NewInnoNet

The Near-Zero European Waste Innovation Network

HORIZON 2020 | CSA| WASTE-4a-2014| Grant Agreement No. 642231

Start date of project: 2015/02/01 **Duration:** 30 Months

Identifier:	**D5.3 Final Integrated Strategic Innovation and Research Agenda**
Date:	**2017/06/30**
Class:	**Deliverable**
Responsible Partner:	**IVL Swedish Environmental Research Institute**
Annexes:	**5 (A-E)**
Distribution:	**PU (public)**
Title:	**Unleashing the power of secondary materials: A strategic research and innovation agenda for effective material recycling from ELV, WEEE and plastic packaging waste streams**

The project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement no 642231

NewInnoNet

Unleashing the power of secondary materials: A strategic research and innovation agenda for effective material recycling from ELV, WEEE and plastic packaging waste streams

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 642231

Executive summary

To pave the way towards a circular economy with less environmental impact, all sectors of economy as well as administrations and consumers must be mobilized. The European Union's economy loses a significant amount of raw materials in current waste streams, due to inadequate collection performance, inadequate sorting and recycling performance, lack of appropriate market drivers and gaps in product design for circularity. In addition there is a need for more policy and legislation instruments to promote the circular economy.

Purpose of the agenda

The purpose of this agenda is to provide guidance for EU policy makers regarding needs in research and innovation to support material recycling towards and within a circular economy. The research and innovation actions in the agenda address existing bottlenecks identified during the NEW_InnoNet project and thus suggest first steps to initiate the paths towards more circular value chains as identified in the project's roadmap exercise. In this way, the actions suggested will contribute to reduce the loss of valuable materials and stimulate more and better material recycling for end-of-life vehicles (ELV), waste electrical and electronic equipment (WEEE) and plastic packaging waste (PPW).

The main addressees of this agenda are EU policy makers working in the research and innovation field. However, we hope that the agenda will also inspire other stakeholders to focus on the identified actions and stimulate innovation towards a near zero waste objective for the three waste streams in question.

Scope

The agenda targets material recycling for end of life vehicles (ELV), waste electrical and electronic equipment (WEEE) and plastic packaging waste (PPW). It is important to stress that material recycling is only one piece of many needed to complete the jigsaw puzzle of a circular economy. Prevention, minimization and reuse of products and components should be prioritized over material recycling, but it is necessary to ensure that material recycling can address the remaining amounts of waste. In the first place, because the time lag between production and discharge of products results in high quantities of materials in society that are not yet designed for circularity, in the second place, because recycling technologies need to be aligned with the new (circular) product designs. With the emphasis on material recycling, the agenda also covers collection, sorting and design of new products (see Figure 1), all of which have a direct impact on recycling performance.

The agenda focuses on technology, but also on the market for secondary raw materials, and policy and design issues as enablers for the achievement of the vision are considered. The research and innovation actions proposed in the agenda are designed to support the ambitions of the Circular Economy Package and other EU initiatives.

Vision: Unleashing the power of secondary materials

This agenda envisions a circular economy in Europe by the year 2030. On this time horizon the potential of recycled materials is fully unleashed by achieving high rates of materials recovered from ELV, WEEE and PPW and the use of recycled materials as quality input for various applications, including high-grade applications.

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

Key research and innovation themes supporting the vision

The following five research and innovation themes have been identified as key contributors supporting the vision specified for the Agenda:

Effective collection

Effective collection concerns having appropriate, easily available and cost-effective collection systems where user behaviour has been taken into consideration. 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.

Optimized sorting and recycling

To optimize recycling of materials, the realization of effective and flexible sorting and recycling techniques adapted to process discarded products entering the end-of-life chain is necessary. In addition losses are minimized, removal of hazardous materials and components is efficient and a minimum loss in quality of the recovered materials is achieved.

Well-functioning market for recycled raw materials

A well-functioning market and economy concerns the ***accomplishment of an effective and established market including innovative business models for recycled materials*** able to compete with virgin raw materials as well as with landfilling and energy recovery. A well-functioning market also concerns the absence of noncompliant actors and the illegitimate handling of recycled raw materials.

Supporting policies and legislation

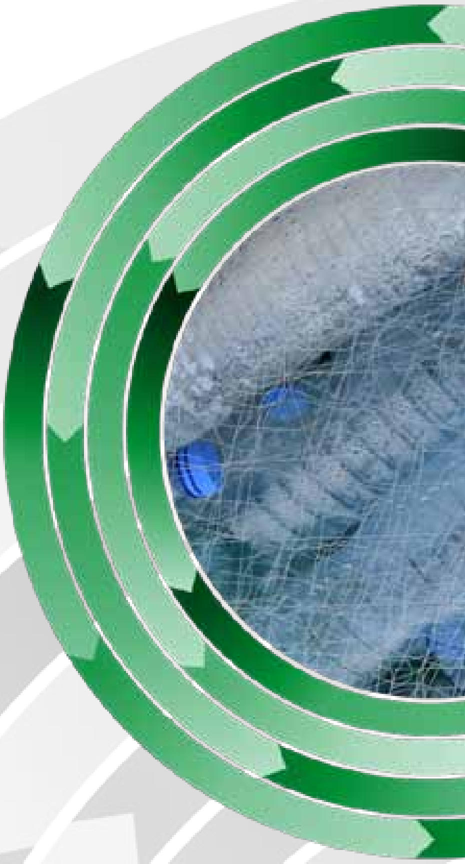
Supporting policies and legislation are needed to stimulate material recycling and their secondary utilization. This also concerns harmonized legislation and policies and the enforcement of these to create fair conditions and a well-functioning market throughout the EU, and ideally globally. It also includes effective monitoring, with shared methods for measuring overall legislation performance and fulfilment, such as recycling rates (based on output) for different value chains to actualize transparency and credibility for stakeholders.

Design for circularity

Design for circularity concerns ***developing products for which the end-of-life treatment has already been taken into consideration in the product design phase***, as well as ***the active inclusion of recycled materials in product designs.*** This will result in high recycling efficiency with minimum losses in the recycling chain and also enable high-grade applications for recycled materials. Important aspects to consider include, for example, the choice of materials and how these materials are combined, consumer preferences, identifiability and the accessibility of hazardous parts, components and fasteners etc.

Research and innovation actions needed

For each of the above research and innovation themes a set of dedicated actions is proposed to deal with various technological and non-technological aspects. The themes and corresponding actions are presented in Figure S1.



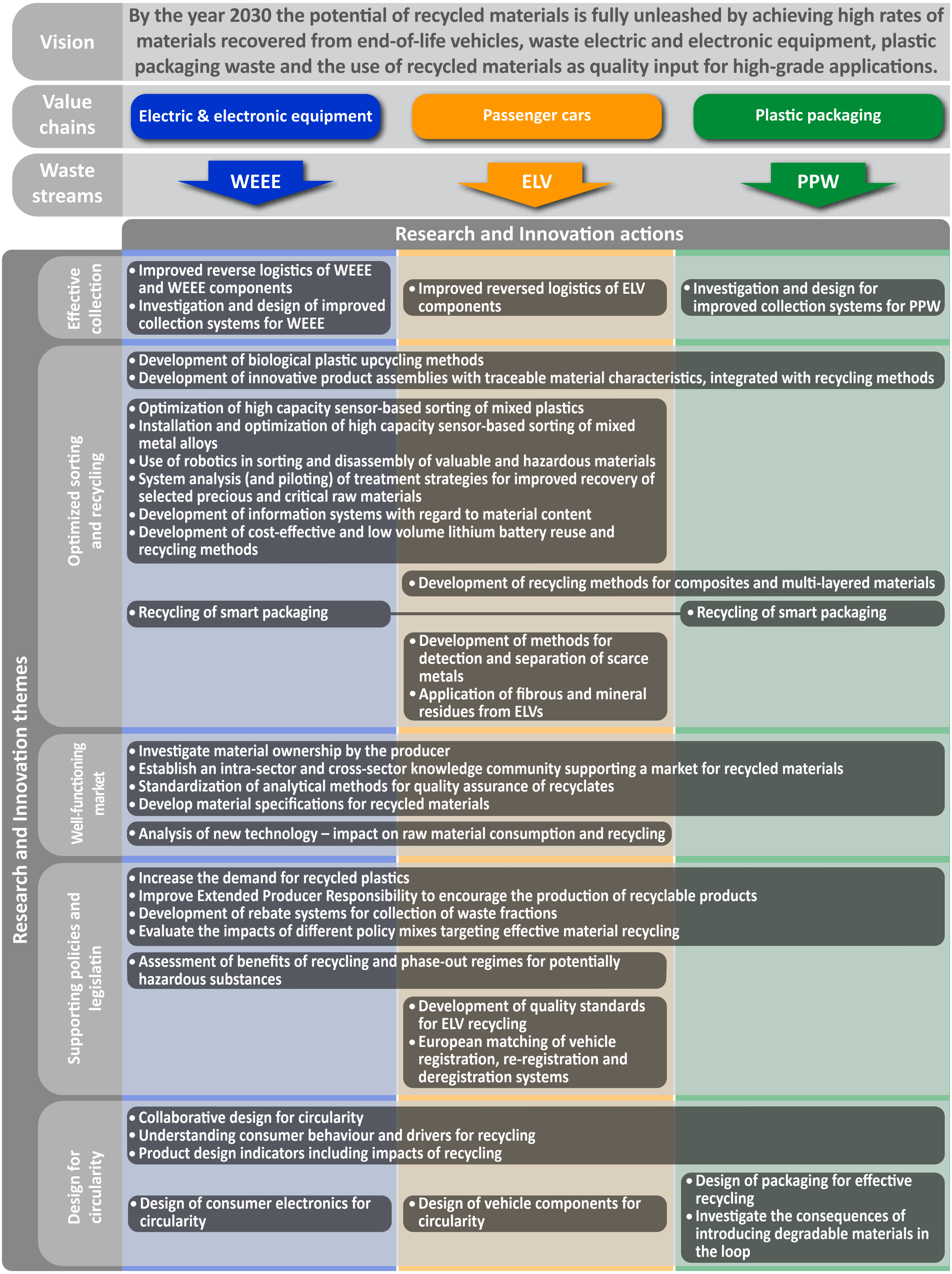


Figure S1:SRIA - themes and corresponding actions

Contents

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

In 2013, total waste generation in the EU amounted to approximately 2.5 billion tonnes, of which 1.6 billion tonnes were not reused or recycled (European Commission, 2015a). Also, a considerable part of the recycling was downcycling to lower quality materials. Increasing competition for raw materials and the ambition to become more independent and self-sufficient means that there is a need for developing sustainable solutions for recycled materials (more materials and of higher quality), as well as for keeping the materials in loops within the EU whenever possible and effective.

In recent years, a heightened awareness of waste management issues at the EU level and a striving towards a more circular economy has led to an increased focus on the end-of-life of 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 communicated from the Commission in December 2015 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 recycled raw materials (European Commission 2016a).

In addition, revised legislative proposals on waste were put forward in December 2015 regarding the Directive on Waste (2008/98/EC), the Directive on Packaging Waste (94/62/EC), the Directive on Landfill (1999/31/EC), the Directive on electrical and electronic waste (2012/19/EU), the Directive on batteries and accumulators and waste batteries and accumulators (2006/66/EC) and the Directive on end-of-life vehicles (2000/53/EC). A revision of waste legislation is currently under discussion, setting long-term recycling targets for municipal waste and packaging waste. Long-term targets are also being revised to reduce landfill and general requirements for extended producer responsibility schemes have been suggested.

In the area of production, the Commission will use the Ecodesign directive to promote increased circularity. Here, there is an increased focus on electronic products. In the area of consumption new or revised criteria will emphasise circular economy aspects. In order to support the market for recycled raw materials in the action plan the Commission suggests initiatives to develop quality standards for recycled raw materials, and proposes improvements to "end-of-waste" regulation. Furthermore, the Commission will act on the interface between chemicals, products and waste legislation. Also, the Raw Materials Information System will be further developed and research on raw material flows will be supported according to the action plan (European Commission, 2017). Priority areas in the action plan include plastics and critical raw materials, as well as biomass and bio-based products.

This research and innovation agenda has been developed within the EU financed (EU 2020) project NEW_InnoNet (Near-zero European Waste Innovation Network) in close collaboration with the registered stakeholders of the project.

1.1. Scope

The agenda addresses research and innovation (R&I) crucial to 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 maintain the value of materials through improved material recycling from waste and the stimulation of the recycled raw materials market, with an emphasis on metals and plastics. The three addressed value chains provide good examples of the challenges of implementing the circular economy concept. The three waste streams are continuously increasing. Cars and electric and electronic equipment are increasingly complex products and the materials used in their construction change frequently. The waste streams from these product groups are considerable. PPW is the largest waste stream from plastic use, which is continuously growing and developing through new design and material selection, and have very short life cycles.

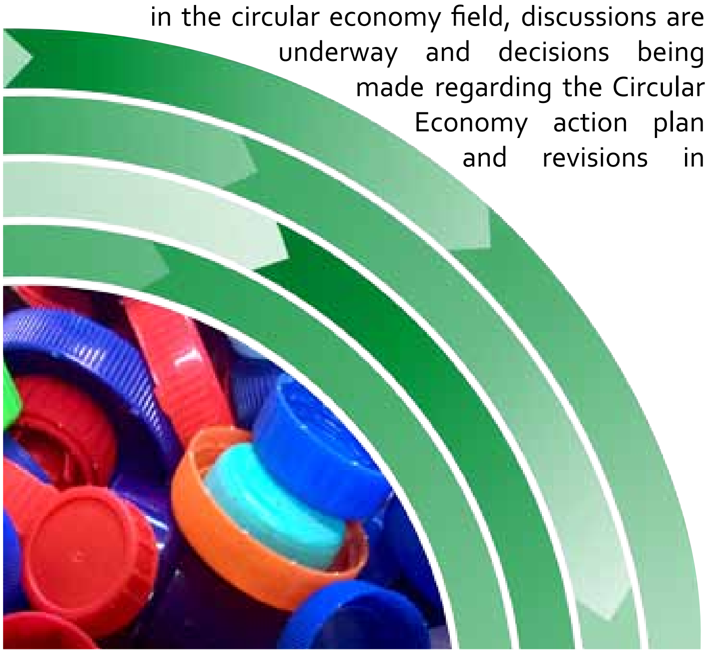
The agenda focuses on material recycling, with the ambition of maintaining the value of materials recovered and providing a market for them. This is only one piece of many needed for the overall jigsaw puzzle of a circular economy and for moving towards a near zero waste Europe. In line with the waste hierarchy, prevention, minimization and reuse of waste should be prioritized over material recycling. However, it is necessary to ensure that the waste that is generated is recycled in the most efficient way. This is the scope of the agenda.

waste legislation. 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 on materials recycling related to three important waste streams: ELV, WEEE and PPW.

In terms of current policies related to materials, resources and circular economy the agenda fits in well, due to the

Figure 1:Scope of the Strategic Research & Innovation Agenda

As this agenda is being written there is considerable activity in the circular economy field, discussions are underway and decisions being made regarding the Circular Economy action plan and revisions in



fact that these initiatives point to higher collection and recycling rates as one of several key factors to stimulate circular economy.

With its emphasis on material recycling, the scope of the agenda also covers waste collection and sorting, as these steps to a large extent determine materials recycling performance. Technological issues are highlighted, however, market, policy and design issues have also been considered as crucial enablers for achieving the vision.

The main target group of the agenda is EU and national level policy makers responsible for the development and implementation of innovation and research policies addressing the materials and waste streams in focus.

The agenda is a collaborative effort involving recyclers, producers, sector organizations, public authorities and academia, with the overarching goal of strengthening European industry in taking the lead for a more materials-efficient future.

1.2. Purpose

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

1.3. From bottlenecks via roadmaps and stakeholder engagement to research and innovation actions

The agenda presents research themes and a set of research and innovation actions for each theme. The work with the agenda is to a large extent based on previous work in the NEW_InnoNet project; the three value chains (NEW_InnoNet 2016a; 2017a; 2017b), bottlenecks identified (NEW_InnoNet 2016b) as well as pathways described in roadmaps for the studied waste streams.

Bottlenecks and research themes:

The structure of the agenda was defined after a review of other research and innovation agendas and discussions within the partner consortium. The decision was to make an agenda focusing on the results to be achieved in a set of areas – the research themes which support the overall vision of the agenda. Also, the aim was to provide a set of detailed suggestions of prioritized actions for each theme respectively. This in order to make the agenda more operational and less of an overview.

The research themes cover the scope of the agenda in a broad sense and also relate to the bottlenecks identified for each of the three value chains (NEW_InnoNet 2016b). A first step of grouping the bottlenecks had already been taken previously, and based on this the review of other agendas and discussions within the partner consortium the strategic research and innovation agenda (SRIA) research themes were defined.

Roadmaps and R&I actions:

The bottlenecks have also formed the basis for the roadmaps where transformational pathways and solutions were generated based on stakeholder consultation and engagement. The roadmaps are based on common visions addressing the value chain bottlenecks. Transformational pathways towards the visions were concretissed in collaboration with stakeholders in workshops. The roadmaps identified relevant actors in the value chain and indicated a time perspective and technology readiness level (TRL) for the actions to be taken. These actions have been used as a basis for the research and innovation actions detailed in the agenda.

Research and innovation actions were concretised and detailed for the agenda based on the transformational pathways in the roadmaps. As an example, the coordination and support action E.1 Collaborative design for circularity suggested under the theme Design for circularity was derived from the ELV Economy pathway, ideation on cooperation between producers and recyclers, and Strategic objective on promoting circular design among product developers. Another example is the research and innovation action B.9 Development of recycling methods for composites and multi-layered materials suggested under the theme Optimised sorting and recycling, which was derived from the PPW roadmap, where it was presented as a Technological and scientific action.

Stakeholder engagement and R&I actions:

The description of the R&I actions for the agenda was done in close collaboration with the task leaders of the bottleneck analysis and roadmap developments, and also in an iterative process involving other project partners and stakeholders. The first draft list of R&I actions was prepared within the partner consortium, based on the actions and ideations of the roadmaps, as exemplified above. Actions that were not considered relevant as research and innovation actions were not included, some of these are considered in the policy brief (NEW_InnoNet 2017c). A list of proposed actions, was distributed to the NEW_InnoNet registered stakeholders as well as other identified organizations throughout Europe working in the field who were encouraged to contribute at four different levels:

1. *Evaluate R&I actions*
2. *Suggest other R&I actions*
3. *Provide feedback on suggested actions*
4. *Provide feedback on full text*

For the evaluation of actions a scale from 1 "very important (urgent) to carry out" to 4 "irrelevant – discard" was used. Each R&I action could be given a score, and several actions could be given the same importance. At the same time input regarding the addressed waste streams for the action as well as the time frame suggested was requested. For new suggestions the same format as for the other actions was requested, a suggestion just including a headline for the action was not an option, but elaborated proposals were necessary.

