or realised recycling rates. It provides important input for planning future activities to improve efficiency of the recycling process and utilisation of the recycled raw materials, increasing predictability of the markets. Efficient monitoring enables better supervision and prevention of illegal export and reduction of non-compliant treatment. The real-time monitoring and data transfer system can be used for optimisation of the collection and can be linked also to the processing plants.

Relevant value chains: ELV, WEEE

Type of action: RIA

Time frame: 0-5 years

3.2 Optimised sorting and recycling technologies

Table 3 shows an overview of research and innovation actions related to sorting and recycling technologies identified in order to minimize the losses in the recycling process and downcycling of recycled material.

Table 3. Overview of key research and innovation actions related to optimised sorting and recycling technologies.

Section	Research and innovation actions	Relevant waste streams	Type of action	Time frame
3.2.1	Use of robotics in sorting valuable materials	WEEE, ELV	RIA	5-10 years
3.2.2	Development of novel product assemblies with traceable material characteristics, integrated with recycling methods	ELV, PPW, WEEE	RIA	3-5 years
3.2.3	Optimization of high capacity sensor-based sorting for mixed plastics	ELV, WEEE, PPW	IA	0-5 years
3.2.4	Development of methods for detection and separation of precious metals	ELV, WEEE	RIA	5-10 years
3.2.5	Development of recycling methods for composites and multi-layered materials	ELV, PPW	RIA	5-10 years
3.2.6	Development of cost effective and low volume Lithium battery reuse and recycling methods	ELV	RIA	5-10 years
3.2.7	Application of fibrous and mineral residues from ELV's	ELV	RIA	0-5 years
3.2.8	Standardisation of analytical methods for quality assurance of recyclates	ELV, PPW, WEEE	RIA	5-10 years
3.2.9	System analysis (and piloting) of integrated treatment strategies for improved recovery of selected precious or critical raw materials	ELV, WEEE	RIA or IA	1-5 years

3.2.1 Use of robotics in sorting valuable materials

Application of robotics in sorting is a competitive alternative to handpicking as it allows reducing the costs of sorting while providing a satisfactory and stable across time, quality output from sorting installations. When looking at parts harvesting for reuse or recycling of specific valuable components in the future there is an opportunity to evolve robotic sorting into robotic disassembly for parts harvesting.

The current research and innovation actions are more focused on the speed and accuracy of detection rather than the sorting process itself or the use of robotic arms. Research actions dealing with research on optical systems as well as other systems for recognition are needed.

The research and innovation action should focus on:

- How to deal with the diversity of products and materials for robotics in sorting
- Extending the sorting capabilities into the used non-recognizable materials/parts for robotics in sorting
- Improvement of the speed of detection/sorting introducing robotics
- Development of self-learning systems for analysis and sorting

Expected impacts: Application of robotics in sorting and recycling will enable reduction of the sorting costs and improve the quality of the sorting output. As a consequence the value of materials recycled through this process will be of higher quality and are more likely to be up-cycled into new products.

Relevant waste streams: ELV, WEEE

Type of action: RIA

TRL-level: 10 for robotic sorting (robotic sorting on low valuables is commercially available). 10 for robotic disassembly (robotic disassembly is already done on single products, but not on miscellanies waste streams).

Time frame: 5-10 years.

3.2.2 Development of novel product assemblies with traceable material characteristics, integrated with recycling methods

To ensure a higher quality of materials from the sorting processes a more extensive sorting of materials is needed which in turn requires other detection methods compared to the currently used. Today sorting is done based primarily on shape, density, magnetic properties and optical detection. Commercially available systems have reached their highest level of processing and research is needed to create better detection of specific materials.

Current research is focusing on introducing chemical markers to a specific material, laser markings of specific components as well as highly effective density separation methods. Chemical marking of materials has been successfully developed for less complex products such as PET bottles, but not for complex products such as WEEE and ELVs. In this research action chemical markers will be examined as a solution to couple complex product development with better material sorting, with a strong focus on non-metallic fractions. In addition sorting methods need to be developed linked to the marking system.

This action is connected to a large extent with the prior action because when using robotic systems, they need to get adapted to markers used in order to detect and sort the right materials.

This research and innovation action should address in particular:

- Standardization of the use of markers in materials overarching products and brands
- If and how the used markers may affect the materials in terms of their future use and waste management
- Development of code systems for material recognition
- Demonstration of how the existing sorting and detection installations could be adopted to the new techniques without losing their processing efficiency.

Expected impacts: Using of code recognition systems can significantly increase the effects of recycling, increasing recycling rate, in particular the quality of recycled materials and as a result efficiency of sorting plants. As a consequence it will be easier to create circular business models with producers keeping control over their own materials.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA

TRL-level: The TRL-level of controlled density separation by means of magnetic density separation is at level 8. The principle is proven but for the system to be commercially viable some research has to be done. The TRL-level the recognition systems based on laser and chemical markers is 10 because it is used already for products marking and anti-counterfeiting purposes. The TRL level for these systems within the boundaries of waste separation (on normal speed and volume) is on a level TRL 3 level.

Time frame: The time frame of developing and demonstrating efficient use of new recognition systems like markers in waste management is estimated to 3-5 years. The standardization of these systems into complete value chain of WEEE will depend largely on how producers and brand owners want to standardize the use of these systems.

3.2.3 Optimization of high capacity sensor-based sorting for mixed plastics

The share of plastics in cars has been growing gradually overtime and is expected to continue. Fillers and additives provide additional performance and relatively low cost, while laminates and composites further enhance the material properties combining the strong features of several materials. Use of these novel systems is predicted to increase in the coming years. The end of life impact of the complex compositions is high, especially since recycling is costly and energy intensive. New sorting solutions are needed to facilitate recycling of both traditional plastics and new material combinations, subsequently decreasing the energy requirements.

To date, these plastic fractions from for example ELV are generally not recycled but incinerated or landfilled as a main component of the shredder residue. Over the past decade, a sensor based approach resulted in a more efficient sorting of plastics, using Colour, X-Ray, Laser and ultrasound spectroscopy, which should be explored for more effective sorting of these fractions.

This action should address in particular:

- Improvement of the sorting efficiency of similar polymer grades with different compositions (gas filled, layered, etc.).
- Investigate possibility of coupling several sorting methods for better detection and higher grade of separation into homogeneous streams

Expected impact: Expected impacts are higher recycling yield of plastics as well as an improved quality of intermediates and final product. In addition a better environmental (energy) performance of plastics separation will be achieved.

Relevant waste streams: ELV, WEEE, PPW

Type of action: IA (Demo)

TRL-level: 7

Time frame: 0-5 years

3.2.4 Development of methods for detection and separation of precious metals

With an increasing electrification of vehicles the utilisation of precious metals in vehicle components has accelerated. In the meantime, product designers have realized to minimize and miniaturize the use of these metals in the sub-assemblies.

Today these metals are not recycled, but form an element in the existing ferrous - non-ferrous fractions, or become part of automotive shredder residue. In both ways, elements are disposed in a diluted way in other metal fractions or ends up in fractions sent for energy recovery or landfill.

