Istituto di Tecnologie Industriali e Automazione
Consiglio Nazionale delle Ricerche

from research …. to market

Sistemi di De-and remanufacturing per l'economia circolare

Marcello Colledani[b,c] , Prof. Tullio Tolio[a,b], Dr. Giacomo Copani[a], Prof., Dr. Nicoletta Picone[a]

(a) Director of ITIA-CNR, Institute for Industrial Technologies and Automation

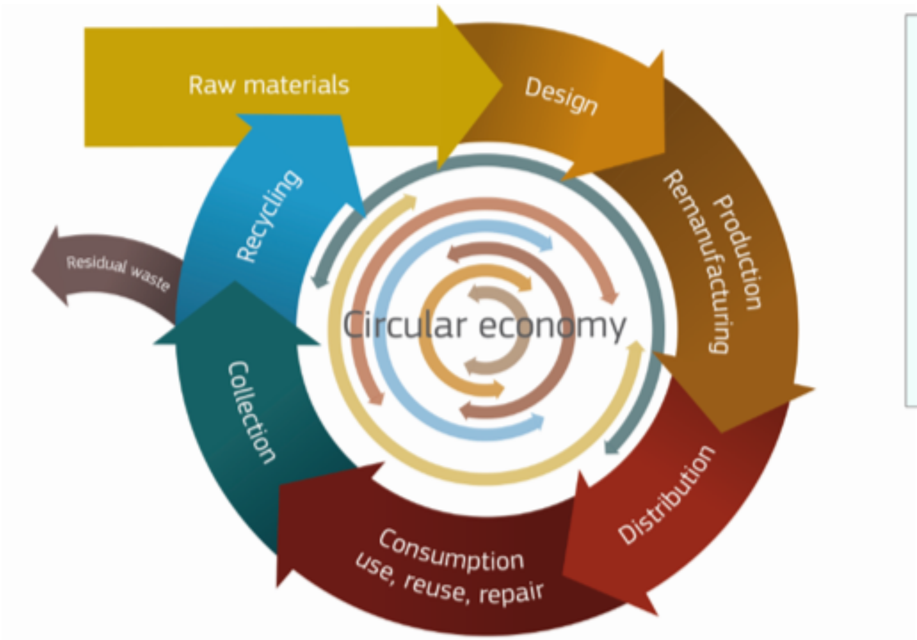
(b): Professor at the Department of Mechanical Engineering – Politecnico di Milano – Italy.

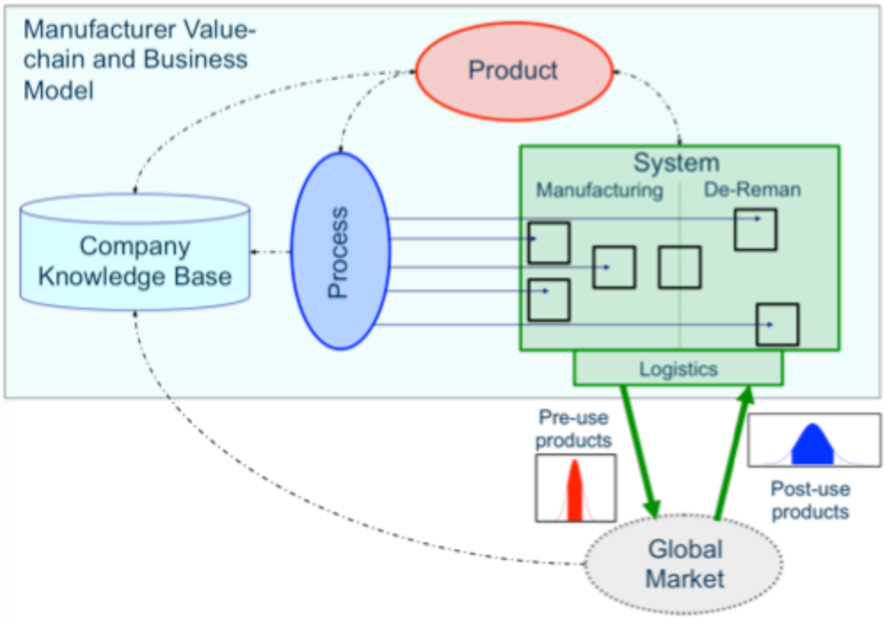
(c): Research Associate at ITIA-CNR, Institute for Industrial Technologies and Automation.

SOStenibilità delle TEcNologie ManifatturiERE: dalla teoria alla pratica. Milano, 29-1-2018.

De-and remanufacturing in a Circular Economy

De- and remanufacturing can be defined as the set of technologies, tools and knowledge-based methods to recover, re-use and upgrade materials and functions from post-consumer products, to support a sustainable implementation of the circular economy paradigm.