The evaluation of the R&I actions in the draft indicated that all actions were regarded as very important or important at least by some stakeholder. As the comments from stakeholders were not weighed against each other, all of the actions were kept. Generally all actions were given high evaluations. The actions have not been ranked against each other.

A second opportunity to provide feedback on the agenda was given to registered stakeholders, the project advisory board and EU policy makers. This time contribution was possible in four different ways:

1. *Comment and complement the R&I actions in the agenda*
2. *Add R&I actions*
3. *Give feedback on the structure and readability of the agenda.*
4. *Provide feedback on full text*

Comments from this stakeholder iteration pointed to needs for further clarification and more detail in the actions in the draft. This was acted upon.

Validation and alignment with existing EU-initiatives:

The drafting of the NEW_InnoNet SRIA is not a standalone project. It is embedded in a policy framework regarding waste, circular economy and sustainability, which is supported by several funding programmes. The Horizon 2020-programme and its predecessors, for example, have been a major force in promoting European research and innovation in both industry and SMEs. It is important to take into account these policy- and funding programmes when making recommendations for future research and innovation priorities.

The final list of actions was therefore validated with relevant EU initiatives in research, programmes and projects. The Circular Economy Action Plan, Horizon 2020's relevant Work Programmes current projects and The European Innovation Partnership on Raw Materials Strategic Implementation Plan was considered. This enabled the prevention of any duplication and the actions are described in a way to synergize with existing initiatives and projects (where relevant).

More details on the agenda research themes and respective research and innovation actions are given in the following chapters.

Facts & figures about End-of-Life Vehicles

12M

passenger cars were taken into use within the EU in 2013

(Eurostat, 2015)

6M

passenger cars were scrapped in 2013

(Eurostat, 2016a)

Material composition of passenger cars

non-metals **25%**

iron & steel **>50%**

non-ferrous metals **<25%**

The material content in passenger cars varies depending on type of car, age, propulsion system etc. Today's vehicles consist of about 75% of metals with steel and iron contributing to the greatest share followed by non-ferrous metals such as aluminium, copper, zinc and magnesium (ARN, 2015). The non-metals are mainly plastics, rubber, fluids and glass. Growing use of electronics has led to increased use of precious and rare earth metals such as gold, neodymium and dysprosium.

85 - 95%

Of the discarded passenger cars, the material recycling and reuse rate amounts to 85-95% for most countries within the EU (Eurostat, 2016b).

TARGET → **The reuse and recovery rate of discarded vehicles (ELVs) shall amount to at least 95% of weight, of which at least 85% shall be reused or material recycled according to the ELV Directive 2000/53/EC.**

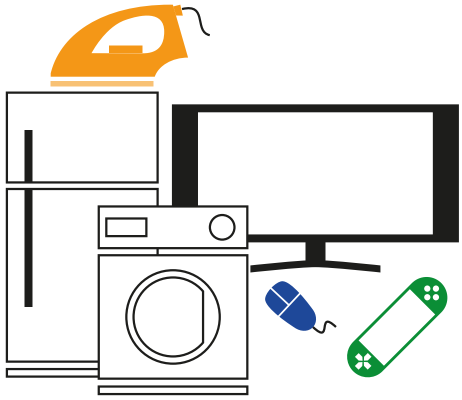
Losses

Due to their net economic value an unknown but significant number of ELVs are not sent to an authorised treatment facility but to non-compliant actors as an unregulated and illegal export.

Facts & figures about Waste Electric & Electronic Equipment

~ 9Mt

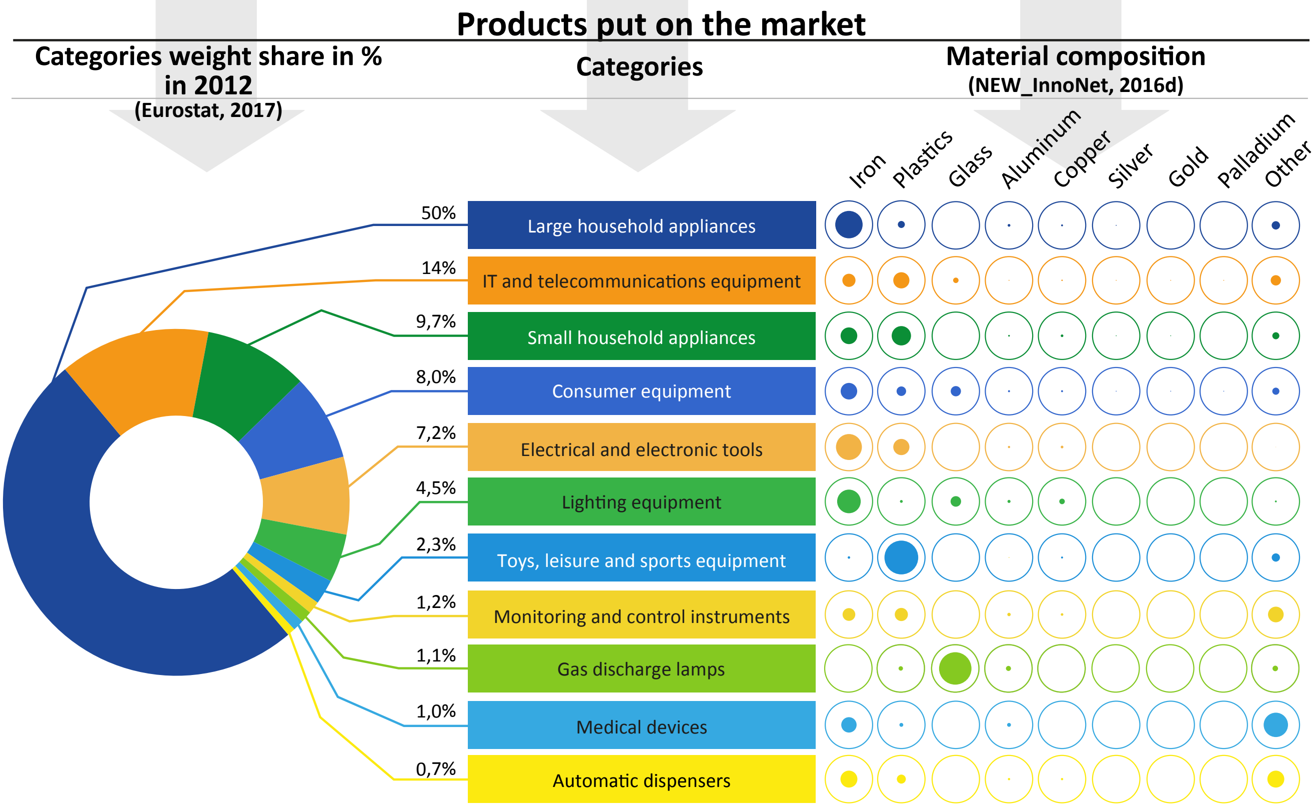
of electrical and electronic equipment (EEE) was put on the market in the EU in 2012
(Eurostat, 2016c)



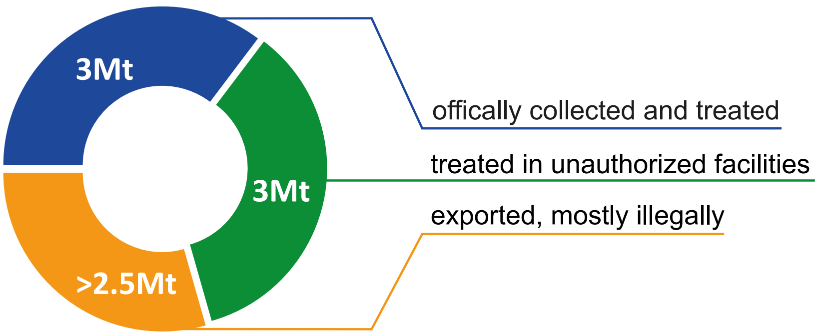
~ 9Mt

of WEEE was discarded by consumers, businesses and governmental agencies across Europe in 2012
(European Commission, 2014)

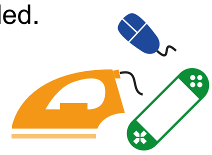
WEEE is an extremely heterogeneous waste stream in terms of materials composition including for example: base metals, precious metals, rare earth metals (REMs), engineering plastics, other organics, hazardous substances (brominated flame retardants, lead, beryllium, arsenic), glass, ceramics (Hagelüken, C. & Corti, C., 2010)



What happens to the 9Mt WEEE scrapped? (CWIT, 2015)

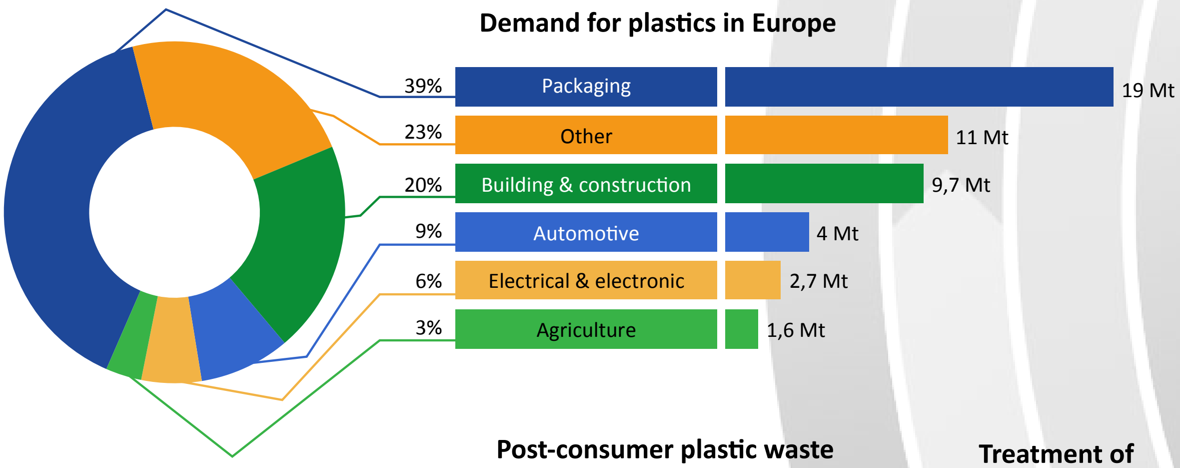


A part of the waste, mainly consisting of smaller WEEE appliances, ends up in the municipal solid waste (MSW) and is either incinerated or landfilled.

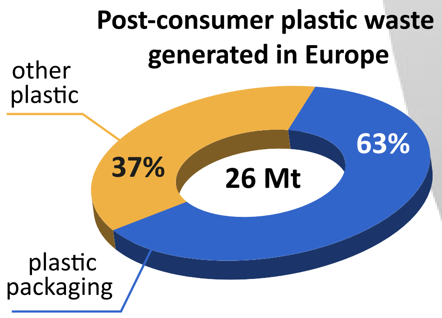


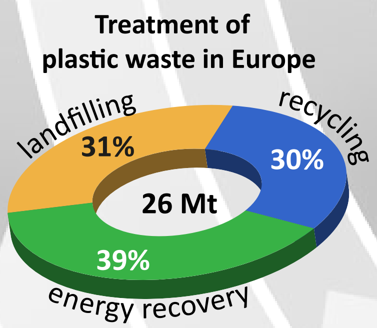
Facts & figures about Plastic Packaging Waste

Packaging is the largest application sector for the plastics industry, representing about 40% 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.

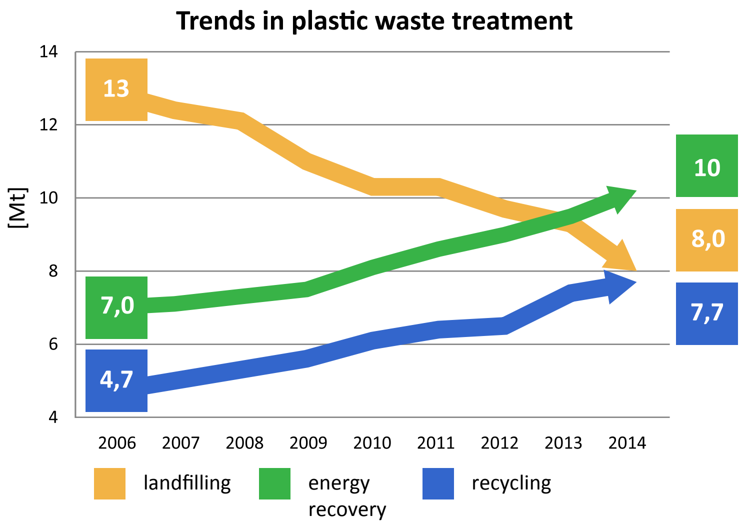


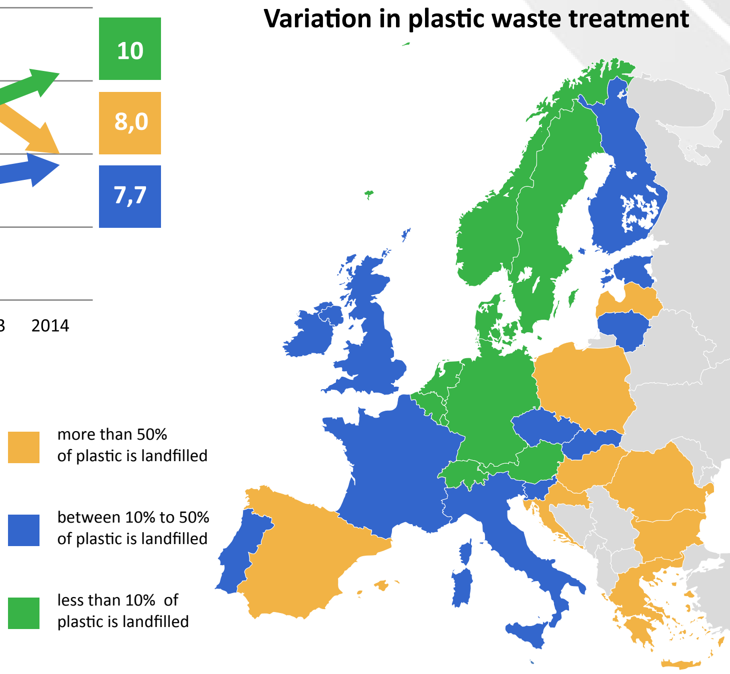
In 2014, about 26 million (Plastic Europe, 2015) tonnes of post-consumer plastics were generated, of which 16 million tonnes (63%) were plastic packaging (Hestin, M., Faninger, T., Milios, L., (2015)). The collection rate of plastics differs throughout Europe.





Due to technical as well as economic bottlenecks the recycling yield of the material sent for recycling is on average 73% (Hestin, M., Faninger, T., Milios, L., 2015), and the 27% shortfall is used for energy recovery or landfilling. The recycled materials are used in a vast variety of products, generally those that have limited mechanical property requirements in the final application.





Landfilling is still the dominant treatment method of plastic waste in the Eastern and Southern parts of Europe where countries are largely exempted from waste landfill restrictions. Countries in the Northern parts of Europe have banned the landfilling of the organic/combustible waste.

2. Towards the vision – Research and innovation themes and research and innovation actions needed

2.1. Vision - Unleashing the power of recycled materials

This agenda envisions a circular economy in Europe by the year 2030. On this time horizon the potential of recycled materials is fully unleashed by achieving high rates of materials recovered from end-of-life vehicles (ELV), waste electric and electronic equipment (WEEE), plastic packaging waste (PPW) and the use of recycled materials as quality input for high-grade applications.

This is achieved through technological solutions, supported by societal measures, new infrastructures, and improved transnational collaboration and by new, sustainable business models.

2.2. Research an innovation themes and actions

To reach the vision of achieving high rates of materials recycled with minimum losses in quality from ELV, WEEE and PPW there are five research and innovation themes that should be prioritized. For each theme the current situation and main challenges for each of the three studied waste streams have been identified and relevant research and innovation actions defined, this is illustrated in the Figure 3.

Effective collection

Effective collection concerns having appropriate, easily available and cost-effective collection systems where user behaviour has been taken into consideration. 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.

Optimized sorting and recycling

To optimize recycling of materials, the realization of effective and flexible sorting and recycling techniques adapted to process discarded products entering the end-of-life chain is necessary. In addition losses are minimized, removal of hazardous materials and components is efficient and a minimum loss in quality of the recovered materials is achieved.

Well-functioning market

A well-functioning market and economy concerns the accomplishment of an effective and established market including innovative business models for recycled materials able to compete with virgin raw materials as well as with landfilling and energy recovery. A well-functioning market also concerns the absence of noncompliant actors and the illegitimate handling of recycled raw materials.

Supporting policies and legislation

Supporting policies and legislation are needed to stimulate material recycling and their secondary utilization. This also concerns harmonized legislation and policies and the enforcement of these to create fair conditions and a well-functioning market throughout the EU, and ideally globally. It also includes effective monitoring, with shared methods for measuring overall legislation performance and fulfilment, such as recycling rates (based on output) for different value chains to actualize transparency and credibility for stakeholders.

Design for circularity

Design for circularity concerns developing products for which the end-of-life treatment has already been taken into consideration in the product design phase, as well as the active inclusion of recycled materials in product designs. This will result in high recycling efficiency with minimum losses in the recycling chain and also enable high-grade applications for recycled materials. Important aspects to consider include, for example, the choice of materials and how these materials are combined, consumer preferences, identifiability and the accessibility of hazardous parts, components and fasteners etc.

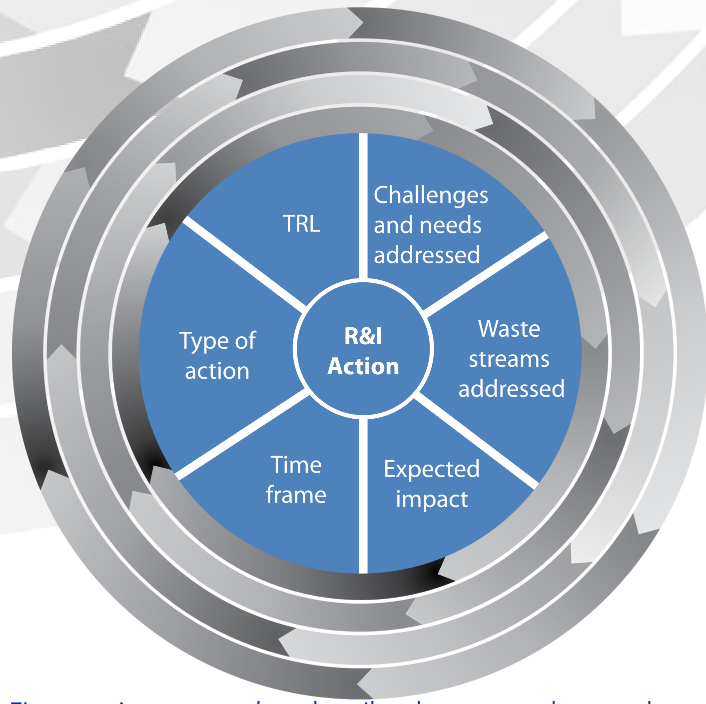


Figure 2: Aspects used to describe the proposed research and innovation actions

Based on the current situation and the challenges identified for each research and innovation theme, required actions have been identified. These are described in detail in the following chapters.