Development of solutions for both pre-shredder and post-shredder strategies is needed. Pre-shredder strategies (by dismantling) need different approach than post-shredder strategies. The precious metals also end up in the fines and needs to be separated in an efficient way. In the latter, a key activity is to understand the availability of different metal and non-metal fractions contained in the post-shredder material and development of technical solutions to concentrate and extract the precious metals.

Expected impacts: Detection and additional separation of precious metals will improve the profitability of dismantlers and recyclers. The overall environmental performance of vehicles and EEE will also be improved as an improved functional material recycling of the metals will be achieved.

Relevant waste streams: ELV, WEEE

Type of action: RIA

TRL-level: 7 for pre-shredder techniques and 2 for post shredder techniques.

Time frame: 5-10 years

3.2.5 Development of recycling methods for composites and multi-layered materials

Several new compositions that enhance mechanical and physical properties of the materials are steadily growing in a variety of applications. Similar to other products where light weighting is of decisive importance for usability or emissions, plastics are an ideal solution to lower the vehicle weight. Ongoing plastic innovation allows integration of polymeric materials in high performance components such as engines and bearing parts. Also aesthetics of these materials is continuously improving, opening new possibilities for use in increasing amount of products and components.

Used in a combined form with non-polymeric elements in a laminate or composite, plastics cannot be recycled technically and economically without prior dismantling.

This research and innovation action should address in particular:

- Development of new recycling techniques to enable recycling of complex compositions
- Development of new methods for recovery of constituents, such as fibres, in the new materials as separate fractions for use secondary raw material

Expected impacts: This action supports recycling operators to provide solutions which can both recover the valuable engineering plastics and composites, while not harming existing recycling systems.

Relevant waste streams: ELV, PPW

Type of action: RIA

TRL-level: 3

Time frame: 5-10 years

3.2.6 Development of cost effective and low volume Lithium battery reuse and recycling methods

Lithium-based batteries have become an inherent part of the electrification of transport, as well other energy storage applications. Contrary to Lead and Nickel based industrial batteries, Lithium based batteries contain relatively small amounts of valuable materials. Absence of self-financing leads towards a chain deficit, which needs to be covered by the product owner. Lithium is imported into Europe and if European automotive manufacturers want to be players in the field of electrical vehicles they need to have their own battery production.

Together with other aspects such as logistics, disposal and recycling lead to high costs for the product owner which affects the affordability of e-mobility in general.

Discarded batteries include both end-of-life batteries (worn out), as well other batteries (e.g. due to accidents). The end-of-life batteries may provide potential for reuse of cells, modules or complete battery packs towards second life applications. When replaced in a car, a lithium based battery still has a high capacity left which potentially could be used. This potential needs however to be further investigated.

This research and innovation action should address in particular:

- Design the battery for improved second life application
- Ageing behaviour
- Battery classification for safe handling/transportation
- Recycling of the battery

Expected impacts: Lowering cost, extended life time, improving recycling efficiencies and regaining materials such as lithium is of strategic importance.

Relevant waste streams: ELV

Type of action: RIA

TRL-level: For Li-ion battery reuse TRL 3 and for Li-ion battery recycling TRL 6.

Time frame: 5-10 years

3.2.7 Application of fibrous and mineral residues from ELV's

While the major share of vehicle composition consists of metals and (hard) plastics, there is an increasing mass of other materials in the vehicle such as foams, carpentry, wood, rubber and glass which usually form Shredder Heavy Fraction (SHF) and Shredder Light Fraction (SLF). SHF is the residual after separation all materials in the shredder, SLF is created by the shredder aspirator, which sucks all dust and other light elements.

After liberation and sorting of metals and plastics, these materials are often sent for energy recovery or landfilled. Still, there is a potential for material recycling, which largely depends on the gate fees for energy recovery and landfilling.

While separation into clean grade fractions is technically and economically not viable, product application in a mingled form is possible under conditions respecting limits of hazardous substances.

Technologies to be developed to apply fibres and minerals and are able to remove hazardous substances and prepare standard grades. Elimination of accumulated persistent organic pollutants such as PCB's, as well as mineral oils and mercury contents might be an indispensable step.

Expected impacts: Increased material recycling of fibrous and mineral residues from ELVs.

Relevant waste streams: ELV

Type of action: RIA

TRL-level: 5

Time frame: 0-5 years

3.2.8 Standardisation of analytical methods for quality assurance of recyclates

Elemental analysis is an important step to validate if a separated waste fraction can become a raw material for new applications. Inherently as a 'waste', unwanted materials accumulate in the recycling chain, especially when it is arising in a mixed form.

Legal initiatives and thresholds for concentrations of particular substances change rapidly. There are pressures to define new thresholds for certain substances – such as some brominated flame retardants to levels beyond those that can be measured reliably by currently available analytical methods.

Analytical methods are conformed on a national level, while even on national level there is no uniformity on the analysis methods. As a result, analysis of similar material samples may have an outcome variety of hundreds of percent.

The lack of uniformity leads to an unlevel playing field. While in one country separated fractions can be applied for e.g. construction materials, in other countries this might not be possible. This is mainly caused by different analytical standards, hurdling the application of fractions.

Expected impact: An improved consumer acceptance to use secondary materials is expected. In addition uniform analysis methods tailored to heterogenic waste streams will developed.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA

Time frame: 5-10 years

3.2.9 System analysis (and piloting) of integrated treatment strategies for improved recovery of selected precious or critical raw materials

The recycling of critical and precious raw materials is currently hindered by several factors such as small concentrations per product leading to unfeasible economy of processing, lacking methods for identification and separation of components containing valuable materials and lacking information about quantities available for recycling. Usually same type of components can be found in several end-of-life product groups. Some examples include:

- Printed circuit boards in WEEE and increasingly in ELV but also in many other products and systems
- Permanent magnets in computers, vehicles, air conditioners, wind power turbines and several other applications
- ITO (Indium tin oxide) in screens used in several applications, solar panels, etc.

New strategies based on system thinking (integrated treatment of same type of components from different products, centralized plants, etc.) and development of technological solutions (e.g. 3.2.1 Robotic sorting) for identification and separation of target components could improve the economic feasibility of recycling and enhance introduction of industrial scale plants.

Expected impact: The project would enhance industrial scale introduction of the technology solutions developed for recovery of critical materials, providing a new European source of critical raw materials.

Relevant waste streams: ELV, WEEE

Type of action: RIA or IA

Time frame: 1-5 years

3.3 Well-functioning market

Table 4 shows an overview of needed research and innovation actions to achieve a well-functioning and competitive market and economy for recycled material.

Table 4. Overview of key research and innovation actions related to a well-functioning market and economy for recycled materials.

Section	Research and innovation action	Relevant waste streams	Type of action	Time frame
3.3.1	Material ownership by the producer	ELV, WEEE, PPW	IA	10 years
3.3.2	Establishing an intra-sector and cross-sector knowledge community building the market for secondary materials	ELV, WEEE, PPW	CSA	0-5 years
3.3.3	Analysis of new technology - impact on raw material consumption and recycling	ELV, WEEE	RIA	0-5 years
3.3.4	Developing material specifications for secondary material	ELV, WEEE	RIA	0-5 years

3.3.1 Material ownership by the producer

A pathway to a Near Zero Waste EU is to create new business models based on the ownership of the material by the producer. Within the circular economy many of those new business models are already drawn up, but we are only in the starting stage of the roll-out of these models. One reason is that procurement models are still working on the basis of a traditional client – supplier relationship. Within the described value chain for PPW there are already schemes in place where extended producer responsibility (EPR) is implemented and working. These schemes focus mostly on making sure that if a product becomes waste it is disposed correctly and with a certain recycling rate. But to what extent recycling is needed (material, energy or heat) is often not described.

New business models should be based on the idea that a certain amount of material should be made into useable materials/components for the same industry that created the product containing the materials. Involvement of brand owners is crucial to create sustainable value chains where waste is put back into the value chains as a product, component or secondary material. Brand owners and retailers can implement Corporate Social Responsibility strategies that promote the use of certain percentage of recycled materials in products. Such behavior can encourage other stakeholders and speed up the way towards circular economy. Only the manufacturers are able to really close the circle of a material by implementing secondary materials into products. They can also play a huge role in the business case by designing for recycling.

Expected impact: New business models would allow more effective recycling while meeting the economic interests of manufacturers.

Relevant value chains: ELV, WEEE, PPW

Type of action: IA

Time frame: 10 years

3.3.2 Establishing an intra-sector and cross-sector knowledge community building the market for secondary materials

An active and dedicated community where sharing and building knowledge for a common objective of building the market for secondary materials should be established. In this collaborative effort, experts are invited to participate and work on specific objectives for building a market for secondary materials. Making sure that different actors throughout the life cycle have a shared interest.

Intra-sectorial activities, as well as cross sectorial are needed.

Examples are for inter-sectoral activities:

- Plastics sector: Secondary plastic granulate as a material source for plastic manufacturing
- Metal recycling: Technological solutions for sorting of non-ferrous alloys
- Dismantling: Depollution of new generations of vehicles
- Authorities: Illegal and substandard practices in the end-of-life chain

Examples are for cross-sectoral activities:

- Sorting methods for various waste streams: shredder waste, municipal waste
- Recycling of reinforced plastics stemming from end-of-life aircrafts and vehicles and WEEE
- Treatment of high voltage batteries, difference between automotive, aviation, equipment (e.g. trains)

Expected impacts: Better exchange of information between value chain actors and better exchange between various waste treatment categories will be achieved. This could further facilitate larger joint volumes of secondary material, new opportunities for industrial symbiosis, etc.

Relevant waste streams: ELV, WEEE, PPW,

Type of action: CSA

Time frame: 0-5 years

3.3.3 Analysis of new technology - impact on raw material consumption and recycling

Electric and electronical equipment (EEE) is under rapid and continuous development and the same is true for mobility solutions. Alternative mobility is regarded as a main innovation area for European businesses. The technical breakdown of alternative mobility differs from traditional propulsion due to batteries, electric engines, catalysed convertors, electronics, fuel cells and a higher level of weight reduction measures. EEE component and material composition varies at a high speed. Furthermore, as Europe produces a quarter of global vehicle supply, lower access to 'scarce' materials may pose a real economic and competitiveness barrier. Ever-smaller electronic equipment with very small amounts of materials makes it even harder to recycle the scarce raw materials. Recycling reduces the dependence on imported rare materials. In addition to recycling, substitution of REEs is of high interest.

In this research action, main impact of new technologies will be analysed in the light of material consumption - and subsequently recycling of material at end of life. This needs to be done for different product groups and continuously as products are developing, and a life cycle perspective needs to be taken into account.

Expected impacts: The added value gained though this continuous research is to create a knowledge basis on the overall impact of product design on recycling after its services life, in a technical, ecological and economic perspective. Strategic intelligence on new technology and material impacts will make possible the avoidance of problems in material supply and recycling.

Relevant waste streams: ELV, WEEE

Type of action: RIA

Time frame: 0-5 years

3.3.4 Developing material specifications for secondary material

One of the challenges for creating a stable market for the secondary materials is the high specific demand on the material properties for new applications, such as mechanical and chemical properties. The materials on the market today may contain substances which are regulated by different legislations, such as REACH. This has complicated effective use of these fractions as secondary raw material. There is a clear need to analyse the amounts of these substances in the resulting recyclates and how these will interact with the surrounding environment during use (release).

Realistic levels of material specifications can be determined for each specific application, creating possibilities for the secondary materials to replace virgin. Specification sheets should be generated similar to the virgin materials (data sheets) that guarantee the quality of the material properties of the recycled fractions. Also the regular supply of the materials with the same quality must be assured, satisfying supply on demand.

The action should focus on:

- Risk assessment of the contamination of the recycled fractions and possible release of the substances from the recycled fraction
- Determine possible applications for secondary material -
- Setup of a common specification sheet for secondary materials

Expected impact: The action will facilitate increased trust in secondary material quality and thus increased use of secondary material.

Relevant waste streams: ELV, WEEE

Type of action: RIA

Time frame: 0-5 years

3.4 Effective policies and legislation

Table 5 gives an overview of the research and innovation actions to reach effective and harmonized policies and legislations which promote efficient recycling of materials.

Table 5. Research and innovation actions contributing to effective polices and legislations.

Section	Research and innovation actions	Relevant waste streams	Type of action	Time frame
3.4.1	Assessment of benefits of recycling and phase-out regimes for potentially hazardous substances	ELV, WEEE	RIA	5-10 years
3.4.2	Assessment of regulatory barriers prohibiting qualitative recycling across EU	ELV, WEEE	RIA	5-10 years
3.4.3	Development of quality standards for ELV recycling	ELV	CSA	0-5 years
3.4.4	European matching of vehicle registration, re-registration and deregistration systems	ELV	CSA	0-5 years
3.4.5	Implement mandatory post-consumer recycled content	ELV, WEEE, PPW	CSA	
3.4.6	Increase the demand for recycled plastics	ELV, PPW, WEEE	CSA	0-5 years
3.4.7	Improve EPR-encourage the production of recyclable products	ELV, WEEE, PPW	SCA	0-5 years
3.4.8	Development of economic systems for collection of waste fractions	ELV, WEEE, PPW	RIA	0-5 years
3.4.9	Tools for increased use of recycled materials in new products	ELV, WEEE, PPW	RIA and CSA	3-5 years

3.4.1 Assessment of benefits of recycling and phase-out regimes for potentially hazardous substances

The use of hazardous materials is controlled by REACH and RoHS regulations and within WEEE it changes often, not only the use of substances but also the concentration levels. Because of this, it is often not possible to mechanically recycle materials coming out of WEEE. One example is lead in the glass TV-tubes. Technically, it is recyclable, but it is prohibited due to legislation on the use of lead. In the meantime, lead is still needed for production of batteries, glass etc. The benefits of recycling and phase-out regimes for potentially hazardous substances have to be balanced, including sufficient lead-times to develop and introduce technically reliable and safe substitutions.