Figure 2 presents aspects used to describe each of the proposed research and innovation action. The R&I action and the needs it addresses are presented, as well as the challenges it faces. Expected impact describes the positive effects foreseen when the suggested research and innovation action is implemented – and possibly commercialized and implemented on a large scale.

The time frame is 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, this indicates maturity i.e., how close to commercialization a technology has come. The TRL has a scale from 1 to 9 with 9 being the most mature technology.

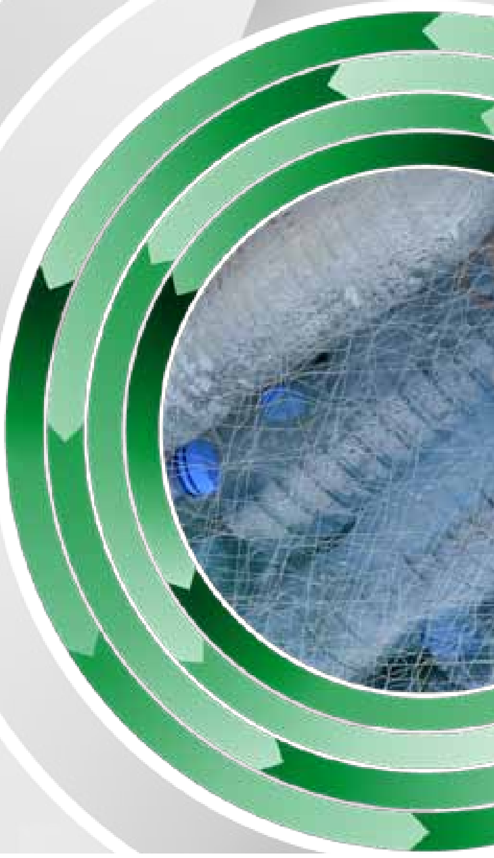
For each action relations to ongoing EU initiatives, the Circular Economy Action Plan, Horizon 2020's relevant Work Programmes and The European Innovation Partnership on Raw Materials' Strategic Implementation Plan are briefly presented. The actions suggested may support certain parts of the EU CE action plan and if this is the case this is pointed out. An action may actually be addressed in Horizon 2020 or the European Innovation Partnership on Raw Materials' Strategic Implementation Plan, but as the challenge has not been solved at the time of writing the action is still proposed, but with a note that ongoing activities and their results need to be taken into account when launching the action. In addition, current FP7/H2020 which are related to the suggested R&I actions are also noted.

Table 1 below lists the different types of actions presented in the agenda, based on the typology used in 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	CSA	accompanying measures (standardization, dissemination, policy dialogues etc.) no research
SME Instrument	SME	combination of demonstration activities (testing, prototyping, etc.), market replication

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

The research and innovation actions are shortly presented in tables in the following chapters for each respective research theme, and more in detail in the appendix.



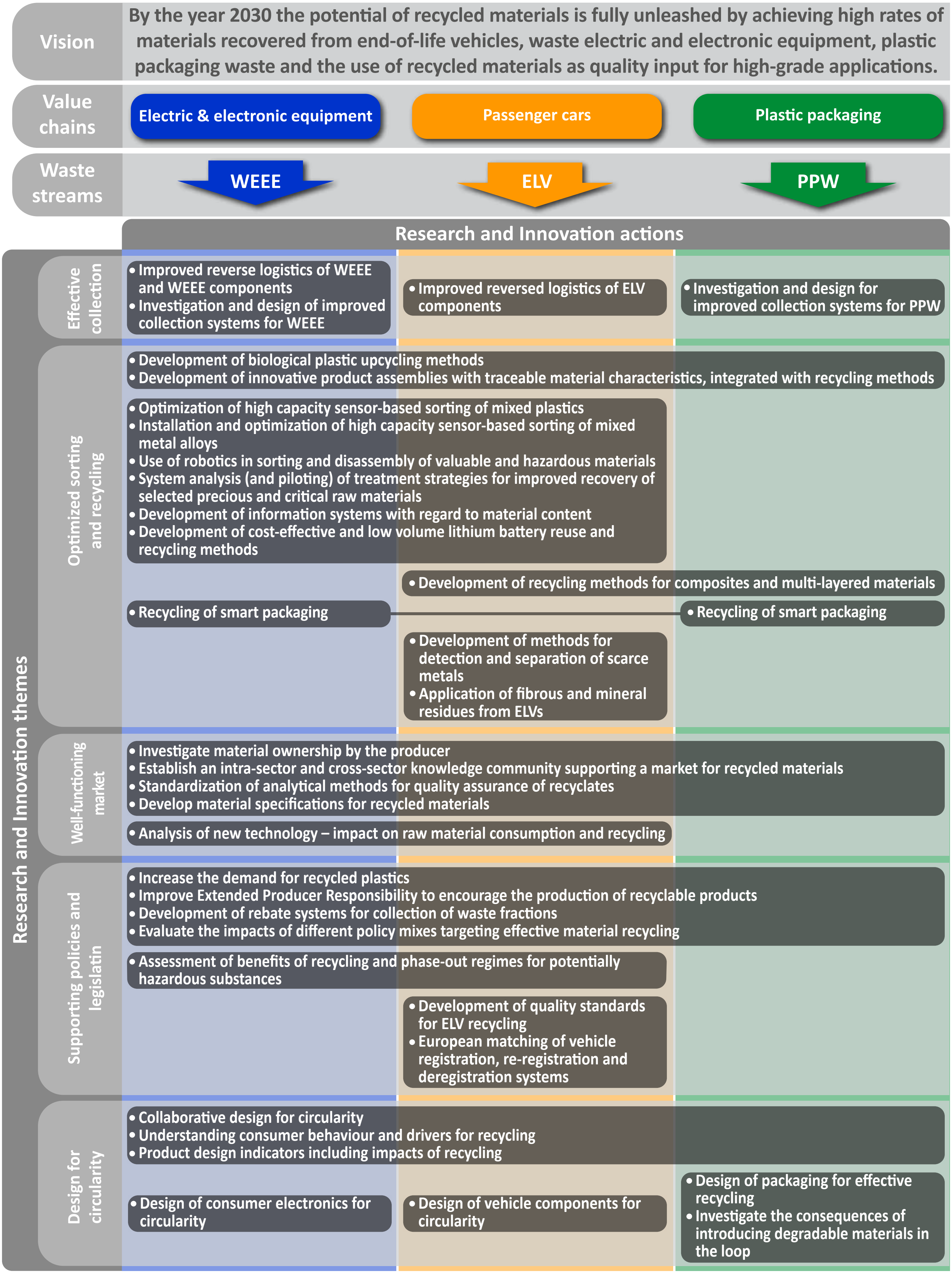


Figure 3:SRIA - themes and corresponding actions

3. Effective collection

3.1. Current situation and challenges

3.1.1. 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 to the manufacturer without incurring any cost. For transport of end-of-life vehicles when needed, the collecting actor has the right to charge for services provided.

Inadequate performance and collection monitoring are the principal challenges facing ELVs. As ELVs possess a net economic value, ineffective (de-)registration measures may result in ELVs not being delivered to authorised treatment facilities, but instead 'leaching' to noncompliant actors and unregulated and illegal export. Today there is a lack of Europe-wide harmonization of regulations, poor governance and ineffective enforcement of regulations. For example, there is today no binding European vehicle registration system, making it difficult to track vehicles. As a consequence this impacts the quantities available for recycling in Europe and adversely affects profitability and employment in the authorized recycling industry. The challenge of monitoring of legislation fulfilment is handled under the theme of policy and legislation.

Another challenge is the recycling industry's adaptation to the expected change in materials content 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 non-existent. In addition, the recycling of critical raw materials from electronics and other small components, plastics, would require a new kind of systemic thinking, such as the effective transport and logistics of the separated components from the high number of dismantlers (mainly SMEs) to centralized recycling plants.

The lack of uniform and transparent reporting methods among Member States is another challenge, which means that it is difficult to make comparisons within the EU. This is well understood in the Circular Economy Package that specifically recommends the use of monitoring protocols instead of 'recycling rates'. In a similar vein, the Environment Directorate-General commissioned a public study on the whereabouts of end-of-life vehicles, as well as on calculation methods (Oeko-Institut, 2016).

3.1.2. WEEE

Member States within the EU have implemented and established the WEEE Directive (2012/19/EU) differently. This is due to differences in EEE consumption patterns, administrative structures, historic development of WEEE management, waste legislation, standard of living, technical infrastructure and the level of consumer involvement. The way things are organized per country is mostly based on population density and the implementation of technology. This may occasionally vary between regions within a particular country. Today, WEEE is collected through take-back systems, collection points in stores or collection centres often managed by municipalities.

The key challenges in the WEEE chain are low (officially reported) collection efficiencies, challenges in monitoring and a significant variation between EU Member States.

A large amount of WEEE is not sorted but instead discarded as municipal solid waste (MSW), and either incinerated or landfilled. In addition significant amounts are stored by end users. According to the European Commission (2014), reported collection rates in 2010 and 2012 were over 50 per cent of the estimated total amount of WEEE in only four Member States, and over 40 per cent in only seven Member States. Over 25 per cent of the total WEEE is estimated to be illegally exported and about 30 per cent ends up at non-compliant treatment plants (CWIT, 2015). Achieving the minimum collection targets (45 per cent of EEE put on the market from 2016 to 2018 and 65 per cent from 2019) will be a challenge for many countries.

The current situation calls for the development of tracking systems enabling better monitoring of the fate of waste electronics, but also for the identification and deployment of elements leading to good practices. In addition the current situation calls for raising the awareness of end users on the correct disposal of WEEE.

3.1.3. PPW

To reach set targets different collection systems have been introduced among EU Member States, including curbside collection, bring site collection, deposit/refund systems, recycling centres, civic amenity sites and privately organised on-site collection for the industrial and commercial sectors. 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 may be different collection schemes in force in different regions or cities, while sometimes parallel collection systems co-exist in the same location.

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

Another major challenge for PPW at the collection stage is the heterogeneity of collected plastics due to use of several different plastics and composites in packaging products, and the complexity and cost of source separation of different materials. Contamination of the collected packaging (food residues and other materials) is an additional obstacle at the collection stage, increasing recycling costs and leading to a diminished product quality. More information and awareness raising for consumers is necessary to facilitate efficient collection for recycling (NEW_InnoNet, 2016a)

3.2. Research and innovation actions needed

Research and innovation actions that address challenges identified in connection with collection of the three waste streams are proposed. These focus the further development of collection systems for the waste streams including the design of systems that take into account the needs of producers that will use the recycled material, as well as the behaviour of consumers using the collection system. In addition, awareness raising and the dissemination of knowledge on best practices are addressed. Another collection challenge refers to the reverse logistics of the components gained in the treatment processes.

Table 2 presents an overview of research and innovation actions proposed for the theme Effective collection, a more detailed presentation of each of them is given in the appendix.

Section	Research and innovation action	Relevant waste streams	Type of action	Time frame
A.1	Improved reverse logistics of ELV components	ELV	IA	5-10 years
A.2	Improved reverse logistics of WEEE and WEEE components	WEEE	IA	5-10 years
A.3	Investigation and design of improved collection systems for WEEE	WEEE	RIA, CSA	5-10 years
A.4	Investigation and design for improved collection systems for PPW	PPW	RIA, CSA	5-10 years

Table 2: Overview of key research and innovation actions related to Effective collection.

4. Optimised sorting and recycling

4.1. Current situation and challenges

4.1.1. ELV

Recycling systems and technologies for bulk metals, such as steel, iron, aluminium and copper in ELVs, reached maturity many decades ago and scrap metal has become a vital element in new production.

After the shredding of the depolluted bodywork, and the subsequent sorting processes, the metal ends up in smelters as raw material. However, due to deterioration in the quality of recycled bulk metals, it may be necessary to add virgin metal or to refine the recyclate, especially when producing materials destined for use in high-quality applications. This may be due to complex material composition or technical or economic constraints in the recycling process. Except for catalysts, the material recycling of rare metals used in lower concentrations and in specific vehicle components such as electronics, is practically non-existent today. Instead, these are generally dispersed in the bulk metals or in the shredder residues in which their properties are lost. The reason for this is that the rare metals are only used in small quantities and the shredding technology is not designed to separate and recover them. In addition it is difficult to compete with virgin materials.

In general, plastics components and partially car glass are generally not dismantled and instead end up in the shredder residue, which is treated differently in different parts of Europe. In many countries the residue is incinerated. In central Europe the shredder residue is further mechanically processed and sorted, and in some sophisticated post-shredder plants sellable recycled plastics are extracted. However, the technological and economic challenges are immense as recycled plastics (from post-shredder separation) have major shortfalls in quality and thus in price. Besides mechanical processing, chemical recycling of the shredder residue e.g., gasification, takes place in some European countries.

As regards the ferrous shredder scrap, foreign materials such as copper are dissolved in the steel and included in the steel product. An increasing copper content can have a particularly negative effect on the recyclability of steel, since it can restrict its use, e.g., to structural steels.

The introduction of new and more complex materials as a result of electrification, miniaturization and increased comfort requirements as well as new material developments such as high-strength steel, metal and non-metal composites, but also new refrigerants in air conditioning systems, etc., requires more sophisticated ELV sorting and recycling processes. To face these challenges the recycling industry also need more information about the different materials being used in vehicles, irrespective what the source of this information might be. Complexity of construction and the widespread use of new non-metallic and metallic lightweight materials and electronically connected parts, are making the depollution, dismantling and reuse of components and even the shredding more challenging and less profitable in comparison with today's conventional vehicles.

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

The introduction of new and more complex materials also affects the viability of dismantling for recycling and the performance of sorting, separation and recycling technologies. Challenges include development of cost-effective recycling solutions for lightweight composites as well as plastics and glass; 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 across the whole treatment chain. In addition, the electrification of vehicles induces new recycling needs, such as the recycling of fuel cells and new types of rechargeable batteries. The complexity of depollution also increases (e.g., new refrigerants, new liquids like AdBlue).

Since 2015, the recovery target of end-of-life vehicles (ELVs) shall amount to at least 95 weight per cent, of which at least 85 per cent shall be reused or material recycled in accordance with ELV Directive, 2000/53/EC. As the proportion of non-metals and non-ferrous metals successively increases, achieving set targets may be challenging in the future. Other challenges for reaching the recycling target are the strict limitations with regards to POP materials (e.g., brominated flame retardants, e.g., DecaBDE[1]), which make the material recycling of plastics from ELVs more complicated.

4.1.2. WEEE

WEEE is handled differently across Europe. In countries where labour costs are cheap, manual dismantling still dominates. In countries with high labour costs, automated sorting facilities are typically used. Manual intervention is only utilized for the removal of hazardous parts prior to mechanical shredding and subsequent automated sorting.

For mechanical sorting facilities smaller WEEE appliances from which hazardous components have been removed are processed in a WEEE shredder smaller in size than an ELV shredder. Larger WEEE appliances such as washing machines or stoves are sent to bigger shredders that are also used for ELVs and other metal scrap. Refrigerators as well as lamps have their own specific treatment processes. After shredding, the output material is sorted based on physical and chemical properties, such as magnetism, density, conductivity, colour or composition. 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, etc., are sent to smelters or for materials recycling. Recyclable plastics are also sent for materials recycling, whereas brominated plastics are sent for disposal or incineration. WEEE shredding generates a fine fraction that contains inert materials such as glass etc., as well as valuable metals. For this reason this fraction is often sent to smelters. In addition to glass from screens other common fractions generated during WEEE processing include concrete from washing machines and insulation foam from refrigerators.

The development of cost-efficient processing chains for complex products with variable materials composition and low concentrations of critical and valuable materials per application or component, is a challenge when it comes to electronics recycling. This has led to the optimization of the recycling processes for materials that are technically and economically most feasible for recovery. Other valuable materials, such as most of the critical raw materials and plastics end up in disposal fractions, are used in lower grade applications or in some cases exported. In addition

1) Bis(pentabromophenyl)ether

miniaturization, the minimization of devices, appliances and components has led to decreased amounts of valuable materials per application, which makes it necessary to intensify the recycling of individual materials to increase economic feasibility. Another challenge is tracing the materials composition of devices and components to enable more efficient separation. Unwanted (e.g. wood, rubber) as well as hazardous substances, such as brominated flame retardants and hazardous plasticizers in technical plastics also hamper material recycling as they have to be separated and removed from the materials cycle.

Another permanent challenge is the fast changing composition of EEE due to new technical developments, which may lead to completely new types of products (e.g. smart clothes) or new generations of devices such as TV and computer screens which have developed from CRT[2] displays to LCD-CCFL[3] (with Hg) to LCD-LED[4]). Therefore, the treatment processes permanently have to be adapted to the new input materials. Information on the composition, on the localisation of hazardous and valuable components is crucial.

4.1.3. PPW

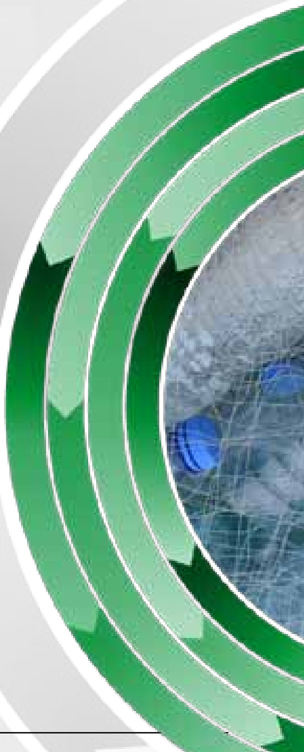
After collection PPW is sorted into different fractions according to the type of polymer. Sorting processes differ depending on the collection system. Collection systems vary across Europe, ranging from systems in which plastics are collected separately, to the curbside collection of household waste and systems that include plastics collection alongside 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 that are diverted to disposal or incineration. The estimated yield in the sorting stage is 82 per cent of the input, and 73 per cent in later recycling stages (NEW_InnoNet, 2016c). The cause of the losses in the sorting/separation and recycling stages is 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 recycled material generated, resulting in blends and materials with inferior properties. Although automatic separation technologies have improved significantly, these are still not able to separate all materials and multi-material combinations (laminated packages). Also the cost of separating multiple materials is still prohibitive. A possible way of improving recycling rates is to separate plastics from mixed municipal waste after collection. However, due to contamination it is still difficult to produce high quality recycled raw materials. The best performing PPW recycling schemes combine source-separated collection with additional separation to obtain high quality recycled raw materials that can leverage 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 of using recycled packaging materials in food-contact applications is the risk of migrating unknown substances to foodstuff. Generally, the materials end up in products with lower demands on mechanical properties and visual aesthetics. The value of the recycled fraction might be increased if its functionality could be upgraded and if it would be possible to guarantee that hazardous chemicals is removed from recycled material, allowing it to be used for more high-level applications.

4.2. Research and innovation actions needed

Table 3 summarizes the research and innovation actions needed to meet challenges related to sorting and recycling, a more detailed presentation of each of them is given in the appendix. In addition to technical development to minimize losses and increase the quality of the recycled materials, regulatory and supporting actions to facilitate sorting and recycling are also important.



2) Cathode Ray Tube

3) Liquid Crystal Display with Cold Cathode Fluorescent Lamp

4) Liquid Crystal Display with Light Emitting Diode

Section	Research and innovation actions	Relevant waste streams	Type of action	Time frame
B.1	Development of biological plastic upcycling methods	ELV, WEEE, PPW	RIA	5-10 years
B.2	Development of innovative product assemblies with traceable material characteristics, integrated with recycling methods	ELV, WEEE , PPW	RIA, CSA	0-5 years
B.3	Optimization of high capacity sensor-based sorting of mixed plastics	ELV, WEEE	IA (Demo)	0-5 years
B.4	Installation and optimization of high capacity sensor-based sorting of mixed metal alloys	ELV, WEEE	IA (Demo), SME	0-5 years
B.5	Use of robotics in sorting and disassembly of valuable and hazardous materials	ELV, WEEE	RIA	5-10 years
B.6	Development of methods for detection and separation of scarce metals	ELV	RIA	5-10 years
B.7	System analysis (and piloting) of treatment strategies for improved recovery of selected precious and critical raw materials	ELV, WEEE	RIA or IA	0-5 years
B.8	Development of information systems with regard to material content	ELV, WEEE	RIA	5-10 years
B.9	Development of recycling methods for composites and multi-layered materials	ELV, PPW	RIA	5-10 years
B.10	Recycling of smart packaging	WEEE, PPW	RIA	5-10 years
B.11	Development of cost effective and low volume lithium battery reuse and recycling methods	ELV, WEEE	RIA	5-10 years
B.12	Application of fibrous and mineral residues from ELVs	ELV	RIA	0-5 years

Table 3: Overview of key research and innovation actions related to optimized sorting and recycling.

5. Well-functioning market

5.1. Current situation and challenges

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

- Development of quality standards for recycled raw materials (in particular for plastics)
- Analysis and policy options to address the interface between chemicals, products and waste legislation, including ways 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 requirements from industrial partners that could be applied to these materials in the collection and recycling system. In this way, a market pull for recycled 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 poor quality.

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

Today there is relatively high awareness about the risks for human health related hazardous substances. Citizens are primarily concerned about children's exposure to hazardous substances from different sources, e.g., food, dust and consumer goods. There are therefore reasons for companies that produce consumer goods to meet market demands and to require materials free from at least the most hazardous substances. Manufacturing companies in the area of consumer goods often express doubts about the use of recycled material that originates from mixed waste streams, as information on the content of hazardous substances is usually missing. Traceability of the hazardous substances was considered an important issue for companies manufacturing electronics, interior items, clothes, shoes, toys and children's products that were interviewed about their experiences in connection with hazardous substances and material recycling. Some companies did not believe that they could use recycled material at all because they could not guarantee safety (toys), while others intended to increase recycled material to 100 per cent (textile).

The benchmarking of 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 can be gained. On the other hand legislation, standards and guidelines are developed for virgin materials and not always suitable for recycled materials. These must be further developed/renewed. Another obstacle is that producers set high demands on material performance, often unnecessarily high, which creates problems when replacing virgin materials with recycled ones, since it is difficult for recycled raw material to guarantee these set demands.

In some cases, the costs of landfilling or incineration alternatives are quite low due to overcapacities and therefore create a lock-in to boost recycling. It can be estimated, that competition is unlevel/unfair, because gate fees do not take into account all costs, such as those incurred in 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 the economic feasibility of high-quality recycling.

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

5.2. Research and innovation actions needed

Table 4 is an overview of the research required and the innovation actions needed to overcome identified challenges related to the market and the economy, a more detailed presentation of each of these is provided in the appendix. The proposed actions do not claim to create, but rather facilitate and thus accelerate, the accomplishment of a well-functioning and competitive market and economy for recycled materials.

Section	Research and innovation action	Relevant waste streams	Type of action	Time frame
C.1	Investigate material ownership by the producer	ELV, WEEE, PPW	RIA	5-10 years
C.2	Establish an intra-sector and cross-sector knowledge community supporting a market for recycled materials	ELV, WEEE, PPW	CSA	0-5 years
C.3	Standardization of analytical methods for quality assurance of recyclates	ELV, WEEE , PPW,	RIA	5-10 years
C.4	Analysis of new technology – impact on raw material consumption and recycling	ELV, WEEE	RIA, CSA	0-5 years
C.5	Develop material specifications for recycled materials	ELV, WEEE, PPW	RIA	0-5 years

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

6. Supportive policies and legislation

6.1. Current situation and challenges

6.1.1. ELV

The collection and treatment of ELVs are governed by the ELV Directive, 2000/53/EC, which states that 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 cost (to the manufacturer), however the transporting company has the right to charge for pick-up and transport of end-of-life vehicles to a dismantling facility when needed. The directive furthermore regulates which parts and components must be removed in the dismantling and recycling process. According to the directive the recovery rate of end-of-life vehicles must amount to at least 95 per cent of body weight, of which at least 85 per cent must be reused or material recycled.

The automotive industry has taken an initiative to meet the legal information obligations of the ELV directive by establishing the International Dismantling Information System (IDIS) (IDIS, 2016). This system compiles guidelines to promote the proper dismantling of end-of-life-vehicles. However, according to the dismantling industry, IDIS is of limited help in their daily work and only provides information obvious to the dismantlers.

European-wide harmonization of EU legislation enforcement and effective governance are considered the principal challenges, standing in the way of effective ELV policies and legislation. Today, differences in the implementation of the legislation between Member States, e.g., registration/deregistration systems for vehicles, lead to inconsistencies in reporting and in European statistics. In addition, they also make it relatively easy to circumvent official recycling systems and use substandard recycling practices.

There is an unlevel playing field between Producer Responsibility Organization (PRO) approved and non-PRO approved authorized treatment facilities. This is because the PRO approved authorized treatment facilities, in general, are subject to tighter control mechanisms and compelled to show that PRO requirements are being adhered to. In addition, differences in the enforcement of the legislation will lead to a situation where recycler requirements differ between countries.

6.1.2. WEEE

According to 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 over time when higher recycling targets are being implemented successively. There is an overarching collection target of 45 per cent of electronic equipment sold that will apply from 2016, and as a second step, a target of 65 per cent of equipment sold from 2019 and onward, or 85 per cent of electronic waste generated.

In the EU Action plan for the Circular Economy proposed by the European Commission in December 2015 (European Commission 2015b) actions for improving the exchange of information between manufacturers and recyclers when it comes to 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-harmonized legislation and inadequate control/monitoring of the value chain enables illegal export and noncompliant treatment. Statistical data is reliable to a certain extent and only enables a (rough) estimation of the quantities of WEEE and specific materials and components in the electronics available for treatment. This hampers the feasibility assessment of new recycling technologies and concepts.

6.1.3. 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 per cent by weight. Through the revision of the Directive within the Circular Economy package an increase of this target to 55 weight per cent is proposed, 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 and household sites or at any other level, regardless of the material used. A specific plastics strategy will also be part of the Circular Economy package, focusing on improved recycling, preventing marine litter, and removal of potentially dangerous chemicals.

The implementation of the Packaging and Packaging Waste Directive varies considerably among the Member States. This can be explained by the significant differences in the development of the extended producer responsibility system (EPR) for PPW within the EU. According to the European Commission, EPR schemes are the main driver for reaching 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 main divergence issues in waste management practices between countries across the EU:

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

The current practice in the EU shows that recycling targets are the main driver for plastic recycling. The political will to improve recycling and to increase the recycling target is therefore key to boost ambitions regarding the closing of plastic packaging material cycles.

As EU Member States individually have the choice of developing their own strategies to meet the PPW recycling target, varying organizational structures have already been implemented in the different Member States both at the PPW collection and sorting level and in connection with waste management infrastructure.

However, differences between countries are not necessarily negative, the potential for increased and more effective material recycling through harmonization is expected. New recycling and reuse targets and conformity in measuring performance can drive recycling as the preferred option, replacing landfill and incineration. An overall action plan for implementation could allow a faster transition towards a circular economy and achieve harmonization of legislation where relevant.

In addition, some current product standards are dedicated and limited in use to primary materials only, and are not adapted to fully exploit the potential use of recycled plastics in some applications, e.g., food packages.

6.2. Research and innovation actions needed

Table 5 gives an overview of the research and innovation actions needed to address identified challenges; a more detailed presentation of each of these is given in the appendix. Policy mixes encouraging circular solutions, including material effective recycling, the European-wide harmonization of current legislation where relevant, as well as enforcement of current legislation will enable development and facilitate the introduction of new recycling solutions leading to higher recycling efficiencies.

Section	Research and innovation actions	Relevant waste streams	Type of action	Time frame
D.1	Increase the demand for recycled plastics	ELV, WEEE , PPW,	RIA, CSA	5-10 years
D.2	Improve Extended Producer Responsibility to encourage the production of recyclable products	ELV, WEEE, PPW	CSA	5-10 years
D.3	Development of rebate systems for collection of waste fractions	ELV, WEEE, PPW	RIA	5-10 years
D.4	Evaluate the impacts of different policy mixes targeting effective material recycling	ELV, WEEE, PPW	RIA, CSA	5-10 years
D.5	Assessment of benefits of recycling and phase-out regimes for potentially hazardous substances	ELV, WEEE	RIA	5-10 years
D.6	Development of quality standards for ELV recycling	ELV	CSA	5-10 years
D.7	European matching of vehicle registration, re-registration and deregistration systems	ELV	CSA	5-10 years

Table 5: Research and innovation actions contributing to supportive polices and legislations.

7. Design for circularity

7.1. Current situation and challenges

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

7.1.1. 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 necessary to increase the recyclability of vehicles.

Manufacturers selling vehicles on the European Market are compelled to comply with recyclability requirements as a part of the Whole Vehicle Type Approval. According to the 2005/64/EC Directive concerning the type-approval of motor vehicles with regard to their reusability, recyclability and recoverability, Original Equipment Manufacturers (OEMs) have to prove that the (to be approved) new vehicle model is (theoretically) recyclable to at least 85 per cent.

Besides the above-mentioned directives there are currently no (or very few) incentives for product manufacturers to develop easy-to dismantle and recyclable products. Product design is strongly driven by performance requirements, cost minimization and consumer expectations that currently do not emphasize recyclability or reusability and longevity. Other design drivers include reduction of climate impact, reduction of vehicle emissions and cost-efficiency improvement by minimizing material use in the manufacturing stage.

The current requirements and the rapid development of materials, including ideas for using more renewable materials, have led to complex designs, the use of multimaterial combinations and composites, miniaturization, the 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. Communication along the value chain, e.g., between manufacturers and recyclers or between recyclers and product designers is insufficient, and recyclability is not a key priority for consumers.

7.1.2. WEEE

Among other things, the EU Action plan proposed by the European Commission in December 2015 (European Commission 2015b) suggests that an emphasis on circular economy aspects should be included in future product requirements under the Ecodesign directive, and that standards of material efficiency for setting future Ecodesign requirements regarding the durability, reparability and recyclability of products should be developed further. Electrical and electronic products are especially emphasized in the Ecodesign Working Plan (European Commission 2016b), which focuses on energy-related product groups. In the Ecodesign Working Plan it is stated that during review of ecodesign and energy labelling regulations the Commission will examine how aspects relevant to the circular economy can be assessed and addressed. These include aspects such as resource efficiency, reparability, recyclability and durability.

Design and composition are considered, along with the large proportion of uncontrolled treatments, to be the most significant challenges for WEEE. As for ELVs, there is today little or no incentive for manufacturers of WEEE to consider recycling and disassembly aspects in the design phase. The main drivers are cost minimization and consumer expectations. This in turn has resulted in complex designs in terms of the number and combinations of materials being used, integrated/joined or alloyed materials etc., which makes the dismantling of parts and materials challenging from both an economic and technical perspective. In addition, the miniaturization of electronic components and the reduced use of valuable materials per application decrease the feasibility for recycling. The rapid development and short lifecycles of products and the prevalence of unwanted substances are impediments to an improved recycling of WEEE. Keeping pace with these rapid developments is challenging for recyclers. Communications and collaboration along the value chain, e.g., between manufacturers and recyclers, or between recyclers and product designers, are insufficient and recyclability is not a key priority for consumers.

7.1.3. PPW

The packaging and packaging waste directive (94/62/EC) states that packaging shall be designed, produced and commercialized in a such a way as to permit its reuse or recovery, including recycling, and to minimize its impact on the environment when packaging waste or residues from packaging waste management operations are disposed of. However, the trends in design of plastic packaging include improving performance, minimization 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 entails special recycling challenges. Current technological solutions are neither adapted nor fitted for the recycling of plastic composites and degradable plastics. Furthermore, the increasing amount of different materials and impurities to be separated jacks up processing costs.

Requirements for prolonged food freshness have resulted in complex layered material designs to assure 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 for ecodesign of packaging solutions that can provide high performance during their lifetime and which are suitable for effective separation and recycling. There is a need for research activities to develop both drop-in materials with prolonged durability and assured recyclability, and the development of degradable packaging with selected lifetime appropriate both for the use of the application and subsequent waste management, including collection, sorting and disposal.

7.2. Research and innovation actions needed

Table 6 summarizes the actions for research and innovation needed to achieve sustainable product design; a more detailed presentation of each of them is given in the appendix.

Section	Research and innovation actions	Relevant waste streams	Type of action	Time frame until introduction
E.1	Collaborative design for circularity	ELV, WEEE, PPW	CSA	0-5 years
E.2	Understanding consumer behaviour and drivers for recycling	ELV, WEEE, PPW	RIA	0-5 years
E.3	Product design indicators including impacts of recycling	ELV, WEEE, PPW	RIA	0-5 years
E.4	Design of vehicle components for circularity	ELV	RIA	5-10 years
E.5	Design of consumer electronics for circularity	WEEE	RIA	5-10 years
E.6	Design of packaging for effective recycling	PPW	RIA	5-10 years
E.7	Investigate the consequences of introducing degradable materials in the loop	PPW	RIA	0-5 years

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

8. Acknowledgements

NEW_InnoNet would like to thank all project stakeholders and external experts for their contributions during the project. Between 2015 and 2017, more than 400 stakeholders provided contributions and feedback on the NEW_InnoNet project via questionnaires, interviews and workshops. All NEW_InnoNet results – including this Strategic Research and Innovation Agenda – benefitted largely from these stakeholder contributions as they added valuable information, expertise and experiences from different sectors and backgrounds. The NEW_InnoNet project takes full responsibility for the content of its reports.

9. References

The reference list includes references in the Appendix.

- ARN (2015), Impact van nieuwe materialen en aandrijflijnen op ARN- In opdracht van ARN Holding, Rapport nr.: RAP1215-PR150029
- CWIT (2015), Countering WEEE illegal trade, Summary report, available at http://www.cwitproject.eu
- European Environmental Agency (EEA) (2016) Circular economy in Europe. Developing the knowledge base, EEA Report No 2/2016, ISBN: 978-92-9213-719-9
- European Commission (2014), Study on collection rates of waste electrical and electronic equipment (WEEE), available at http://ec.europa.eu/environment/waste/weee/pdf/Final_Report_Art7_publication.pdf
- European Commission (2015a), Directive of the European Parliament and of the Council amending Directive 94/62/EC on packaging and packaging waste. Explanatory memorandum, available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52015PC0596&from=EN
- European Commission (2015b) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the loop – An EU action plan for the Circular Economy, COM(2915) 614 final, available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614
- European Commission (2016a), Circular Economy Strategy, available at http://ec.europa.eu/environment/circular-economy/
- European Commission (2016b), Communication from the Commission. Ecodesign Working Plan 2016-2019, COM (2016) 773 final
- European Commission (2017), Raw Material Information System, available at http://rmis.jrc.ec.europa.eu/
- European parliament (2006), Directive 2006/122/ECOF, available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:372:0032:0034:en:PDF
- European parliament (2016), Circular economy package – Four legislative proposals on waste. Briefing EU Legislation in Progress June 2016
- Eurostat (2015), available at http://ec.europa.eu/eurostat/statistics-explained/index.php/Passenger_cars_in_the_EU, Data extracted 161118
- Eurostat (2016a), available at http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Total_number_of_end-of-life_vehicles,_2007%E2%80%9313.png, Data extracted 161230
- Eurostat (2016b), available at http://ec.europa.eu/eurostat/web/waste/key-waste-streams/elvs, Data extracted 170224
- Eurostat (2016c), available at http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Electrical_and_electronic_equipment_(EEE)_put_on_the_market_and_waste_EEE_collected_and_treated,_EU,_2007%E2%80%9313.png, Data extracted 161230
- Eurostat (2017), available at http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselee&lang=en, Data extracted June 170406
- Hagelüken, C. & Corti, C. (2010), Recycling of gold from electronics: Cost effective use through 'Design for recycling'. Gold Bulletin 43:3. www.goldbulletin.org. and European Commission 2015. Study on WEEE recovery targets. Writers: Seyring, N et al, available at http://ec.europa.eu/environment/waste/weee/pdf/16.%20Final%20report_approved.pdf
- Hestin, M., Faninger, T., Milios, L., (2015). Increased EU Plastics Recycling Targets: Environmental, Economic and Social Impact Assessment, Final Report. Bio by Deloitte.
- IDIS (2016), available at: http://www.idis2.com/index.php?&language=english, Data extracted 161124
- Jansen M., Thoden van Velzen U., Pretz T. (2015), Handbook for sorting of PPW concentrates-Separation efficiencies of common plastic packaging objects in widely used separation machines at existing sorting facilities with mixed postconsumer PPW as input, Rapport 1604, food and biobased research, Wagening UR, available at https://www.kidv.nl/6226/wur-handbook-for-sorting-of-plastic-packaging-waste-concentrates.pdf