This action should focus on:

- Develop methods for assessing and comparing benefits and drawbacks of recycling of materials containing hazardous substances
- Assessment of benefits and drawbacks of recycling of materials containing hazardous substances

Expected impacts: Implementation of assessment results in regulation for clarification of and guidance, facilitating best practice. Update, clarification and guidance of hazardous substances regulations will create a more stable marketplace for recycled materials as well as a good base to work on for more recycled content in new products.

Relevant waste streams: ELV, WEEE

Type of action: RIA

Time frame: 5-10 years

3.4.2 Assessment of regulatory barriers prohibiting qualitative recycling across EU

The legal situation that applies to the recycling industry with both waste and product legislations that apply (REACH, ROHS for products, POP, WSR, WFD for waste) is highly complex. The definition of waste is differently interpreted in different countries and by different actors. Clarification and guidance is needed. In addition, European legislation requires every newly prepared chemical composition on the EU market to be registered according to REACH legislation. New thresholds for certain substances (such as some brominated flame retardants) are defined at levels below those that can be reliably quantified for secondary raw materials.

Also, in this respect, clarity needs to be offered to both recyclers and chemical companies that including any recycled material would lead to exemption from the obligation to register the chemical composition of the material. It is difficult to assure the chemical composition of a recycled product in advance.

This action should focus on investigating policy mixes and regulatory systems that finds a better balance between a) health and safety of materials and products, and b) environmental and resource gain of recycling.

Expected impacts: Increased material recycling and use of secondary material due to balanced and relevant policy mix and regulatory systems.

Relevant waste streams: ELV, WEEE

Type of action: RIA

Time frame: 5-10 years

3.4.3 Development of quality standards for ELV recycling

Between European nations there is a lack of a coherent and uniform quality assurance system for the collection, storage, logistics, processing, recycling and reuse of ELV's. Collectors, processors and compliance systems benefit from European standards, as it supports a level playing field for operators while a minimum standard is created and a tool for industry enforcement. Furthermore it diminishes the role of substandard players, as a high level of downstream reporting is required. Only processors with minimum quality and reporting standards can participate and receive products for recycling. Independent and trained auditors are capable to verify the quality of operations. The quality system can build on already existing quality assurance systems which are in place in some Member States.

A set of standards are to be developed with respect to the collection, sorting, storage, transportation, preparation for re-use, treatment, processing and disposal of all kinds of ELVs and aims to cover the EU28. A process of monitoring with audits should be put in place.

Expected impacts: Through common reporting methods through recycling chains on European level an improved reliability for contracting parties as well as a better self-regulation and reduction of mandatory audit and control will be achieved.

Relevant waste streams: ELV

Type of action: CSA

Time frame: 0-5 years

3.4.4 European matching of vehicle registration, re-registration and deregistration systems

Traditional vehicle registration systems have not been designed to facilitate vehicle recycling. The interest of national fleet registers is to administer and communicate vehicle and ownership data, serving the needs of first responders, police, taxation units, roadworthiness certification, etc. These mandatory systems are designed according to national standards, there is no European vehicle deregistration system yet in place. Communication between Member States is still limited and on a voluntary level.

Correct vehicle deregistration can facilitate qualitative recycling, while better communication between Member States can solve the 'disappearing' of ELVs. Uniform deregistration protocols are the starting point for well-functioning recycling systems, where illegal practices are phased out and consumers are motivated to select the correct recycling system.

Expected impacts: Minimization of the 'business case' of substandard recyclers as well as creating high consumer incentive to deliver ELVs at authorised treatment facility will be achieved.

Relevant waste streams: ELV

Type of action: CSA

Time frame: 0-5 years

3.4.5 Implement mandatory post-consumer recycled content

Several plastic products and components on the market can retain the required material properties although containing a certain amount of recycled material. Several companies have explored the possibility to use secondary raw material in combination with virgin material in their applications and have established the thresholds for the contents without compromising the quality of the final material.

Legislation on mandatory use of recycled materials in certain products will also promote stabilisation of the market for secondary raw material.

This action should focus on:

- Development of a guideline for a policy for mandatory use of secondary raw materials in different applications
- Investigation of how to assure a reliable market and material access for the policy to be effective

Expected impact: Increased use of secondary polymeric materials in different applications and promoting a larger market for the recyclates.

Type of action: CSA

Relevant waste streams: ELV, WEEE, PPW

Time frame:

3.4.6 Increase the demand for recycled plastics

To ensure that recycling is economically viable it is necessary to have a certain amount of waste in the recycling plants and a certain commercial demand. To reinforce the demand of recyclates to be used in plastic applications, certain non-technological measures could be introduced that will create stable market conditions for recycled plastics and enable recyclers to invest in capacities and new technology with the aim to increase plastic recycling.

This action should focus on analysing and evaluating a policy mix for increasing demand for secondary raw material. Some of the policy actions that could be undertaken are:

- Alignment with chemical legislation
- Promote green procurement, which encourages the use of recyclates
- Implement deposit systems for ELV and certain PPW and WEEE in order to increase the collection rates
- Offer financial incentives for design for recycling of plastic products and components, e.g. avoiding multilayer and multi-material when possible
- Increase the value of the PPW by using the recycling materials in industrial packaging instead of societal applications, namely to foster upcycling.

Expected impact: Economic incentives in the member states are a key element for establishing a functional secondary raw material market for plastic waste and thus contributing to growth and employment. Proposals for eco-taxes (production of non-recyclable products, landfilling, incineration, etc.) can be established by the EC.

Relevant waste streams: ELV, WEEE, PPW

Type of action: CSA

Time frame: 0-5 years

3.4.7 Improve EPR-encourage the production of recyclable products

A legislative way to increase the recycling rates of materials is to encourage recyclable products and thus higher recycling rates with financial incentives by further developing the EPR. EPR can provide the funding and standards necessary to establish a stable market for secondary raw materials. The producers will be encouraged to design new products considering the waste management and end-of-life of the materials. A recyclability label can be introduced to distinguish these products to achieve consumer awareness, which will give an added incentive for the producers.

Expected impact: The recycling aspects of products will be considered in the design phase to a higher extent. As a consequence the losses in the recycling process will decrease and the recycling rate will increase.

The action should focus on:

- Suggesting different fees for recyclable and non-recyclable applications
- Suggesting a unified label stating recyclability of the product for consumer information

Relevant value chains: ELV, WEEE, PPW

Type of action: SCA

Time frame: 0-5 years

3.4.8 Development of economic systems for collection of waste fractions

There are several examples of successful collection of waste fractions when the customers have incentive to return the product for a small reimbursement, for example collection of PET bottles and a small refund for the disposal of cars. The rebate systems can be applied to a variety of products, providing tools for better collection of end-of-life products.

This action should focus on:

- Evaluating which products can be subjected to the rebate system

- Investigating the logistics needed for implementation of the systems in different member states
- Suggesting appropriate reimbursement fees and the incentives for the producers and collecting partners to implement the system

Expected impact: The system will increase the collection rates of the targeted materials and consequently increase the recycling streams.

Relevant value chains: ELV, WEEE, PPW

Type of action: RIA

Time frame: 0-5 years

3.4.9 Tools for increased use of recycled materials in new products

Making the content of recycled materials in new applications obligatory for producers will serve as a driver to keep materials within their own value chain of product or brands. The use recycled materials can be implemented in industrial packaging, promoting larger volumes used and avoiding the complications associated with food-contact restrictions. This could lead to new business models where more circular material flows are implemented.

The action should focus on:

- Creating good data on products, end-of-life phase on composition and materials used.
- Investigate possible benefits of using a larger fraction of the recycled materials in industrial packaging instead of societal applications
- Provide a guideline for legislation on minimum input recycled materials implemented throughout the whole EU
- Development of a monitoring system to track the use of recycled materials

Expected impacts: Implementing regulation for a minimum use of secondary raw materials will improve the market for recycled materials. This will also create a more loose connection of the pricing of secondary plastics and metals to the global pricing, ensuring a specific market for secondary raw materials.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA and CSA

Time frame: 3-5 years

3.5 Sustainable product design

Table 6 summarizes the actions for research and innovation to achieve sustainable product design.

Table 6. Research and innovation actions contributing to sustainable product design.

Section	Research and innovation actions	Relevant waste streams	Type of action	Time frame until introduction
3.5.1	Design of packaging for effective recycling	PPW	RIA	0-5 years
3.5.2	Investigating the consequences of introducing degradable materials in the loop	ELV, WEEE, PPW	RIA	
3.5.3	Investigation of the effects of different policy and measures aiming for design for recyclability of products	ELV, WEEE, PPW	RIA	5-10 years
3.5.4	Collaborative design for recycling	ELV, WEEE, PPW	CSA	0-5 years
3.5.5	Investigation of end-consumer demand and practice	ELV, WEEE, PPW		

3.5.1 Design of packaging for effective recycling

The packaging applications are becoming more advanced, integrating use of several materials and thus creating challenges for separation prior to recycling as well as contamination of the homogeneous material flows. The use of one type of polymer throughout the whole packaging application will facilitate both sorting and recycling steps. The important materials properties must be retained. A lot of research is conducted on reinforcement of the materials with fibres from the same material. Another possibility is to create multilayered structures using one material, but with different characteristics throughout the layers.

The action should focus on:

- Exploring the possibilities of using the same material for the application, assuring the required material properties
- Development of novel material systems containing only one type of material that can provide prolonged food shelf-life

Expected impact: The recycling of the packaging applications is improved through elimination of need of separation of different material fractions, also avoiding contamination of the resulting secondary raw materials.

Relevant waste streams: PPW

Type of action: RIA

Time frame: 0-5 years

3.5.2 Investigating the consequences of introducing degradable materials in the loop

New degradable materials have been gaining an increased use on the market as environmentally friendly alternative. They can however interfere with the present separation and recycling processes and can be difficult to separate. Several studies have been conducted on investigation of influence of these materials when mixed in the bulk material fraction on the material properties of the resulting recyclates. More research is needed on the analysis of mixed streams of degradable and conventional materials to realize the possibilities and challenges on separation and recycling of the collected materials.

The action should focus on:

- Investigation of the possibilities and challenges to separate the degradable materials from the collected fractions
- Characterisation of the material properties of the recyclates that contain different amounts of degradable material content
- Development of new technological solutions for recycling of the degradable materials

Expected impact: Novel processes for collection and separation of the different material flows will be developed. Technology to recycle the degradable materials will be established.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA

Time frame:

3.5.3 Investigation of the effects of different policy and measures aiming for design for recyclability of products

With several initiatives, policies and measures aiming for increasing the design efforts for recyclability in the pipeline there is a need for follow-up and evaluation of the efficiencies and consequences of these as they have been in practice for some time.

The action should focus on:

- Investigation of the consequences of policies and measures for increased recyclability of products
- Suggestion of modifications when relevant

Expected impact: Improved policies and measures and increased recyclability of products.

Relevant waste streams: ELV, WEEE. PPW

Type of action: RIA

Time frame: 5-10 years

3.5.4 Collaborative design for recycling

Possibilities for recycling should be considered already in the design phase. In order to get the right competence regarding recycling communication with recyclers are crucial.

The action should focus on:

- Connecting the right actors aiming for collaboration with the actual delivery of a new product design in the end
- Providing the opportunity for actors to meet and the driver to actually produce new joint solutions

Expected impact: Producers and recyclers are increasingly collaborating in design for recycling and new recyclable products are showcased and finally put on market.

Relevant waste streams: ELV, WEEE, PPW

Type of action: CSA

Time frame: 0-5 years

3.5.5 Investigation of end-consumer demand and practice

The end-consumer demand and practice will have an impact on the products and product design. This is a wide area of its own and a need for social science research as well as interdisciplinary studies is foreseen.

To be further developed – please provide your ideas on the topic

Expected impact:

Relevant waste streams: ELV, WEEE, PPW

Type of action:

Time frame:

4 Current situation and main challenges

This chapter describes the current situation and related main challenges for each research and innovation theme which is the basis for the identified and described research and innovation actions described in the previous chapter.

4.1 Collection and monitoring

4.1.1 ELV

According to the ELV directive (2000/53/EC) member states are obligated to take measures to ensure that economic operators set up systems for the collection, treatment and recycling of end-of life vehicles. In addition, the directive states that the last owner has the right to deliver an end-of-life vehicle without any cost. For transport of obsolete vehicles when needed, the collecting actor has the right to charge for services provided.

Inadequate performance and monitoring of collection are main challenges for ELVs. As ELVs possess a net economic value, ineffective (de-)registration measures results in ELV's are not delivered to an authorised treatment facility, but are 'leaching' to noncompliant actors and unregulated and illegal export. Today there is a lack of Europe-wide harmonisation in regulation, poor governance and ineffective enforcement of regulation. For example there is today no binding European vehicle registration system which makes it difficult to track vehicles.

As a consequence this reduces the quantities available for recycling in Europe and impact to the profitability and employment of the recycling industry. Treatment in uncontrolled conditions may increase environmental and occupational safety risks and lead to lower recycling efficiencies.

Another challenge is the recycling industry’s adaptation to the expected change in material contents in vehicles. For example the collection and recycling systems for specific components in electric cars, such as Li-ion batteries and fuel cells (in the future) are still immature or not existing. In addition recycling of critical raw materials from electronics and other small components would demand new kind of systemic thinking, such as collection of the separated components to centralised recycling plants.

Another challenge is the lack of uniform and transparent reporting methods among Member States which has led to a largely incomparable situation within the EU. This is well understood in the Circular Economy Package which is pointing specifically to monitoring protocols instead of ‘recycling rates’. In relation, DG Environment commissioned a public study on whereabouts of end of life vehicles, as well on calculation methods (Oeko-Institut, 2016).

4.1.2 WEEE

Member States within EU have implemented and established the WEEE Directive (2012/19/EU) differently. This due to difference in EEE consumption, waste legislation, standard of living, technical infrastructure and the level of consumer involvement. The way it is organised per country is mostly based on population density and the development of use of technology. This can sometimes vary per region within a country. The WEEE is today collected through take-back systems, collection points in stores or collection centres often managed by municipalities.