- Kohlmeyer R. et al. (2015), Perspektiven der zunehmenden Fahrzeugelektronik für das Altfahrzeugrecycling, available at http://www.vivis.de/kostenfreie-artikel/beitraege/category/129-autos?download=1050:perspektiven-der-zunehmenden-fahrzeugelektronik-fuer-das-altfahrzeugrecycling
- NEW_InnoNet (2016a), D3.4 Technological roadmap to Near Zero Waste in Plastic Packaging, available at http://www.newinnonet.eu/downloads/D_3.4_Draft_Roadmap_Plastic_Packaging_and_Annex.pdf
- NEW_InnoNet (2016b), Bottleneck analysis of WEEE, ELV and Plastics packaging chains: key findings and commonalities, available at http://www.newinnonet.eu/downloads/D2.5%20Bottleneck_analysis_key_findings_and_commonalities.pdf
- NEW_InnoNet (2016c), Report summarising the analysis of the Plastic packaging value chain, available at http://www.newinnonet.eu/downloads/D%202.4_RP_Report%20summarising%20the%20analysis%20of%20the%20plastic%20packaging%20value%20chain2.pdf
- NEW_InnoNet (2016d), Report summarising the results of the analysis of Electronics value, available at http://www.newinnonet.eu/downloads/D2.2_RP%20Report%20Summarising%20the%20Analysis%20of%20WEEE%20Value%20Chain.pdf
- NEW_InnoNet (2017a), Technological roadmap to Near Zero Waste in ELV, forthcoming
- NEW_InnoNet (2017b), Technological roadmap to Near Zero Waste in WEEE, forthcoming
- NEW_InnoNet (2017c), Policy brief, available at http://www.newinnonet.eu/downloads/D%205.2_RP_(vFinal)_IVL_Policy_brief.pdf
- Oeko-Institut (2016), Public consultation on potential measures to improve the implementation of certain aspects of the Directive on end-of-life vehicles, with emphasis on ELVs of unknown whereabouts, available at http://elv.whereabouts.oeko.info/index.php?id=58
- Plastic Europe (2015), Plastics, the facts 2015, http://www.plasticseurope.org/Document/plastics---the-facts-2015.aspx
- Seyring N., Weißenbacher J.,Hestin M et.al (2015), Study on WEEE recovery targets, preparation for re-use targets and on the method for calculation of the recovery targets, European Commission, available at http://ec.europa.eu/environment/waste/weee/pdf/16.%20Final%20report_approved.pdf
- UNEP (2013), Metal Recycling, Opportunities, Limits, Infrastructure

APPENDIX: Detailed descriptions of research and innovation actions

A. Effective collection

A.1. Improved reverse logistics of ELV components

As more complex and lightweight materials are introduced due to electrification, stricter emission regulations, improved fuel consumption during use and demands for increased comfort, etc., an extended dismantling in terms of number of parts and components of ELVs may contribute to increased resource efficiency in ELV treatment and is therefore preferable. Generating more dismantled parts for recycling calls for efficient logistic management solutions (reverse logistics) between the dismantling facilities and the subsequent end-of-life treatment facilities for respective parts. Compared to traditional logistics reverse logistics are generally more complex. For ELV components this is due to the large number of (mainly small) disassembly facilities. For new waste streams such as vehicle electronics or composite materials trade relationships and contacts between disassembly facilities and (WEEE, plastics, composites) recycler still have to be established (Kohlmeier et al, 2015). The complexity is also due to high costs incurred compared to the transported value, as well as uncertainty in demand and supply. For lightweight materials such as plastics and composites low filling rates are another challenge as these are bulky and take up a lot of space during transport.

This research and innovation action should address:

- How to increase the low filling rate for bulky materials
- Possible cooperation and coordination of disassembly facilities and waste recyclers (establishing networks).
- Opportunities to pool ELV components with other waste streams, such as PPW and WEEE, and maybe with similar waste streams from repair shops.
- Reverse logistics by car manufacturers when parts are reused (the parts can be refurbished) or remanufactured and re-sold through their official repair centres

Expected impact: An improved reverse logistics will decrease costs incurred in transporting parts and components and reduce the environmental transport footprint. Decreased transport costs are necessary to make the material recycling economically feasible.

Relation to current EU initiatives: This action corresponds with all initiative calls for an improved collection system. More specifically, HORIZON 2020's CIRC-01-2016-2017 call encourages the reorganization and governance of supply chains for circularity. Action area II.4.4. in the European Innovation Partnership (EIP)on Raw Materials' Strategic Implementation Plan identifies the need for an innovative approach and infrastructures for the collection of products. However, the European Innovation Partnership is focused on WEEE, and this Agenda's inclusion of ELV thus complements the Strategic Implementation Plan.

Relevant waste streams: ELV

Type of action: IA

Time frame: 5-10 years

A.2. Improved reverse logistics of WEEE and WEEE components

Rapid change in the design and functionality of consumer electronics brings in its train an elevated consumption. However, most of the devices replaced are still fully functional. They have not been discarded and instead just lie around in European homes. In order to recover this EEE, with all its inherent value, several combined actions must be put in place to close the loop. The used EEE needs to be valorized, owners rewarded according to the state of the device, and a transparent and certified second-hand market established. And to connect the used EEE owner and the second-hand seller a reverse logistic scheme must be implemented.

Also, many companies are developing a circular economy strategy, where cost-effective product take-back schemes play an essential role in the overarching strategy. For example, more than two million people in six countries use HP's "Instant Ink." When a customer is running low on ink, an Internet-connected printer notifies HP and a replacement cartridge is automatically delivered, with a return envelope for the used cartridges, which HP reuses, repairs or recycles depending on the cartridge status.

Young innovative logistics companies are focusing their activities on this niche sector. These companies offer Asset Recovery Solutions that provide a value return opportunity for all retired electronic equipment at the same time they offer a process for the disposal of retired legacy IT Electronics, providing secure data removal and offering an opportunity to refurbish products and get additional value from the returns (new clients).

This research and innovation action should:

- Address legislative barriers: Government policy and regulation have not kept pace with circular economy requirements, for example, the definition of WEEE and its' implementation. The transboundary shipment of waste is regulated by the Waste Shipment Regulation

(WSR). This makes it challenging to organize cost-effective product take-back schemes and consolidate repair and upgrade operations

- Address cooperation and coordination among all the WEEE stakeholders: introduce business models that encourage WEEE owners to return their devices for the extraction of most of their residual value (reuse, repair, reselling, recycling).
- Investigate different reverse logistics options and insert these at the centre of the company's circular design strategy

Expected impact: Enhanced reverse logistics, together with an appropriate reward scheme, will encourage owners to return a device that still has value to the producer, who will be able to extract most of this value (reuse, repair, reselling, recycling). A reliable and certified second-hand market will also benefit from reverse logistics.

Relation to current EU initiatives: This action corresponds with all initiatives' calls for an improved collection system. More specifically, Horizon 2020's CIRC-01-2016-2017 call encourages the reorganization and governance of supply chains for circularity. Action area II.4.4. in the European Innovation Partnership on Raw Materials' Strategic Implementation Plan identifies the need for innovative approached and infrastructures for collection of products, specifically WEEE. This action on the agenda should thus be aligned with the ones initiated by the European Innovation Partnership on this topic.

Relevant waste streams: WEEE

Type of action: IA

Time frame: 5-10 years

A.3. Investigation and design of improved collection systems for WEEE

E-waste is the fastest growing waste stream and is expected to expand at an ever-faster pace. Experts in the sector have predicted that special efforts will need to be made in connection with WEEE collection, as this is still one of the major hurdles that must be overcome if the objectives set by EU legislation are to be achieved. Data provided by the EU in 2014 reveals that WEEE collection rates are below 50 per cent in the majority of EU Member States. One of the major problems to be addressed here is making the process economically viable, so that the overall costs of collection do not exceed the value of the secondary materials sold to the recyclers. Instruments to finance and facilitate the return of used products to the value chain and enable their preparation for reuse and recycling have been implemented by EPR schemes. Despite the existence of such instruments efforts still need to be made to improve collection performances and avoid illegal WEEE recovery routes driven by the value of materials embedded in some WEEE streams (ICT and high-tech electronics), and their inappropriate handling and/or export. The importance of proper collection is also emphasized, for example, in the UNEP report on Metal recycling (UNEP 2013), as well as in the conclusions of an EC study on WEEE Recovery targets (Seyring et al. 2015), which states that "collection targets have a far greater influence on the final material recovered than the recycling and recovery targets". The fact that only around 3 million tonnes of the estimated total of 9 million tonnes of WEEE, were officially collected, treated and reported to authorities across Europe in 2012, raises several concerns among WEEE-stakeholders (CWIT, 2015). Innovative and cost efficient collection systems must be developed so that collection rates can improve. Incentives are required for stakeholders involved in WEEE collection, these can take the form of standardization (CENELEC is engaged in this respect) and innovative business models introduced that enable actors involved in the collection to generate value.

In addition to the quantity of collection, the proper collection quality also has to be addressed. Specific WEEE streams, such as displays, devices containing batteries, photovoltaic modules, have to be collected in a way that prevents the WEEE from being damaged. Proper and careful collection is necessary to enable the correct dismantling (de-pollution and reclamation of valuable components and recycling), to avoid contamination and fire hazards. Collection quality may be influenced by the collection containers, the handling procedures to fill the containers, the training of the collecting staff.

This action should:

- Investigate best practices for collection systems in the different Member States
- Develop innovative business models in which all WEEE stakeholders (i.e., producers, retailers, waste management actors, collectors, recyclers, logistics, service providers, municipalities, consumers etc.) are involved
- Improve existing incentives and develop new ones to encourage consumers to collect WEEE
- Incorporate measures in the collection systems to meet the requirements of recyclate users
- Develop best practice (containers, procedures, training) to ensure a proper high quality collection (avoiding damage)

Expected impact: Optimization of WEEE collection will help improve material recycling. Decreasing or eliminating fractions ending up in landfills and incineration plants. The quantity and quality of secondary materials reaching the market will increase, and the need for downcycling will be reduced. Improvements in the collection of WEEE may take place through implementation of innovative business models.

Relation to current EU initiatives: The proposed action supports the: Identification and dissemination of good practices in the waste collection system task in the Circular

Economy Action Plan. In addition, the proposed action is closely related to Horizon 2020 SC5-15b-2017: On Good practice in waste collection systems and to the European Innovation Partnership on Raw Materials' Strategic Implementation Plan, action area II.4.3: Mapping and assessing existing waste collection systems and barriers for implementation. The focus of the action presented here will need to be aligned with the outcomes of these. The EWIT project executes this task mainly for Africa.

Relevant waste streams: WEEE

Type of action: RIA, CSA

Time frame: 5-10 years

A.4. Investigation and design for improved collection systems for PPW

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 emphasize the significance of recycling of PPW to ensure that a minimum amount ends up in municipal waste. Additionally the efficiency of collection systems should be improved and recycling schemes should as much as possible be adapted to the requirements of the users of recyclates. The design of innovative collection systems must focus on making it easy to sort the materials correctly.

The introduction of new materials on the market necessitates an innovative approach to the collection and separation of these waste fractions. Different plastic fractions must be collected according to their material properties and content (degradable, reinforced etc.). This means that consumers must be able to identify the material and know how to differentiate the different products.

This action should:

- Investigate the best solutions for collection systems in the different Member States
- Investigate and evaluate the behaviour of the consumers
- Address the design of collection bins that promote easy separation by type of material or application
- Raise consumer awareness and incorporate measures in the collection systems to meet the requirements of recyclate users

Expected impact: Optimization of the collection of PPW will facilitate material recycling and consequently decrease or eliminate the proportion of the fraction that ends up in landfills and incineration plants. The quantity and quality of recycled plastic material reaching the market will increase, and the need for downcycling will be reduced. Recommendations of best solutions for collection systems should allow Member States or regions to elevate their performance to the level of the currently best performing EU Member States.

Relation to current EU initiatives: This action supports the Circular Economy Action Plan that targets Identification and dissemination of good practices in waste collection systems. The action is closely related to proposals set forth in Horizon SC5-15b-2017: On Good practices in waste collection systems, and the focus of the action presented here will need to be aligned with the outcome of that call. The outcomes of activities concerned with mapping and assessing existing waste collection systems and barriers for implementation (Action area II.4.3.) in the European Innovation Partnership on Raw Materials' Strategic Implementation Plan will form a good basis for the R&I action proposed here.

Relevant waste streams: PPW

Type of action: RIA and CSA

Time frame: 5-10 years

B. Optimized sorting and recycling

B.1. Development of biological plastic upcycling methods

Plastics are highly carbon-rich and as such can be used as substrate in the biological and chemical industries. In a plastic-based biorefinery, a virtually endless range of new products including bioplastics, building blocks, solvents and other value-added chemicals could be produced from otherwise unrecyclable materials such as thermoset foams, mixed plastics or end-of-life recyclates. This will require the development of new methods, biocatalysts and processes tailored to plastic waste in an interdisciplinary effort involving biotechnology, chemistry and engineering.

This research and innovation action should address:

- Plastic pre-treatment and depolymerization methods compatible with biotechnology
- Development of biocatalysts capable of degrading plastic monomers
- Production of value-added raw materials from plastic waste

Expected impact: By establishing plastic waste as a carbon source for biotechnological conversion, completely new markets can be opened up and plastics resistant to more traditional recycling methods (e.g., PU foams) can be valorized.

Relation to current EU initiatives: The proposed action is covered in Circular Economy Action Plan and Horizon 2020, albeit in a higher level of abstraction; where the Circular Economy Action Plan and Horizon 2020 propose more generic challenges and goals/targets, this Agenda proposes concrete actions that can be performed to reach these goals. The Circular Economy Action Plan addresses several challenges related to sorting and recycling and suggests a new set of long-term recycling targets for municipal waste and packaging waste. Horizon 2020 addresses recycling issues at a generic level. The calls CIRC-03-2016 and SC5-14b-2016-2017 CSAs are expected to lead to increased economic performance in terms of higher material energy, cost efficiency and flexibility in minerals processing and in metallurgical and recycling processes. The Strategic Implementation Plan, with its focus on WEEE and CRM, does not address plastic upcycling methods. The P4SB project addresses utilization of the conceptual and material tools of contemporary Synthetic Biology to bring about the sustainable and environmentally friendly bioconversion of oil-based plastic waste into fully biodegradable counterparts. Some of the results of these projects will be relevant for this action.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA

TRL-level: 3-5

Time frame: 5-10 years

B.2. Development of innovative product assemblies with traceable material characteristics, integrated with recycling methods

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

Current research focuses on attaching chemical markers to specific materials, laser marking specific components and developing highly effective density separation methods. The 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 coupling complex product development with better materials sorting, with strong focus on non-metallic fractions. In addition, sorting methods linked to the marking system will be necessary.

This action is closely connected with action B.5 below, because when robotic systems are implemented these must be adapted to use markers to detect and sort the appropriate materials.

This research and innovation action should address:

- Standardization in the use of markers in materials overarching products and brands
- If and how markers affect materials in terms of future use and waste management
- The development of code systems for materials recognition
- Demonstration of how existing sorting and detection installations might be retrofitted with new techniques without losing processing efficiency
- How marking or code systems can be extended also to include information on presence or absence of hazardous chemicals

Expected impact: The use of code recognition systems can significantly increase the effects of recycling. These systems will accelerate recycling rates, advance the quality of recycled materials and improve the efficiency of sorting plants. As a consequence it will be easier to create circular business models that will enable producers to maintain control over their own materials.

Relation to current EU initiatives: The proposed action is covered in Circular Economy Action Plan and Horizon 2020, albeit at a higher level of abstraction; where the Circular Economy Action Plan and Horizon 2020 propose more generic challenges and goals/targets, this Agenda proposes concrete actions that can be performed to reach these goals. The Circular Economy Action Plan addresses several challenges related to sorting and recycling and suggests a new set of long-term recycling targets for municipal and packaging waste. Horizon 2020 addresses recycling issues at a generic level. The calls CIRC- 03-2016 and SC5-14b-2016-2017 are expected to lead to increased economic performance in terms of higher material and energy cost efficiency as well as flexibility in minerals processing and metallurgical and recycling processes. The proposed action could possibly make use of outcomes from projects under those calls. The European Innovation Partnership on Raw Materials' Strategic Implementation Plan includes a section on recycling in action area I.B.5, focusing specifically on complex products (WEEE).

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA, CSA

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

Time frame: The time frame for developing and demonstrating the efficient use of new recognition systems such as markers in waste management is estimated at 0-5 years. The time horizon for a standardization of these systems across the entire WEEE value chain will depend largely on the extent to which producers and brand owners want to standardize the use of these systems.

B.3. Optimization of high capacity sensor-based sorting of mixed plastics

The proportion of plastics in cars has increased gradually over time and this trend is expected to continue. Fillers and additives provide additional performance at relatively low cost, while laminates and composites further enhance material properties by combining the salient features of multiple materials. Use of these innovative systems is predicted to increase in the years to come. The end-of-life impact of complex compositions is high, especially since recycling is costly and energy intensive. Contaminants such as brominated flame retardants have to be separated reliably to enable a high grade recycling of the de-contaminated plastics fraction. New sorting solutions are needed to facilitate the recycling of both traditional plastics and new material combinations, subsequently decreasing energy requirements.

To date, plastic fractions from ELVs are not generally recycled. Instead the greater part of the shredder residue is incinerated or landfilled. Over the past decade, a sensor-based approach that utilizes Colour, X-Ray, Laser and ultrasound spectroscopy, has resulted in more efficient plastics sorting. This avenue should be explored to leverage an even more effective sorting of these fractions and the separation of contaminants.

This action should:

- Address improvement of the sorting efficiency of similar polymer grades with different compositions (gas filled, layered, etc.).
- Investigate the possibility of implementing multiple sorting methods for better detection and a higher grade of separation into homogeneous streams
- Address possible reliable separation technique that efficiently can sort contaminants in plastics based also on content, such as brominated flame retardants, and fillers

Expected impact: Higher recycling yield of plastics as well as improved quality of intermediates and final product. In addition, a better environmental (energy) performance of plastics separation will be realized.

Relation to current EU initiatives: The proposed action is covered in the Circular Economy Action Plan and Horizon 2020, albeit at a higher level of abstraction; where the Circular Economy Action Plan and Horizon 2020 propose more generic challenges and goals/targets, this Agenda proposes concrete actions that can be performed to reach these goals. The Circular Economy Action Plan addresses several challenges related to sorting and recycling and suggests a new set of long-term recycling targets for municipal waste and packaging waste. Horizon 2020 addresses recycling issues at a generic level. The calls CIRC- 03-2016 and SC5-14b-2016-2017 are expected to lead to increased economic performance in terms of higher material, energy and cost efficiency as well as flexibility in minerals processing and metallurgical and recycling processes. The proposed action could possibly make use of outcomes from projects under those calls. The European Innovation Partnership on Raw Materials' Strategic Implementation Plan includes a section on recycling in action area I.B.5, focusing specifically on complex products (WEEE). Some research and innovation has been performed in the topic, for example in the CloseWEEE (metals) and CLIPP PLUS (plastics) project. The results of these projects should be taken into account at the start of this action.