The key challenges in WEEE chain are the low officially reported collection efficiencies and the significant variation between EU member states. In some eastern European countries the collection system is still very ineffective. In several other countries there are challenges in monitoring of the collection rates. In addition, a part of WEEE either ends up to incineration and landfills or is still stored by consumers. According to the European Commission (2014), the reported collection rates in 2010 and 2012 were over 50 percent of the estimated total amount of WEEE only in four member states and over 40 percent in seven member states. Over 25 percent of the total WEEE is estimated to be illegally exported and about 30 percent ends up to non-compliant treatment (CWIT, 2015). From 2016, the separate collection rates will be calculated as a percentage of EEE put on the market. Based on the 2012 numbers achieving the minimum collection targets (45 percent of EEE put into the market from 2016 to 2018 and 65 percent from 2019) can be a challenge for several countries.

The current situation calls for development of tracking systems enabling better monitoring of the fate of waste electronics, but also for identification and deployment of the elements leading to good practices.

4.1.3 PPW

To reach set targets different collection systems have been introduced among EU Member States, including kerbside collection, bring site collection, deposit/refund systems, recycling centres, civic amenity sites and privately organised on-site collection for the industrial and commercial sector. The collection systems include separate collection, mixed collection with other recyclables as well as mixed collection with residual waste. The collection systems are generally influenced by different local legislative and economic parameters and even within one single member state there could be different collection schemes in the different regions or cities, while sometimes parallel collection systems co-exist in a same place.

Limited source separation of PPW is estimated to be the key challenge in PPW chain. In 2012 the separate collection rate in the EU was 41 percent, or 6.5 million tons (Hestin, Faninger et.al. 2015). The remaining, 9.4 million tons ended up in the residual waste stream, from which only a relatively small part was diverted at mechanical separation plants. Most of it ended up to direct disposal or energy recovery.

Other main challenges for PPW in the collection stage are:

- Heterogeneity of the collection systems between different countries, in some cases inside the countries between different regions leading to significant differences in recycling rates
- Heterogeneity of collected plastics due to use of several different plastics and composites in packaging products, and complexity and cost of source separation of different packagings
- Contamination of the collected packagings (such as food residues and other materials) is an additional obstacle increasing the recycling cost and leading to lower product quality
- Poor information to the consumers, which prevents efficient collection for recycling

4.2 Sorting and recycling technologies

4.2.1 ELV

The recycling system and technologies for bulk metals in ELVs such as steel, iron, aluminium and copper has been mature since many decades where scrap metals has become a vital element of metal making.

After shredding of the depolluted bodywork and subsequent sorting processes, the metals end up as raw materials in smelters. As the material quality of recycled bulk metals deteriorates, recycled metals need however to be diluted by adding virgin metals or the metal needs to be refined, especially when producing materials used for high quality applications. This is due to e.g. complex material compositions and technical as well as economical restraints in the recycling process. Except for catalysts, the material recycling of rare metals used in lower concentrations and in specific vehicle components like in the vehicle's electronics, is practically non-existent today. Instead they are generally dispersed in the bulk metals in which their properties are lost. Reasons for this are because they are used in small amounts and have difficulties in competing with virgin materials.

As plastics parts in general are not dismantled they end up in the shredder residue which is treated differently throughout Europe. In many countries today the residue is incinerated. In central Europe the shredder residue is further mechanically processed and sorted after which sellable recycled plastics are generated. However the technological as well as the economic challenges are immense as recycled plastics have major shortfalls in qualities and thus in price. Besides mechanical processing, chemical recycling of the shredder residue e.g. gasification do occur in Europe.

The introduction of new and more complex materials due to electrification and increased comfort demands etc. to the end-of-life treatment places higher demands on more sophisticated sorting- and recycling processes. The complexity of constructions, increased use of new non-metallic lightweight materials and electronics connected parts have made the dismantling and reuse of the components more challenging and less profitable compared to today's conventional vehicles.

One example is lamellar composites of metals and polymers with a strong bonding between the two are hard to separate. More safety measures are needed in collection and dismantling stages because of the use of high voltage components. Although there is a market for disassembled parts for material recycling, their price does not always justify the cost of the manual labour.

The introduction of new and more complex materials also affects the viability of dismantling for recycling and performance of sorting, separation and recycling technologies. Challenges include development of cost effective recycling solutions for lightweight composites; tracers for materials and components; recycling of electronics, small electric motors etc. containing critical and valuable metals; separation of intermingled, alloyed and glued materials; and solutions reducing the amount of shredder residues and losses to in whole the treatment chain. Furthermore, electrification of vehicles induces new recycling needs, such as recycling of fuel cells and new types of rechargeable batteries.

Since 2015, the recycling rate of discarded vehicles (ELVs) shall amount to at least 95 weight percent, of which at least 85 percent shall be reused or material recycled in accordance with the ELV Directive, 2000/53/EC. As the share of non-metals is successively, increasing, achieving the set targets might be challenging in the future.

4.2.2 WEEE

WEEE is handled differently throughout Europe. In countries where the labour costs are cheap, manual dismantling still dominates. In countries with high labour costs, automated sorting facilities are typically used. Manual work has been reduced only to remove hazardous parts before mechanical shredding and subsequent automated sorting.

For automated sorting facilities smaller WEEE appliances from which hazardous components have been removed are processed in a WEEE shredder which is smaller in size compared to a shredder for ELVs. Larger WEEE appliances such as fridges or stoves are sent to larger shredders which are also used for ELVs and other metal scrap. After shredding, the output material is sorted based on physical and chemical properties, such as magnetism, density, conductivity, colour or composition. The output fractions differ depending on the type and size of the plant and the processed WEEE. Common output fractions such as ferrous metal, copper, aluminium, printed circuit boards, precious metals and copper, are sent to smelters and material recycling. The recyclable plastics are also sent for material recycling whereas brominated plastics are sent for disposal or incineration. WEEE shredding generates a fine fraction which contains inert materials such as glass etc., as well as valuable metals why this fraction often is sent to smelters. Beside glass from screens other common fractions occurring during WEEE processing include concrete from washing machines and insulation foam from refrigerators.

Development of cost efficient processing chains for complex products with variable material composition and low concentrations of critical and valuable materials per application or component is a challenge in electronics recycling. This has led to optimisation of the recycling processes for materials which are technically and economically most feasible to recover. Other valuable materials, such as most of the critical raw materials and plastics end up in fractions which are disposed, used in lower grade applications or in some cases exported. In addition miniaturisation, minimisation of the devices, appliances and components has led to decreased amounts of valuable materials per application which makes it necessary to increase the recycling of individual materials to improve the economic feasibility. Another challenge is tracing of the material composition of the devices and components to enable more efficient separation. Unwanted substances, such as brominated flame retardants in technical plastics also hamper material recycling, because there are no cost effective solutions for separation and removal of them from the material cycle.