Relevant waste streams: ELV, WEEE

Type of action: IA (Demo)

TRL-level: 7

Time frame: 0-5 years

B.4. Installation and optimization of high capacity sensor-based sorting of mixed metal alloys

Nonferrous and ferrous metals are efficiently collected and recycled in Europe, both during production and at the end of the product lifecycle. Reclaiming metals contained or alloyed in scrap offers substantial potential for improving resource efficiency.

As for the metal scraps from the treatment of ELVs and WEEE, there are several downcycling effects due to

- non-alloy specific recycling.

Example: Aluminium is usually separated from the shredder output fractions as a mixture of several alloys. The mixed alloys are remelted together into secondary aluminium, which is then used as low quality cast alloy and cannot be used as high quality wrought aluminium.

- contaminants.

Example: Copper in steel scrap restricts the use mainly to structural steel. The copper content in the ELV shredder scrap can be as high as 0.3 %.

The development of ultra-sensitive analysis and separation technologies for alloyed steel and aluminium scrap can prevent 'downcycling' and further improve metals recycling as a whole. This helps to substitute primary raw materials.

During recent years, several sensor-based separation approaches that utilize XRT, XRF or LIBS have been developed, but not yet applied when treating ELV and WEEE scrap. Their implementation and further exploration should be promoted by this activity to leverage an even more effective sorting of these fractions and the separation of contaminants.

This action should:

- Address improvement of the sorting efficiency of metal alloys.
- Address the development of economic metal recycling processes and industrial-scale pilot trials of such processes, together with the development of ultra-

sensitive analysis and separation technologies for alloyed steel and aluminium scrap.

- Investigate the possibility of implementing multiple sorting methods for better detection and a higher grade of separation into homogeneous streams.
- Establish an alloy-specific sorting of metals and the separation of contaminants (e.g., Cu in steel scrap) for metal scrap from ELV and WEEE treatment.

Expected impact: High grade recycling of metal scrap will be achieved. A better environmental (energy) performance of metals recycling will be realized and primary raw materials can be saved. The alloy-specific sorting of metals saves a lot of CO_2 and raw materials over the entire production chain. It can be considered as a key technology for the whole metals industry on the way towards more climate protection and resource conservation.

Relation to current EU initiatives: The proposed action is covered in CEAP and H2020, albeit at a higher level of abstraction; where the CEAP and H2020 propose more generic challenges and goals/targets, this Agenda proposes concrete actions that can be performed to reach these goals. The CEAP addresses several challenges related to sorting and recycling and suggests a new set of long-term recycling targets for municipal and packaging waste. H2020 addresses recycling issues at a generic level. The calls CIRC- 03-2016 and SC5-14b-2016-2017 are expected to lead to increased economic performance in terms of higher material, energy and cost efficiency as well as flexibility in minerals processing and metallurgical and recycling processes. The proposed action could possibly make use of outcomes from projects under those calls. The EIP's SIP includes a section on recycling in action area I.B.5, focusing specifically on complex products (WEEE).

Relevant waste streams: ELV, WEEE

Type of action: IA (Demo), SME

TRL-level: 8

Time frame: 0-5 years

B.5. Use of robotics in sorting and disassembly of valuable and hazardous materials

The application of robotics in sorting and disassembly is a competitive alternative to handpicking as this may reduce the costs of sorting at the same time as it provides a stable and satisfactory quality output over time. When it comes to parts harvesting for reuse, recycling of specific valuable components and removal of hazardous materials and substances, in the future robotic sorting may evolve into robotic disassembly for parts harvesting and detoxification.

Current research and innovation actions are more focused on speed and accuracy of detection rather than the sorting process itself or the use of robotic arms. Research actions on optical systems as well as other systems for recognition are needed. In contrast to assembly robots in production lines, the disassembly robots face a challenge when it comes to coping with an inhomogeneous input material (e.g., different WEEE devices from mixed collection), partially in poor condition (e.g., rusty screws, damaged devices). Therefore a certain flexibility and specific programming and training are needed.

This research and innovation action should focus on:

- How to deal with the diversity of waste products and materials for robotic sorting/disassembly and the partially poor condition of the waste products
- Extending robotic sorting capabilities to used non-recognizable materials/parts
- Improve the speed of detection/sorting through the introduction of robotics
- Development of self-learning systems for analysis and sorting/disassembly

Expected impact: Application of robotics in sorting/ disassembly and recycling will reduce sorting costs and improve the quality of the sorted output. As a consequence the value of materials recycled through this process will be higher (e.g., also compared with post-shredder sorting) and they will be more likely to be up-cycled into new products.

Relation to current EU initiatives: The proposed action is covered in the Circular Economy Action Plan and Horizon 2020, albeit at a higher level of abstraction; where the Circular Economy Action Plan and Horizon 2020 propose more generic challenges and goals/targets, this Agenda proposes concrete actions that can be performed to reach these goals. The Circular Economy Action Plan addresses several challenges related to sorting and recycling and suggests a new set of long-term recycling targets for municipal and packaging waste. Regarding Horizon 2020 the calls CIRC-03-2016 and SC5-14b-2016-2017 are expected to lead to increased economic performance in terms of higher material, energy, and cost efficiency as well as flexibility in minerals processing and metallurgical and recycling processes. The proposed action could possibly make use of outcomes from projects under those calls. The European Innovation Partnership on Raw Materials' Strategic Implementation Plan includes a section on recycling in action area I.B.5, focusing specifically on complex products (WEEE).

Some EU projects relate to sorting and disassembly to some extent. The ADIR project addresses the automated disassembly, separation and recovery of valuable material from WEEE, while part of the CloseWEEE project focus is on closing the loop of post-consumer high-grade plastics. In addition, the sustainably SMART project (Sustainable Smart Mobile Devices Lifecycles through Advanced Re-design, Reliability, and Re-use and Remanufacturing Technologies) also provides some overlap with regard to sorting and disassembly. The results of these projects should be synthesized before starting a new action.

Relevant waste streams: ELV, WEEE

Type of action: RIA

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

Time frame: 5-10 years.

B.6. Development of methods for detection and separation of scarce metals

With the increasing electrification of vehicles the utilization of precious and critical metals in vehicle components has accelerated. In the meantime, designers have increasingly miniaturized products and minimized the use of these metals in sub-assemblies.

Today these metals are not intentionally recycled if not dismantled, but are dispersed throughout the metal fractions and the automotive shredder residue. Thus, these elements are diluted in other metal fractions or are incinerated or end up in landfill.

Both pre-shredder and post-shredder strategies are needed. Precious metals and critical raw materials also end up in the fines and must be efficiently separated. In the latter instance, understanding the availability of different metal and non-metal fractions contained in the post-shredder materials is key to developing technical solutions for concentrating and extracting these precious and critical metals.

The pre-shredder research and innovation action should:

- Determine the amounts and characteristics of precious metals and critical raw materials content in representative samples of components (ECUs, displays, controls)
- Investigate disassemblability and recyclability of electronic components in the WEEE recycling system (e.g., mass balances)

Post-shredder research and innovation action should:

- Investigate precious metals and critical raw materials availability in ASR (materials analysis)
- Address CRM concentration methods inside ASR (explore technologies)

Expected impact: The detection and separation of precious metals will increase the profitability of dismantlers and recyclers. The overall environmental performance of vehicles and EEE will also be improved, as value adding functional material recycling of the metals will be achieved.

Relation to current EU initiatives: The proposed action is covered in the Circular Economy Action Plan and Horizon 2020, albeit at a higher level of abstraction; where the Circular Economy Action Plan and Horizon 2020 propose more generic challenges and goals/targets, this Agenda proposes concrete actions that can be performed to reach these goals. The Circular Economy Action Plan addresses several challenges related to sorting and recycling and suggests a new set of long-term recycling targets for municipal and packaging waste. Horizon 2020 addresses recycling issues at a generic level. The calls CIRC- 03-2016 and SC5-14b-2016-2017 are expected to lead to increased economic performance in terms of higher material, energy and cost efficiency as well as flexibility in minerals processing and metallurgical and recycling processes. The proposed action could possibly make use of outcomes from projects under those calls. The European Innovation Partnership on Raw Materials' Strategic Implementation Plan includes a section on recycling in action area I.B.5, focusing specifically on complex products (WEEE).

In EU projects an increasing amount of attention has been paid to scarce metals. Once again, the ADIR project addresses the automated disassembly, separation and recovery of valuable material from WEEE. CloseWEEE investigates integrated solutions for pre-processing electronic equipment, while the PLATIRUS project focuses on the recovery of platinum group metals from several sources, most notably WEEE. The sustainablySMART project (Sustainable Smart Mobile Devices Lifecycles through Advanced Re-design, Reliability, and Re-use and Remanufacturing Technologies). REE4EU and REEcover will develop different recovery routes to increase recovery of Rare Earth Elements.

Relevant waste streams: ELV

Type of action: RIA

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

Time frame: 5-10 years

B.7. System analysis (and piloting) of treatment strategies for improved recovery of selected precious and critical raw materials

The recycling of critical and precious raw materials is currently hindered by several factors. Among other things, small concentrations per product means that there are insufficient financial incentives for processing, and there is a dearth of methods for the identification and separation of components containing valuable materials and a lack of information about quantities available for recycling. Many products are not designed for recycling. Usually the same type of components can be found in several end-of-life product groups:

- Printed circuit boards in WEEE and increasingly in ELV but also in many other products and systems
- Permanent magnets in computers, vehicles, pedelecs, 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 systems thinking (the integrated treatment or waste stream pooling of similar types of components from different products, centralized plants, etc.) and the development of informational, logistical and technological solutions (e.g., Robotic sorting) for identification and separation of target components has a great potential to improve the economic feasibility of recycling and promote the introduction of industrial scale plants.

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

Relation to current EU initiatives: The proposed action is explicitly covered in the Strategic Implementation Plan's action area I.5., highlighting the need for an integrated approach. While the Circular Economy Action Plan and Horizon 2020 do not address integrated approaches directly, it is in line with the goals of these initiatives, and most calls on the issue of recovery of materials implicitly require or prefer a system approach and synergies between product treatment strategies. This action is thus complementary to Horizon 2020 and the Circular Economy Action Plan by including an action in this area.

Relevant waste streams: ELV, WEEE

Type of action: RIA or IA

Time frame: 0-5 years

B.8. Development of information systems with regard to material content

The information provided by manufacturers of EEE and vehicles about the material content as well as location of hazardous and valuable parts, including content of hazardous substances is insufficient or non-existent today. Even though the automotive industry has implemented the International Dismantling Information System (IDIS) (IDIS, 2016) to provide the dismantlers with dismantling information, the available information is still insufficient as regards (new) hazardous and valuable materials (e.g., critical metals, POPs, carbon fibre reinforced plastics, vehicle electronics) and thus does not perfectly meet needs. Thus the dismantling of the aforementioned materials and components in WEEE, as well as in ELVs, currently relies almost exclusively on experience. Efficient dismantling requires experienced personnel as well as a continuous exchange of information between them. Developments in technology allows manufacturers to provide necessary information besides the traditional labelling that follows the products throughout their life cycles, and that is readily accessible when the discarded product is dismantled and recycled.

This research and innovation action should:

- Investigate information needed by different actors in the recycling chain and for different products
- Investigate how that information can be made accessible without encroaching on manufacturer data confidentiality or risking the misuse of information
- Investigate how the information needed should be presented
- Investigate how feedback from recycling/dismantling can be used for product improvement

Expected impact: Recyclers will have easy access to information about material content and the location of hazardous as well as valuable parts and components, including content of hazardous substances for each individual discarded product. This will facilitate the removal of hazardous parts and components for proper waste management as well as enhancing separation of valuable components and leverage higher functional recycling rates of individual materials. This will also facilitate for recyclers to guarantee that the recycled material is free from hazardous substances, which will enable the use of recycled material in higher level applications.

Relation to current EU initiatives: The Circular Economy Action Plan mentions the importance of labels and product information e.g., the Improve exchange of information between manufacturers and recyclers on electronic products action. The proposed action will contribute to this, but also covers aspects other than labelling. As for Horizon 2020 it does not include information systems with regard to material content. In the European Innovation Partnership on Raw Materials' Strategic Implementation Plan the action is addressed in priority II.C: Knowledge, skills and raw materials flows.

Relevant waste streams: ELV, WEEE

Type of action: RIA

Time frame: 5-10 years

B.9. Development of recycling methods for composites and multi-layered materials

Several new composites (carbon fibre materials, glass fibre materials, wood-plastic-composites, metal-metal composites etc.) that enhance the mechanical and physical properties of materials are playing an increasingly important role in a variety of applications. Similarly to other products, where low weight is of decisive importance for usability and emissions management, plastics and light metals are the ideal solution for decreasing vehicle weight. Ongoing innovation in the plastics field allows integration of polymeric materials in high performance components such as engines and bearing parts. In addition the aesthetics of these materials are continuously being improved, opening up new possibilities for use in an ever-widening number of products and components. The application of metal/metal composites and metal/non-metal composites is also on the increase.

Used in combined form with non-polymeric elements in a laminate or composite, the recycling of plastics is not technically possible or economically feasible without prior dismantling.

This research and innovation action should address:

- The development of new recycling techniques to enable recycling of complex compositions
- The development of new methods for the recovery of constituents, such as fibres, in new materials as separate fractions for use as recycled raw material
- The development of innovative recycling techniques that can handle mixed plastic and metal/non-metal composites

Expected impact: This action enables recycling operators to provide solutions that can both recover valuable engineering plastics and composites, while simultaneously protecting existing recycling systems and avoiding metal downcycling.

Relation to current EU initiatives: The proposed action is covered in the Circular Economy Action Plan and Horizon 2020, albeit at a higher level of abstraction; where the Circular Economy Action Plan and Horizon 2020 propose more generic challenges and goals/targets, this Agenda proposes concrete actions that can be performed to reach these goals. The Circular Economy Action Plan addresses several challenges related to sorting and recycling and suggests a new set of long-term recycling targets for municipal waste and packaging waste. Horizon 2020 addresses recycling issues at a generic level. The calls CIRC- 03-2016 and SC5-14b-2016-2017 are expected to lead to increased economic performance in terms of higher material, energy and cost efficiency and flexibility in minerals processing, as well as in metallurgical and recycling processes. The proposed action could possibly make use of outcomes from projects under those calls. The European Innovation Partnership on Raw Materials' Strategic Implementation Plan includes a section on recycling in action area I.B.5, focusing specifically on complex products (WEEE). Part of the URBANREC project addresses specific solutions to treat mixed hard plastics and is therefore largely complementary to this action.

Relevant waste streams: ELV, PPW

Type of action: RIA

TRL-level: 3

Time frame: 5-10 years

B.10. Recycling of smart packaging

New packaging solutions that include electronic components to ensure relevant information as well as control of food conditions, such as moisture or oxygen levels, will be introduced on the market across the Member States in the near future. The amalgamation of functionalities will create a new waste stream, a combination of PPW and WEEE. This will in turn require new technology for the separation and recycling of the components.

This research and innovation action should:

- Investigate the possibility of differentiating the fraction from the conventional packaging waste stream
- Identify necessary steps for separation of the different components in the packaging design
- Find or develop possible solutions for recycling of the different components
- Give feedback to the product design for better separability.

Expected impact: This action will promote development of innovative technology for identifying new packaging solutions and separation from the waste streams to avoid contamination of the conventional waste fraction as well as assuring the recyclability of the materials in the new applications.

Relation to current EU initiatives: The proposed action is not covered in the Circular Economy Action Plan, Horizon 2020 and the European Innovation Partnership on Raw Materials' Strategic Implementation Plan; this means that it will complement these ongoing EU initiatives. However, Horizon 2020 includes a call on paper-based electronics (PILOTS-05-2017). As recyclability and ecodesign are to be included in the project, this action may be able to find some similarities in its approach. The existing NEW_FUN project aims to develop WEEE based on paper, which might have an impact on the recycling of smart packaging.

Relevant waste streams: WEEE, PPW

Type of action: RIA

Time frame: 5-10 years

B.11. Development of cost effective and low volume lithium battery reuse and recycling methods

Lithium-ion-based batteries are integral to the electrification of transport, as well as to other energy storage applications. The production capacity of Li-ion batteries is increasing rapidly while production costs per kWh are decreasing. The increases in production provide a reliable indication of the recycling capacity that will be required about 10 years from now.

Unlike lead and nickel-based industrial batteries, lithium based batteries contain relatively small amounts of valuable materials. The absence of self-financing leads towards a chain deficit, which must be covered by the producer. Lithium is imported into Europe, and the European automotive manufacturers must start manufacturing their own batteries in order to gain advantage in the electrical vehicles field.

Together with other aspects such as logistics, disposal and recycling this will lead to higher costs for the producer, which will impact the affordability of e-mobility in general.

The category discarded batteries includes both end-of-life batteries (worn out), as well other batteries (e.g., batteries malfunctioning as a result of accidents). The degradation of automotive battery packs has been reduced during the past years thanks to an improved battery technology and better battery management systems. It is expected that battery packs will have a life commensurate with that of the vehicle. Advances in battery technology have taken place so quickly that any large-scale deployment of older degraded automotive batteries packs in stationary second life applications is of little interest. Moreover, the decreasing costs of new cells as well as the need for customized battery management systems for each specific pack make second life applications economically unviable.

There may be potential for the end-of-life reuse of cells, modules or even complete battery packs targeting second-life applications. When replaced, the lithium-based battery from a car still has a high capacity left which can potentially be exploited. This potential needs further investigation.

This research and innovation action should address:

- Discarded battery safe handling/transportation
- Safe battery disassembly
- Recycling of battery materials, i.e., separation, hydrometallurgical- and pyrometallurgical processing

Expected impact: Lowering cost of recycling, improving recycling efficiencies and less European dependency on imported raw materials.

Relation to current EU initiatives: The proposed action is covered in the Circular Economy Action Plan and Horizon 2020, albeit at a higher level of abstraction; where the Circular Economy Action Plan and Horizon 2020 propose more generic challenges and goals/targets, this Agenda proposes concrete actions that can be performed to reach these goals. The Circular Economy Action Plan addresses several challenges related to sorting and recycling and suggests a new set of long-term recycling targets for municipal and packaging waste. Horizon 2020 addresses recycling issues at a generic level. The calls CIRC- 03-2016 and SC5-14b-2016-2017 are expected to lead to increased economic performance in terms of higher material, energy and cost efficiency as well as flexibility in minerals processing and metallurgical and recycling processes. The proposed action could possibly make use of outcomes from projects under those calls. The European Innovation Partnership on Raw Materials' Strategic Implementation Plan includes a section on recycling in action area I.B.5, focusing specifically on complex products (WEEE).