4.2.3 PPW

After collection PPW is sorted into different fractions according to the type of polymer. The sorting processes differ depending on the collection system. Collection systems vary across Europe ranging from systems in which plastics are collected separately to kerbside collection of household waste and systems including plastics collection together with other recyclables. Common identification and sorting techniques used in combination are Near InfraRed detection systems (NIR), ballistic separation, air classification and size classification (Jansen, Thoden et al. 2015) as well as manual sorting and density separation.

During the different processing stages a part of the collected PPW ends up in the processing residues which are diverted to disposal or incineration. The estimated yield in the sorting stage is 82 percent of the input and 73 percent in later recycling stages (New InnoNet, 2016). The causes of the losses in the sorting/separation stage and recycling stage are the heterogeneity and rapidly changing design of the plastic packaging materials. In addition, contamination of the materials and insufficient separation efficiencies can undermine the quality of the secondary material generated, resulting in blends and materials with inferior material properties. Although automatic separation technologies have improved significantly, they are still not able to separate all the materials and multi-material combinations (laminated packages). Also the cost of separation of multiple materials is still very high. One possibility to improve recycling rates is to separate plastics from mixed municipal waste after collection. However, due to contaminations it is still difficult to produce good quality secondary raw materials. The best performing PPW recycling schemes combine source separated collection with additional separation to obtain high quality secondary raw materials that can lead to closed loop recycling systems.

Some of the recycled material is used again for packaging applications, but restricted from contact with food or medicine. One of the challenges to use the recycled packaging materials in food-contact applications is the risk of migrating unknown substances to food. Generally, the material ends up in products with lower demands on the mechanical properties and visual aesthetics. The value of the recycled fraction could increase if its functionality could be upgraded, so it could be used for more high level applications.

4.3 Market

4.3.1 Current situation

In the EU Action plan for the Circular Economy proposed by the European Commission in December 2015, there are a number of actions suggested targeting the market for secondary material (EC 2015b), e.g.:

- Development of quality standards for secondary raw materials (in particular for plastics)
- Analysis and policy options to address the interface between chemicals, products and waste legislation, including how to reduce the presence and improve the tracking of chemicals of concern in products
- Measures to facilitate waste shipment across the EU, including electronic data exchange (and possibly other measures)
- Further development of the EU raw materials information system

The main challenge in improving the functioning of the markets for secondary raw materials is to incorporate the requirements from industrial partners that could apply these materials in the collection and recycling system so that these requirements can be met. In this way, a market pull for secondary raw materials can be created. Currently, driven by waste diversion objectives a lot of secondary materials are pushed onto the market and downcycled because of their poor quality.

Because of the variations in qualities and quantities of input material supply and dependence of prices of virgin materials on a global market, it is difficult to keep the volumes, qualities and prices of the recycled materials stable. This has a negative impact to the motivation of producers to use recycled materials.

The benchmarking of the prices against primary material prices does not take into account the potential environmental and strategic benefits of recycling. The challenge of material quality is twofold. On one hand the quality control of the recyclates and the control of the whole sorting and processing chain can be improved and thus better market trust could be gained. On the other hand the legislation, standards and guidelines are developed for virgin materials and they are not always suitable for recycled materials, and thus need to be further developed/renewed. Another obstacle is that producers set high demands on material performance, often unnecessary high, creating a problem replacing virgin materials with recycled since it is difficult for the secondary raw material to guarantee the set demands.

In some cases, the costs of landfilling or energy recovery alternatives are quite low due to overcapacities and therefore creating a lock-in to boost recycling. It can be estimated, that the competition is unlevel/unfair, because the gate fees do not take into account all the costs, such as the costs of the long-term aftercare of landfills. The same applies to the prices of downcycling applications of non-metallic materials and processing residues. These easy-to-use solutions reduce waste quantities available for recycling and thus economic feasibility of high quality recycling.

Hazardous materials in the products can either prevent or hamper the use of recyclates. Substitution or reduction of these materials is a complex challenge needing both development of better knowledge about the materials and their behaviour in recycling process, development of technological solution and better interaction between different legislators and along the value chain.

4.4 Policies and legislation

4.4.1 ELV

The collection and treatment of ELVs are governed by the ELV Directive, 2000/53/EC stating that the Member States are obligated to take measures to ensure that economic operators set up systems for the collection, treatment and recycling of end-of-life vehicles. In addition, the directive states that the last owner has the right to deliver an end-of-life vehicle without any cost even though the transporting company has the right to charge for pick-up and transport of obsolete vehicles to receiving dismantling facility when needed. The directive furthermore regulates which parts and component need to be removed in the dismantling and recycling process. In addition, the recycling rate of discarded vehicles must amount to at least 95 percent, of which at least 85 percent must be reused or material recycled according to the directive. An initiative by the automotive industry to meet the legal obligations of the ELV directive is the International Dismantling Information System (IDIS) (IDIS, 2016). The system gives compiled information to dismantlers to promote the environmentally proper treatment of end-of-life-vehicles. According to the dismantling industry IDIS is of limited help in the daily work proving information which is obvious to the dismantlers.

Having European wide harmonisation of the enforcement of the EU legislation as well as effective governance is considered to be the main challenges to reach effective policies and legislation for ELVs. Today´s differences in the implementation of the legislation between Member States lead to inconsistencies in reporting and European statistics. In addition they also ease leaking of materials from the official recycling systems and use of substandard recycling practices.

The playing field between Producer Responsibility Organisation (PRO) approved and non-PRO approved recyclers is also unlevel. This because the PRO approved recyclers is under tighter control and they have to show that the requirements of PRO are fulfilled. In addition, differences in the enforcement of the legislation lead to a situation when the requirements for recyclers differ among countries.

Removal of the legislative barriers and harmonisation of the enforcement of legislation can be seen as enabler of development and introduction of new recycling solutions leading to higher recycling efficiencies.

4.4.2 WEEE

According to the WEEE Directive (2012/19/EU), the EU Member States are obligated to establish separate collection systems for WEEE and ensure the correct treatment of all collected WEEE. The recycling target varies depending on the product category but also in time where higher recycling targets are implemented successively. Overall, there is a collection target of 45 percent of the electronic equipment sold that will apply from 2016 and, as a second step, from 2019, a target of 65 percent of equipment sold, or 85 percent of electronic waste generated.

In the EU Action plan for the Circular Economy proposed by the European Commission in December 2015 (EC 2015b) actions for improving the exchange of information between manufacturers and recyclers on electronic products and European standards for material-efficient recycling of electronic waste, waste batteries and other relevant complex end-of-life products are suggested.

Non-harmonised legislation and inadequate control/monitoring of the value chain enables illegal export and noncompliant treatment. Statistical data is unreliable and does not enable the estimation of quantities of WEEE and specific materials and components in electronics available for treatment. This hampers the feasibility assessment of new recycling technologies and concept.

Removal of the legislative barriers and harmonisation of the enforcement of legislation can be seen as enabler of development and introduction of new recycling solutions leading to higher recycling efficiencies.