Relevant waste streams: ELV, WEEE

Type of action: RIA

TRL-level: Li-ion battery recycling from TRL 2 to TRL 5.

Time frame: 5-10 years

B.12. Application of fibrous and mineral residues from ELVs

While the greater part of a vehicle 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 that usually make up the Shredder Heavy Fraction (SHF) and the Shredder Light Fraction (SLF). SHF is the residual after the separation of all materials in the shredder, SLF is created by the shredder aspirator, which sucks out all dust and other light elements.

After liberation and sorting of metals and plastics, these materials are often utilized for incineration or are landfilled. Still, even though there is potential for material recycling, this largely depends on the gate fees for incineration and landfilling.

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

Technologies are still to be developed that will be able to satisfactorily deal with fibres and minerals and remove hazardous substances and prepare standard grades. The elimination of accumulated persistent organic pollutants such as PCBs and PBDEs, as well as mineral oils and mercury contents are a necessary step to achieve this.

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

Relation to current EU initiatives: The proposed action is covered in the Circular Economy Action Plan and Horizon 2020, albeit at a higher level of abstraction; where the Circular Economy Action Plan and Horizon 2020 propose more generic challenges and goals/targets, this Agenda proposes concrete actions that can be performed to reach these goals. The Circular Economy Action Plan addresses several challenges related to sorting and recycling and suggests a new set of long-term recycling targets for municipal and packaging waste. Horizon 2020 addresses recycling issues at a generic level. The calls CIRC- 03-2016 and SC5-14b-2016-2017 are expected to lead to increased economic performance in terms of higher material, energy and cost efficiency as well as flexibility in minerals processing and metallurgical and recycling processes. The proposed action could possibly make use of outcomes from projects under those calls. The European Innovation Partnership on Raw Materials' Strategic Implementation Plan includes a section on recycling in action area I.B.5, focusing specifically on complex products (WEEE).

Relevant waste streams: ELV

Type of action: RIA

TRL-level: 5

Time frame: 0-5 years

C. Well-functioning market

C.1. Investigate material ownership by the producer

One pathway to a Circular Economy may be to create new business models based on ownership of the material by the producer. Within the circular economy, many such business models have already been drawn up. Still these models are only in the initial phase of being rolled out. One reason is that procurement models are still working on the basis of a traditional client – supplier relationship.

New business models need to be developed that stipulate that products must be made up of a share of recycled material from previously manufactured products within the same company. This could encourage the involvement of brand owners to create sustainable value chains, where waste is put back into own value chains as a product, component or recycled material. Brand owners and retailers can implement Corporate Social Responsibility strategies that promote the use of a certain percentage of recycled materials in products, etc. The manufacturers are key actors when it comes to closing a loop by implementing recycled materials into products. However, the consequences of material ownership by the producer should be investigated further.

This research and innovation action should:

- Investigate the potential consequences of material ownership by producers, environmentally, socially and economically.
- Propose actions that support material ownership by producers where this could lead to improved resource efficiency and sustainable development.

Expected impact: Increased knowledge of the potential effects of material ownership that could support policy in line with sustainable development. New business models that would allow more effective recycling while meeting the economic interests of manufacturers and still be in line with social sustainable development.

Relation to current EU initiatives: The proposed action partly supports the Circular Economy Action Plan where EPR is addressed as a potential method for improving recycling. This is also true for EIP. The proposed action is not directly EPR but a further step where the material of the product is owned by the producer. Horizon 2020 does not directly address material ownership by producers, but the concept is included in the calls on systemic, eco-innovative approaches for the circular economy (CIRC-01-2016-2017). These include the redesign of value chains for circularity and the development of systemic services for circular economy. In the event material ownership becomes part of the projects executed under this call, the focus of the proposed action must be aligned with the outcomes of these projects.

Relevant value chains: ELV, WEEE, PPW

Type of action: RIA

Time frame: 5-10 years

C.2. Establish an intra-sector and cross-sector knowledge community supporting a market for recycled materials

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

Examples of intra-sectorial activities are, sharing and building knowledge on:

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

Examples for cross-sectorial activities are, sharing and building knowledge on:

- Material needs in certain applications
- Pooling of similar waste streams
- Establishing relationships between waste generator and waste recycler
- Sorting needs (i.e., facilitate sorting)
- Sorting methods for various waste streams: shredder waste, municipal waste
- Recycling of reinforced plastics stemming from end-of-life aircrafts and vehicles, WEEE and other sources
- Treatment of high voltage batteries, difference between automotive, aviation, equipment (e.g., trains)

Expected impact: 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 recycled material, creation of marketplaces for different recycled raw materials, new opportunities for industrial symbiosis, etc.

Relation to current EU initiatives: The proposed action is partially covered by the Circular Economy Action Plan, Horizon 2020 and the European Innovation Partnership on Raw Materials' Strategic Implementation Plan. The Circular Economy Action Plan formulates the intention of developing the Raw Materials Information System. In addition, it has dedicated many calls to the topics of knowledge and information exchange, all predominantly related to raw materials (World Forum on Raw Materials; International network of raw materials training centres; Expert network on Critical Raw Materials). In addition, under Horizon 2020, the EIT Raw Materials has been founded; a Knowledge and Innovation Community centred on raw materials. The European Innovation Partnership on Raw Materials' Strategic Implementation Plan proposes coordination on raw materials generally and full coordination on research, development and innovation instead of just a knowledge community. With its focus on collaboration and information sharing dedicated to secondary raw materials at end-of-life management rather than raw materials, the proposed action is thus complementary to existing initiatives. The FORCE project aims to set up a governance model, decision support tools and information sharing system to replicate the results for (W)EEE and plastic waste.

Relevant waste streams: ELV, WEEE, PPW,

Type of action: CSA

Time frame: 0-5 years

C.3. Standardization of analytical methods for quality assurance of recyclates

Elemental analysis is an important step in validating if a separated waste fraction can become a raw material for new applications. Unwanted materials accumulate in the recycling chain and are presently regarded as waste, especially when they arise in a mixed form.

Legal initiatives and thresholds for concentrations of particular substances change rapidly. New knowledge concerning toxic effect results in new thresholds for certain substances – such as some brominated flame retardants or POPs (Persistent Organic Pollutants) to levels beyond those that can be measured reliably by currently available analytical methods.

Analytical detection methods are conformed at a national standardization level; but even at a national level there is disagreement over preferred analysis methods of 'waste materials'. As a result, the analysis of similar material samples may have an outcome variety of hundreds of per cent. Thus, there is a need for more specific standardized methods and representative certified reference material. A potential use case for uniform measurement is POPs, such as PFOS – as there are European regulations on phasing out this (European parliament, 2006).

The lack of uniformity leads to an unlevel playing field. Whereas in one country separated fractions can be applied for e.g., construction materials, in other countries this might not be possible. This is mainly due to different analytical standards, and makes the application of these fractions difficult.

In addition to analysing the presence of chemicals that the authorities have set maximum levels for, a manufacturer using recycled raw materials needs to know the overall material content. This is because the manufacturer must validate the absence of other inappropriate substances specific to different applications whose presence will make it impossible to use the recycled raw materials.

Associated with the standardization is the development of non-destructive and cheap analytical multitarget screening methods to make recycled raw materials as competitive with virgin materials as possible.

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

Relation to current EU initiatives: The proposed action is partly addressed in the Circular Economy Action Plan under 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. The other programmes do not include the issue of standardization of analytical methods, making this action a valuable addition to existing initiatives.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA

Time frame: 5-10 years

C.4. Analysis of new technology – impact on raw material consumption and recycling

Electric and electronic 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, catalytic convertors, electronics, fuel cells and a higher level of weight reduction measures. Similarly, EEE components and material composition are subject to rapid change.

As Europe produces a quarter of the global vehicle supply, lower access to 'scarce' materials may pose a real economic and competitiveness barrier. This is the case for both relatively new materials, such as neodymium, indium and cobalt, and traditional materials, such as aluminium and copper. Ever-smaller electronic equipment with very small amounts of rare materials makes recycling even harder. Recycling, and a strengthened market for recycled materials, reduces dependence on imported rare materials. In addition to recycling, substitution of rare earth elements is of high interest.

This research and innovation action should:

- Analyse main potential impact of new technologies in the light of material consumption
- Analyse opportunities for recycling of material at end-of-life.

This needs to be done for different product groups and continuously as products develop, and a life cycle perspective needs to be taken into account. Every four years, EU CRM lists the materials/elements that are critical for Europe. In this analysis the economic importance of materials is evaluated for megasectors and not for individual technologies.

The action results in a holistic and global overview of material flows used and recycled within the automotive and EEE sectors. This will provide a ground for European competitiveness policies.

Expected impact: The added value gained through this continuous research is to create a knowledge base on the overall impact of product design at end-of-life recycling, in a technical, ecological and economic perspective. Strategic intelligence on new technology and material needs will make possible the avoidance of problems in material supply and recycling, and will thus encourage a well-functioning market.

Relation to current EU initiatives: Two existing initiatives partially address this action. In the European Innovation Partnership on Raw Materials' Strategic Implementation Plan, only the effect of substitution in green technologies is considered in priority area I.C.6, whereas the Agenda's proposed action has no limitations in terms of the technology included. The same goes for the Horizon 2020 call NMBP 03-2016, which considers innovative and sustainable materials solutions for the substitution of critical raw materials in the electric power system.

To create the foundation for an impact analysis, major efforts are currently underway regarding the mapping of stocks, flows and future demand and supply of (critical raw) materials, such as ProSUM, SCRREEN, and QUMEC (quantifying the urban mine). Closely related, the HYTECHCYCLING project will deliver reference documentation and studies about existing and new recycling and dismantling technologies and strategies applied to Fuel Cells and Hydrogen (FCH) technologies, This action may be able to build on the framework laid down in these projects

Relevant waste streams: ELV, WEEE

Type of action: RIA, CSA

Time frame: 0-5 years

C.5. Develop material specifications for recycled materials

One of the challenges for creating a stable market for the recycled materials is the high specific demand on the material properties for new applications, such as mechanical, physical and chemical properties. The materials on the market today may contain substances that are regulated by different legislation, such as REACH and POP. The fact that they may contain hazardous substances has complicated effective use of these fractions as recycled raw material. It is clearly necessary to analyse and ensure the amounts of these substances in the resulting recyclates and to ascertain how these will interact with the surrounding environment during use (release). However, it is impossible to ensure the absence of hazardous substances only through analytical measurements simply due to the plethora of chemicals that are in use. The development of information system as outlined in B.8 will complement this action.

Realistic levels of material specifications can be determined for each specific application, creating possibilities for the recycled materials to replace virgin materials. 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 a regular supply of materials with the same quality must be assured, satisfying supply on demand.

The action should focus on:

- Determining possible applications and developing guidelines for recycled materials
- Identifying challenges for material specifications for identified applications throughout the supply chain and working out how they might be overcome
- Setting up standardized specification sheets for recycled materials for different product categories

Expected impact: The action will facilitate increased trust in the quality recycled materials and thus increase the use of recycled materials.

Relation to current EU initiatives: The proposed action supports the Circular Economy Action Plan regarding Development of quality standards for secondary raw materials (in particular for plastics). In the European Innovation Partnership on Raw Materials' Strategic Implementation Plan this area is considered not only in connection with secondary raw material but material specifications in general are addressed. The proposed action could possibly make use of outcomes from projects under the European Innovation Partnership on Raw Materials Strategic Implementation Plan. The proposed action is not covered in any of the calls in Horizon 2020.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA

Time frame: 0-5 years

D. Supportive policies and legislation

D.1. 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 of increasing plastic recycling.

This action should focus on analysing and evaluating a policy mix aiming to increase the demand for recycled raw material. Some of the policy actions that could be considered are:

- Alignment of recycling strategies with chemical legislation
- Promote an information system with regard to hazardous substances in products
- Promote green procurement, which encourages the use of recyclates
- Promoting or demanding use of post-consumer recycled content in new products
- Offer financial incentives for design for circularity of plastic products and components, e.g., substitution of hazardous substances, avoiding multilayer and multi-material whenever possible
- Increase the value of PPW by using the recycled materials in industrial packaging instead of societal applications, to encourage upcycling.

Expected impact: Better basis for policy decisions in the Commission and in the Member States. This could support economic incentives in the Member States, which are crucial to setting up a functional recycled raw material market for plastic waste.

Relation to current EU initiatives: The Circular Economy Action Plan emphasizes new long-term recycling targets and action on Green Public Procurement, areas where this action can be supportive. Horizon 2020 does not address the proposed action. Due to the European Innovation Partnership's focus on metals and critical raw materials, plastic packaging is not addressed.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA, CSA

Time frame: 5-10 years

D.2. Improve Extended Producer Responsibility to 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 Extended producer responsibility (EPR). EPR can provide the funding and standards necessary to establish a stable market for recycled raw materials. Today EPR drives mainly the development of collection systems and the collection rates. The producers should be encouraged to design new products that take waste management and the end-of-life of materials into account.

The action should:

- Evaluate pilot initiatives
- Develop a definition of "recyclability" or "dismantleability" or "separability", including qualitative aspects.
- Suggest variable fees for easy-to-dismantle or hard-to-dismantle relevant components.
- Suggest and evaluate a unified label indicating the recyclability of the product as consumer information
- Identify where (for which components or materials) design decisions can have the highest positive impact to enhance dismantling or high grade recycling.
- Check options to implement legal design requirements.

Expected impact: The CSA will provide a basis for improved EPR, where circularity of products will be taken into account in the design phase. As a consequence losses in the recycling process will decrease and the recycling rate will increase.

Relation to current EU initiatives: The Circular Economy Action Plan encourages design for recycling through EPR and in the Raw Materials Strategic Implementation Plan EPR addresses this as a potential method to increase recycling. However, Horizon 2020 makes no mention of EPR.

Relevant value chains: ELV, WEEE, PPW

Type of action: CSA

Time frame: 5-10years

D.3. Development of rebate systems for collection of waste fractions

There are several examples of successful collection of waste fractions where customers are incentivized to return the product for a small reimbursement, for example collection of PET bottles, a discount when buying a new electronic device if the buyer has returned the old one, 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:

- Evaluate which products can be subjected to the rebate system
- Investigate the logistics needed for implementation of the systems in different Member States

- Suggest appropriate reimbursement fees and incentives for the producers and collecting partners to encourage them implement the system

Expected impact: The system, if implemented, will increase the collection rates of the targeted products and consequently expand recycling streams.

Relation to current EU initiatives: The European Innovation Partnership on Raw Materials Strategic Implementation Plan mentions take-back systems in action area II.5.4: Innovative approaches and infrastructures for reuse and recovery of end-of-life consumer products. The Circular Economy Action Plan and Horizon 2020 do not deal with the suggested action.

Relevant value chains: ELV, WEEE, PPW

Type of action: RIA

Time frame: 5-10 years

D.4. Evaluate the impacts of different policy mixes targeting effective material recycling

In order to enable and promote effective material recycling there is a need for a mix of policies. A policy mix includes a number of instruments and aims for several policy objectives and targets. The mix is also intended to facilitate synergies between the different instruments. Costs of policies and possible unintended side effects must be taken into consideration. This means that potential effects of policy mixes also need to be assessed.

If the recycling processes are to be efficient and economically viable a certain amount of waste must flow into the recycling plants and there must be commercial demand for the recyclate. Compelling producers to use recycled materials in new applications may serve as a driver to keep materials within their own product or brand value chains. Currently design efforts for circularity emanate from the 2009/125/EC Directive, which strives to establish a framework for ecodesign requirements for energy-related products. For packaging materials, demands related to recyclability are included within the Packaging Waste Directive. Whereas the Ecodesign Directive has focused more on energy consumption related aspects, a lack of design efforts for recyclability within this directive has been identified. Preparatory studies in the Ecodesign Working Plan 2016-2019 and other initiative measures designed to ramp up design efforts for recyclability are in the pipeline. However, it will be necessary to evaluate the efficiencies of the proposed measures, and to consider them as part of a larger policy mix.

Policies in such a mix could include:

- Policy for increased collection and recycling of all used materials (e.g., EPR, requirements on collection systems and sorting processes, weight-based waste collection fees, and design requirements promoting circularity, information system transferring knowledge concerning hazardous substance content)
- Policy for increased demand of recycled materials (e.g., tax on virgin materials or certificates for recycled content)
- Policy for innovation in technological processes (e.g., dismantling of WEEE and ELV, shredding and subsequent sorting)
- Policy for more efficient markets for secondary materials (e.g., creation and management of an exchange/market place for recycled plastics, creation and management of conferences or other forums for communication between the actors in the market)
- Overall policy for environmental protection and resource efficiency (e.g., green tax reform or green fiscal reform)

This action should:

- Identify concrete policy mixes for effective recycling
- Consider alignment with current legislation, e.g., chemical legislation
- Investigate research needs for policy areas as well as for specific instruments
- Evaluate the potential consequences of different policy mixes for effective recycling, taking into account potential environmental, economic and social impacts

Expected impact: Proposing and evaluating policy mixes will expand knowledge of potential consequences, facilitating improved and transparent policies and measures and the increased recyclability of products. These measures could be economic incentives in the Member States, and are vital for the establishment of a functional recycled raw material market. Proposals for eco-taxes (targeting the production of non-recyclable products, landfilling, incineration, etc.) can be implemented by the EC based on the increased knowledge provided by this action.

Relation to current EU initiatives: The Circular Economy Action Plan states that the Commission will examine options and actions for a more coherent policy framework that incorporates multiple product policy approaches to in their contribution to the circular economy. The European Innovation Partnership on Raw Materials' Strategic Implementation Plan includes an action area on the Minerals Policy Framework, including a benchmark analysis of policies, a fitness check on legislation and guidance on the streamlined application of EU legislation. However, the Strategic Implementation Plan is mostly focused on raw materials and virgin extraction. The proposed action thus forms an extension of the ambitions formulated in the Circular Economy Action Plan and a complement to the actions defined in the Strategic Implementation Plan.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA, CSA

Time frame: 5-10 years

D.5. Assessment of benefits of recycling and phase-out regimes for potentially hazardous substances

Some hazardous substances present in electronics and vehicles are regulated by the REACH, POP and RoHS legislations. Developments within this regulatory framework, such as risk assessment for substances not yet assessed or legislation updates, can result in changes that may impact the substances or concentration levels that are allowed in EEE and other products made of recyclates from WEEE fractions. Because of this, it is more difficult to use recycled materials containing certain hazardous substances from the WEEE stream. In addition, the WEEE Directive stipulates to separate the hazardous materials (depollution). The benefits of recycling and phase-out regimes for hazardous substances have to be balanced, and include sufficient lead times for the development and reduction of technically viable and safe substitutions.