4.4.3 PPW

The Packaging and Packaging Waste Directive (94/62/EC) obliges the EU Member States to establish collection systems to achieve a PPW recycling rate of 22.5 percent by weight. Through the revision of the Directive within the Circular Economy package the target might be increased to 55 weight percent to be achieved by the end of 2025. The Directive covers all packaging placed on the European market and all packaging waste, whether it is used or released at industrial, commercial, office, shop, service, household or any other level, regardless of the material used.

To efficiently address the circular economy principles, the European Commission, the Council and the Parliament are working together in the amendment of the Waste Directive and Packaging Waste Directive.

On the basis of the report “Resource efficiency: moving towards a circular economy” published in 2014 (European Parliament, 2014), the Circular Economy Package which includes a revised legislative proposal for the Directive on packaging waste in order to set the targets for reduction and recycling of waste was presented in December 2015 by the European Commission.

The main proposals of actions include:

- Increase the preparing for re-use and recycling target for municipal waste to 65 percent by 2030
- Increase the preparing for reuse and recycling targets for packaging waste and the simplification of the set of targets
- A common EU target for reuse and recycled 75 percent of packaging waste by 2030
- Gradual limitation of the landfilling of municipal waste to 10 percent by 2030
- Greater harmonisation and simplification of the legal framework on by-products and end-of-waste status
- New measures to promote prevention, including for food waste, and re-use
- Introduction of minimum operating conditions for Extended Producer Responsibility
- Introduction of an Early Warning System for monitoring compliance with the recycling targets

The time frame to implement the proposals has been detailed in the Implementation Plan for Proposals (European Parliament, 2015).

The implementation of the directive varies considerably among the Member States. This can be explained by the significant differences in the development of extended producer responsibility system (EPR) for PPW within the EU. According to the European Commission, EPR schemes are the main driver for reaching the goals set by the packaging waste directive but the limited ambition of the current/actual recycling target (22.5%) and a lack of requirements lead to significant variations in effectiveness per country (European Parliament, 2016).

There are three aspects which show the discrepancy in waste management practices between countries throughout the EU:

- Operational infrastructure for waste management of PPW
- Different schemes in the collecting and sorting
- Political will to support the implementation of sustainable waste management systems

Bearing in mind the current EU waste legislation, these particularities of the countries make it difficult to compare the performance of different collection and recycling systems and set a "best practice" for PPW collection and/or recycling based on circular economy principles over the whole EU.

This indicates that modifications in the EU waste legislation are needed. New recycling and reuse targets and the conformity in measuring performance can drive recycling as the preferred option instead of landfill or incineration. An overall action plan for implementation is also required in order to allow a faster transition towards a circular economy and achieve the same level of performance in all Member States.

In addition, plastic recycling in Europe is hampered today by product standards limiting the use of recycled materials in food packages. Because of that, recycled materials are mostly used in lower value applications even if they meet higher quality requirements.

4.5 Product design

The EU Action plan for the Circular Economy proposed by the European Commission in December 2015 (EC 2015b) emphasis that better design can provide more durable products, which are easier to repair, and remanufacture and facilitates material recycling.

4.5.1 ELV

According to the ELV Directive dismantling, reuse and recycling must be taken into account when designing and producing new vehicles. Design engineers in the automotive industry today are aware of the aspects needed to take into account in order to increase the recyclability of vehicles.

Manufacturers marketing whole vehicles to the European Market, should comply with eco-design rules as a part of the Whole Vehicle Type Approval. This follows requirements of the Directive 2005/64/EC relating to the type-approval of motor vehicles with regard to their reusability, recyclability and recoverability. Following this Directive, OEM's should prove theoretically that the (to be approved) vehicle is recyclable up to at least 95 percent.

Besides the mentioned directives there are currently no, or very few, incentives for product manufacturers to develop recyclable products. The product design is strongly driven by performance requirements, cost minimisation and consumer expectations which currently do not emphasize recyclability or reusability. Other drivers of the design include reduction of climate impacts, reduction of emissions for cars and improvement of cost efficiency by minimization of the material use in the manufacturing stage.

The current requirements and rapid development of materials have led to complex designs, use of multimaterial combinations and composites, miniaturisation, availability of large number of alternative materials etc. These trends make disassembly and liberation/separation of the components and materials and their recovery in recycling processes difficult and less cost effective than before. The communication along the value chain, e.g. between manufacturers and recyclers or between recyclers and product designers is insufficient and the recyclability is far from the key priorities of consumers.

4.5.2 WEEE

In the EU Action plan proposed by the European Commission in December 2015 (EC 2015b) it is for example suggested that emphasis on circular economy aspects should be included in future product requirements under the Ecodesign directive, and that standards on material efficiency for setting future Ecodesign requirements on durability, reparability and recyclability of products are developed. Electrical and electronic products are especially emphasised and in the Ecodesign Working Plan (EC 2016c), which focus energy-related product groups, it is stated that during review of eco-design and energy labelling regulations the Commission will examine how aspects relevant to the circular economy can be assessed and addressed, aspects such as resource efficiency, reparability, recyclability and durability

The design and composition is considered, likewise the large share of uncontrolled treatment, to be the most significant challenge for WEEE. As for ELVs there are today no or very little encouragement for manufacturers of WEEE to consider the recycling aspects in the design phase but the main drivers are cost minimisation and consumer expectations. This in turn has resulted in complex designs in terms of number and combinations of materials being used, integrated/joined or alloyed materials etc. which makes dismantling of parts and materials challenging both from an economic and technical perspective. In addition miniaturisation of the electronic components and decreased use of valuable materials per application decrease the feasibility of recycling. Also the rapid development and short lifecycles of products as well as unwanted substances are challenges for an improved recycling of WEEE. Keeping pace with the rapid developments is challenging for recyclers. The communication and collaboration along the value chain, e.g. between manufacturers and recyclers or between recyclers and product designers is insufficient and the recyclability is far away from the key priorities of consumers. However, a proposal for an amendment to the Eco-design Directive is expected that will bring the requirements for durability, reparability, reusability and recyclability for several product groups, including electric and electronic products.

4.5.3 PPW

The trends in design of plastic packaging include improving performance, minimisation of material use and reduction of life (cycle) climate impact. This has led to an increased number of different materials and increased use of composite materials and degradable plastics, which causes special challenges for recycling. The current technological solutions are neither adapted nor fitted for recycling of plastic composites and degradable plastics. Furthermore the increasing amount of different materials and impurities to be separated also cause an increase of the processing costs.

The requirements for prolonged food freshness have resulted in complex layered material designs to assure the barrier properties. The different materials are difficult or impossible to separate during waste management and can contaminate the consequent recycled fraction of otherwise homogeneous streams. Also degradable materials create certain contaminating issues. There is a high demand on development of ecodesigned solutions of packaging that can provide high performance during its lifetime and be suitable for effective separation and recycling. There is a high need for research activities to develop both drop-in materials with prolonged durability and assured recyclability, and development of degradable packaging with selected lifetime appropriate for the use of the application and subsequent waste management including collection, sorting and disposal.

5 Development of Agenda

Text on the process of the agenda development and the connection to the NEW InnoNet project to be added.

6 Acknowledgement

To be added

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