This action should focus on:

- Developing methods for assessing the best approach for recycling of materials containing hazardous substances that comply with chemicals legislation and the protection of environment and human health
- Assessing resource efficiency potential, benefits and drawbacks in recycling of different materials containing hazardous substances

Expected impact: Implementation of assessment results for clarification of and guidance on regulation for 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.

Relation to current EU initiatives: The following activities called for by the Circular Economy Action Plan are related to the proposed action: Develop an improved knowledge base and support to SMEs for the substitution of hazardous substances of very high concern and 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. The European Innovation Partnership on Raw Materials Strategic Implementation Plan mentions hazardous materials, but no specific activities are defined. No overlaps with Horizon 2020 have been identified.

Relevant waste streams: ELV, WEEE

Type of action: RIA

Time frame: 5-10 years

D.6. Development of quality standards for ELV recycling

European nations lack a common, coherent and uniform quality assurance system for the collection, storage, logistics, processing, recycling, remanufacturing and reuse of ELVs. Collectors, processors and compliance systems would benefit from European standards , as these support a level playing field for operators by setting up minimally accepted levels and providing tools for industry enforcement. Furthermore, the role of substandard players is diminished, as a high level of downstream reporting is mandated. Only processors that adhere to developed minimum quality and reporting standards can participate and receive waste for recycling. Independent and trained auditors can be used to verify the quality of operations. The system can build on existing quality assurance systems already in place in the Member States.

A set of standards covering collection, sorting, storage, transportation, preparation for re-use, treatment, processing and the disposal of all kinds of ELVs should be developed and aim to cover all EU countries. A process of monitoring by audits will also be required.

This action should focus on:

- Setting a common European basis on compliance with EU health, safety and environmental legislation for ELV processors
- Creating harmonization in Europe on working practices, through validating, auditing and enforcing a similar standard
- Enhancing self-regulation and assisting governments on control-specific procedures

Expected impact: Common reporting methods across recycling chains at a European level will secure improved reliability for contracting parties as well as better self-regulation. This will also reduce mandatory audits and controls.

Relation to current EU initiatives: The proposed action is partly covered by related EU initiatives. The Circular Economy Action Plan addresses: Improved cooperation with Member States for better implementation of EU waste legislation, and combat illicit shipment of end of-life-vehicles, which is partially supported by the proposed action. Similarly, the European Innovation Partnership addresses quality standards designed to prevent illegal export and treatment. The proposed action could possibly make use of outcomes from projects under The European Innovation Partnership on Raw Materials Strategic Implementation Plan. No calls in Horizon 2020 address the proposed action.

Relevant waste streams: ELV

Type of action: CSA

Time frame: 5-10 years

D.7. European matching of vehicle registration, re-registration and deregistration systems

Traditional vehicle registration systems have not been designed to facilitate vehicle recycling. National fleet registers are initially intended to administer and communicate vehicle and ownership data, serve the needs of first responders, police, taxation units, legal liability and provide roadworthiness certification, etc. These mandatory systems are designed according to national standards, no common European vehicle deregistration system is yet in place.

In addition, new technologies such as hydrogen fuel cells and high voltage batteries impose new registration challenges in guaranteeing transparency and safety for the electrified vehicle and its environment.

While voluntary systems such as EUCARIS are in place in Europe, they have limited reach with regard end-of-life products. Also, exchange levels are often based to exchange driver data and cross border enforcement.

The registration/deregistration systems of the Member States differ in basic aspects such as continuous/non-continuous registration and conditions for permanent deregistration. Certain systems provide a better framework to steer ELVs into the legal ELV treatment facilities. Correct vehicle deregistration can facilitate qualitative recycling, and better communication between Member States can solve the problem of 'disappearing' ELVs. Uniform deregistration protocols are the starting point for well-functioning recycling systems, illegal practices might be phased out and consumers may be motivated to select the appropriate recycling system.

The action should focus on:

- Improving understanding on the best way to link deregistration systems to end-of-life treatment; vehicle deregistration as a key information source for the recycling chain.
- Harmonising registration and identification of novel but safety-sensitive components (such as batteries and fuel cells)
- Vehicle deregistration becoming an indispensable part of existing platform discussions and knowledge building

Expected impact: Minimization of the 'business case' of substandard recyclers and incentivizing consumers to deliver ELVs at authorized treatment facilities.

Relation to current EU initiatives: The Circular Economy Action Plan addresses the illegal shipment of ELVs and the European Innovation Partnership on Raw Materials Strategic Implementation Plan addresses the illegal shipment of waste. Horizon 2020 does not deal with this to any great extent. The proposed action of having a common European system for vehicles as mentioned above can support the Circular Economy Action Plan and could possibly make use of results from EIP.

Relevant waste streams: ELV

Type of action: CSA

Time frame: 5-10 years

E. Design for circularity

E.1. Collaborative design for circularity

Ecodesign can be defined as a strategic management approach that considers the environmental impact of the full product life cycle. In addition to environmental criteria, product designers must satisfy a slew of demands regarding product properties and functionality. According to Circular Economy Action Plan, Ecodesign is a key factor when it comes to enabling the circular economy. In order to reach this goal, products should be designed in such a way as to leverage high-quality recycling of materials at the end of the product life span. In addition, product design has been identified as one of the bottlenecks that currently hinder an effective recycling of different products and waste streams. In order to overcome these bottlenecks, new design approaches promoting circularity must be developed, and an increased collaboration put in place between designers, manufacturers and recyclers. The needs of the end-users and demands originating from the European policy framework should also be considered.

The action should focus on:

- Connecting the right actors in a concrete design case, targeting the actual delivery of a new product design, as a practical case example
- Within the studied case example(s), identifying the key components with the greatest benefits or potentials by "design for dismantling or high grade recycling".
- Providing opportunities for networking, match making and mutual learning leading to concrete development projects
- Establishing and proposing potential means for institutionalizing the communication between designers, manufacturers and recyclers.
- Identifying obstacles and potential solutions for increasing collaboration between value chain actors

Expected impact: Producers and recyclers will increasingly collaborate in order to enable design for circularity within selected product groups. New recyclable products are showcased and practical frameworks or tools to support design for circularity are introduced.

Relation to current EU initiatives: The Circular Economy Action Plan and the European Innovation Partnership on Raw Materials Strategic Implementation Plan both address and encourage collaboration but do not specifically address design issues. The proposed actions complement both initiatives. Horizon 2020 does not cover this topic.

Relevant waste streams: ELV, WEEE, PPW

Type of action: CSA

Time frame: 0-5 years

E.2. Understanding consumer behaviour and drivers for recycling

Consumer demand and practices are important drivers for the development of more resource efficient products. Understanding consumer behaviour, and the values behind purchase decisions, is necessary both when designing products to be attractive to consumers, and when providing consumers with the necessary information for making sustainable decisions. In addition, current motivations for recycling are not properly understood. For example, a multitude of small recyclable electronic devices and batteries currently reside in drawers and cupboards in the homes of consumers, or are tossed into municipal waste, causing a significant loss of valuable materials. An interdisciplinary research approach, combining relevant fields of research (such as economics, marketing, sociology, and environmental or sustainability sciences) is considered important for addressing this topic.

The action should focus on:

- Understanding potential drivers and motivations for increasing take back to WEEE collection points by consumers (including attitudes and preferences regarding different waste collection systems and related economic incentives)
- Considering different product groups (e.g., among the product groups targeted within the Ecodesign Directive or other products with significant material savings potential and low collection rates) and related specific requirements from a consumer point of view (such as long-living versus short-living products, electronic devices, domestic appliances)

Potential differences in consumer segments (e.g., related to age, gender, income) and impact of cultural aspects and values should be included in the analysis.

Expected impact: An understanding of the psychological, economic and practical drivers necessary for promoting recycling that are essential for increasing the collection rates of recyclable materials and products, such as different packaging materials and small electronic devices. Understanding consumer demands and requirements related to resource efficient products could be utilized to guide product development and to provide consumers with tailored information, supporting sustainable and resource efficient purchase decisions. As a consequence this might lead to improved collection solutions and policies.

Relation to current EU initiatives: The Circular Economy Action Plan addresses this issue in the section dealing with consumption. The European Innovation Partnership on Raw Materials Strategic Implementation Plan recognizes that there is not enough known about consumer behaviour, but does not suggest any actions. Horizon 2020 does not bring up the issue.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA

Time frame: 0-5 years

E.3. Product design indicators including impacts of recycling

Product design is a key factor when the circular economy is addressed. Low recyclability of products, components or raw materials can lead to increasing costs, environmental burdens and losses of raw materials. According to the principles of circular economy, product design should enable high-quality recycling of materials at the end of the product life span. Ideally, potential benefits and burdens related to the product end-of-life (including recycling, re-use or disposal) should be considered already in the product design phase, and in relation to other life cycle stages (such as manufacturing and use phases). However, there is a lack of agreed metrics or indicators describing the effect of product design on recycling, both on a micro level (product) and macro level (economy or country) (European Environmental Agency, 2016). This means that the real impact of product design on recycling remains unclear and difficult to assess. Information on recyclability or recycling efficiencies is required to direct customer demand and product designs towards products that provide material savings and make efficient use of materials throughout the entire life cycle.

Research activities should consider the developments of the relevant European standards related to material efficiency aspects of the ecodesign criteria for energy-related products (C(2015) 9096 final) and their compatibility with developed indicators. Previous studies and existing methods for assessing material efficiency should be included in the study.

The action should:

- Develop and explain how recyclability should be defined (taking into account quality aspects) and measured in a way widely accepted by stakeholders
- Develop indicators for measuring the impact of recycling in relation to overall material use and resource efficiency, using a life cycle approach (micro level)
- Develop indicators for evaluating progress towards ecodesign and circular use of materials (macro level)
- Create recommendations for future standardization or harmonization activities in the field of resource efficiency assessment

Expected impact: The indicator will quantify the effect of product design in recycling efficiency and resource use. It will indicate to designers the value of designing for recycling. Recycling-friendly product design would become more concrete for consumers and this will mean that their purchasing decisions can be used to affect future product design and the manufacturing industry as a whole.

Relation to current EU initiatives: According to the Ecodesign Working Plan (2016-2019) possibilities for including material efficiency requirements in product regulations should be investigated systematically. This action contributes to the development of a circular economy 'toolbox' for ecodesign, which leverages the resource and material efficiency aspects of new product groups and the revision of existing implementing measures set forth in the Ecodesign Directive. This action should contribute to resource efficiency assessment, life cycle thinking and sustainable product design in general, in line with the goals of the Circular Economy Action Plan.

Relevant waste streams: ELV, WEEE, PPW

Type of action: RIA

Time frame: 0-5 years

E.4. Design of vehicle components for circularity

The automotive industry is constantly exploring and developing new component innovations in vehicle design and manufacturing. This generates new vehicles and services with low fuel consumption and minimal environmental impact, principally in the use phase of the vehicle.

Consequently, many product design innovations have resulted in new lightweight composite structures and the integration of different type of materials and components, such as electronics and interior or chassis components. This may both provide opportunities and have negative consequences for the recycling chain.

A joint research effort of recyclers and manufacturers across the supply chain is needed to quantify the effect of innovative design on recycling efficiency, taking into account recycling aspects, attributes and properties in product design and the manufacturing stage.

The action should:

- Explore prospects for manufacturing and designing components and vehicle parts with the minimum amount of materials commensurable with functionality and efficiency
- Develop innovative fastening methods for components/parts to improve the liberation of parts
- Focus on the development of modularity of parts within the vehicle, without compromising functionality
- Identification of suitable alternatives that can be used as substitutes for hazardous substances
- Identify key components where a better design for dismantling could be beneficial and develop design solutions for these components.

Expected impact: The recycling of ELVs is improved through better liberation of parts/components and separation efficiency generating better quality concentrates/fractions for further recovery is encouraged. In addition, losses generation can be reduced as well as the avoidance of contaminants.

Relation to current EU initiatives: While ELV is not mentioned as a specific area of interest in the existing EU initiatives on circular product design, this action is in line with what is proposed in other EU initiatives. The Circular Economy Action Plan includes a specific section on product design with explicit reference to the Ecodesign Working Plan. The European Innovation Partnership on Raw Materials Strategic Implementation Plan addresses product design with a focus on CRM and metals. Horizon 2020 includes proposals on life cycle management and design for reconfigurability, reuse and disassembly (FOF-20-2017). In addition, the Draft Orientations for Horizon 2020 2018 – 2020 include a call for research into planned obsolescence. This Agenda's action can thus build and expand on existing and upcoming initiatives with regard to product design for ELVs.

Relevant waste streams: ELV

Type of action: RIA

Time frame: 5-10 years

E.5. Design of consumer electronics for circularity

The use of electronics is on the rise in society. Together with improvements in our current electronic devices and new applications such as smart clothes, new solutions in manufacturing and technology have been developed. For example, miniaturization and integration of components and parts enables the incorporation of electronics into new applications and variable designs. However, these changes will create challenges in the recycling phase, for example, in liberation and the separation of materials. In addition, the portability and mobility of various electronic devices are among the key demands posed by consumers. This leads to the lighter, thinner and cordless features of many devices. Additionally, long-lasting energy supply from batteries and accumulators is a necessity for portable devices, and this means increasing battery consumption and lastly a need for recycling. Due to increasing numbers of electronic devices more research is needed on integrating principles for effective recycling into product design and manufacturing steps.

The action should focus on:

- Exploring the possibilities of manufacturing and designing components and parts within applications with a minimum amount of materials without losing functionality and efficiency
- Developing innovative fastening methods for components/parts which will improve the liberation of parts in the sorting and recycling process
- Development of modularity of parts within applications
- Identification of suitable alternatives that can be used as substitutes for hazardous substances

Expected impact: The recycling of electronic devices is improved through better liberation of parts/components and furthermore separation efficiency generates improved quality concentrates/fractions for further recovery. In addition, losses generation can be reduced and contamination avoided.

Relation to current EU initiatives: The Circular Economy Action Plan includes a specific section on product design, with reference to the Ecodesign Working Plan. WEEE and CRM are specifically mentioned as an area of attention. The European Innovation Partnership on Raw Materials Strategic Implementation Plan addresses product design with a focus on CRM and metals. Horizon 2020 includes proposals on life cycle management and design for reconfigurability, reuse and disassembly (FOF-20-2017). In addition, the Draft Orientations for Horizon 2020 2018 – 2020 include a call for research into planned obsolescence. This Agenda's action can thus build and expand on existing and upcoming initiatives with regard to product design in consumer electronics.

Relevant waste streams: WEEE

Type of action: RIA

Time frame: 5-10 years

E.6. Design of packaging for effective recycling

Packaging applications are becoming more advanced; the use of a wide variety of materials creates challenges for separation prior to recycling, and risks contaminating homogeneous material flows. The use of one type of polymer throughout the whole packaging application will facilitate both sorting and recycling steps. However, this is challenging since important materials properties must be retained. A lot of research is being conducted on the reinforcement of materials with fibres from the same source/polymer type. Another possibility is to create multi-layered structures using one material, but with different characteristics in the layers, or to develop multi-layered structures that can be easily separated in the recycling phase.

The action should focus on:

- Exploring the possibilities of using a single material for the application, assuring the required material properties, such as barrier properties, mechanical strength and flexibility
- Development of innovative, easy-to-recycle material systems that can provide prolonged food shelf-life
- Development of specific additives enabling different polymer blends that also support recyclability
- Development of recyclable, multi-layered structures that are easy to separate/recycle

Expected impact: The recycling of the packaging applications is improved through reduced need for separation of different material fractions, and improved recyclability of multi-layered structures; this also prevents contamination of the resulting recycled raw materials.

Relation to current EU initiatives: The Ecodesign Working Plan that is included in the Circular Economy Action Plan will elaborate on how product requirements will be implemented in a specific section on product design. Plastics are specifically mentioned as an area of attention in the Circular Economy Action Plan. The European Innovation Partnership on Raw Materials Strategic Implementation Plan addresses product design but with a focus on CRM and metals. Horizon 2020 includes proposals on design for recycling, but not specifically on plastics. The proposed action thus addresses design of plastic packaging where other initiatives do not.

Relevant waste streams: PPW

Type of action: RIA

Time frame: 5-10 years

E.7. Investigate the consequences of introducing degradable materials in the loop

New degradable materials are increasingly entering the market as an environmentally friendly alternative. These materials can interfere with existing separation and recycling processes. Several studies have been carried out to ascertain the effect these materials may have on the properties of the resulting recyclates when mixed with the bulk material fraction. More research is needed on issues surrounding the separation and recycling of mixed streams of degradable and conventional materials.

The action should focus on:

- Possibilities and challenges encountered when separating degradable materials from collected fractions
- The characterization of the material properties of recyclates containing varying amounts of degradable material content
- Development of new technological solutions for recycling of degradable materials

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

Relation to current EU initiatives: This proposed action has not been addressed in any of the three EU initiatives. It is therefore a relevant addition to the existing initiatives targeting the life cycle of plastics.

Relevant waste streams: PPW

Type of action: RIA

Time frame: 0-5 years

NewInnoNet

Project title: The Near-zero European Waste Innovation Network

Project acronym: NEW_InnoNet

Grant Agreement No.: 642231

Starting date: 01-02-2015

Duration: 30 months

Website: www.newinnonet.eu

Project Coordination: Tjerk Wardenaar, PhD
PNO INNOVATION

Schorpioenstraat 65; 3067 GG Rotterdam; Netherlands
tjerk.wardenaar@pnoconsultants.com

Project Consortium:

PNO CONSULTANTS BV (PNO)	Van Gansewinkel Groep B.V.	FUNDACION Tecnalia Research & Innovation
VTT Technical Research Centre of Finland	IVL Swedish Environmental Research Institute	STIFTELSEN SINTEF
Institute for Ecology of Industrial Areas	ARN Holding B.V.	Plastics Recyclers Europe
European Plastics Converters	IHOBE S.A.	VITO n.v.

NEW_InnoNet is a European project and stakeholder platform within the context of Horizon 2020. Between 2014 and 2017, the project conducted bottleneck analyses, drafted roadmaps and identified promising use cases for circular economy in the automotive, electronics and plastic packaging sectors. The analyses and close interactions with 175+ stakeholders resulted in a Strategic Research & Innovation Agenda (SRIA). The NEW_InnoNet SRIA emphasizes the need for more innovation in recycling in order to quickly and effectively unleash the true power of the circularity of materials, in addition to necessary actions on waste prevention, reuse and remanufacturing. The SRIA proposes research and innovation actions to be taken. The agenda is supported with a policy brief, where policy recommendations are given to provide for a context where innovation in recycling can thrive and develop (www.newinnonet.eu).

Unleashing the power of secondary materials: A strategic research and innovation agenda for effective material recycling from ELV, WEEE and plastic packaging waste streams

NewInnoNet

www.newinnonet.eu