A de- are remanufacturing system includes the set of resources (human and technological), organization, IT infrastructure and associated business model to enable product de-and remanufacturing.

Challenges and requirements for De-and Remanufacturing systems

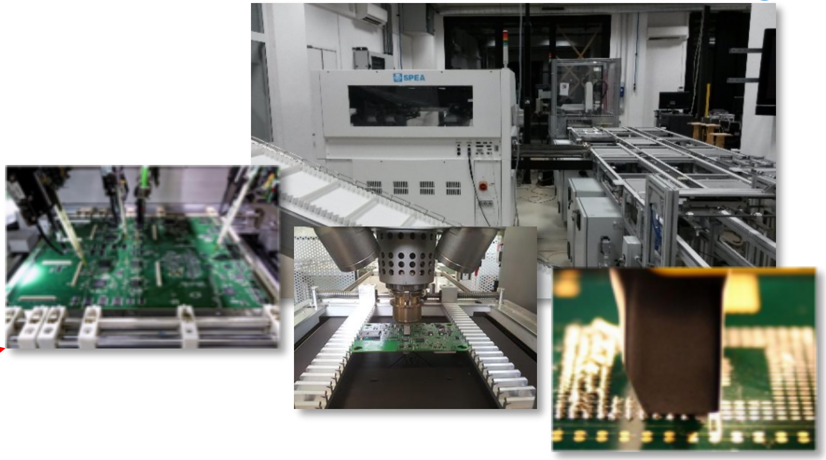
Global trends	Challenges and Requirements
Short life cycle of products and high product variety.	Flexibility and reconfigurability.
High variability in the conditions of post-consumer parts.	Variability of process sequences and processing times.
Pressure on costs and efficiency.	Need for hybrid automation solutions.
Poor information about return products.	• Need for ICT solutions and big data management systems. • Need for in-line part and materials inspections.
High fluctuation in materials' value.	Emphasis on business models, inventory and production planning.
Increasing product complexity.	• Need for knowledge based tools. • Involvement of the manufacturer.
Increasing quality requirements on recovered components/materials.	Need for automation, repeatability of the processes and quality assurance.
Increasing attention on safety and ergonomics.	Need for human-centric design of disassembly/sorting workstations.

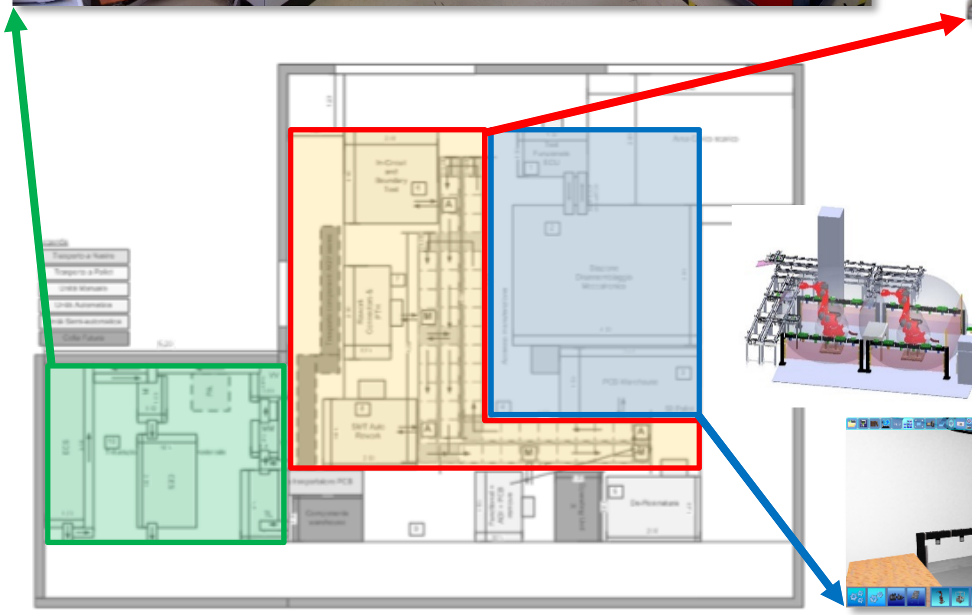
Need for advanced methodologies, tools and enabling technologies for the **smart de-and remanufacturing systems of the future**.

An integrated Pilot Plant for the remanufacturing and recycling of mechatronic components (automotive, large machinery, electronics, white goods), is being designed and installed at ITIA-CNR (January 2013). The pilot project was funded by Regione Lombardia with a grant of 1.5 Million Euro.

Cell 3: Recycling

Cell 2: Reworking



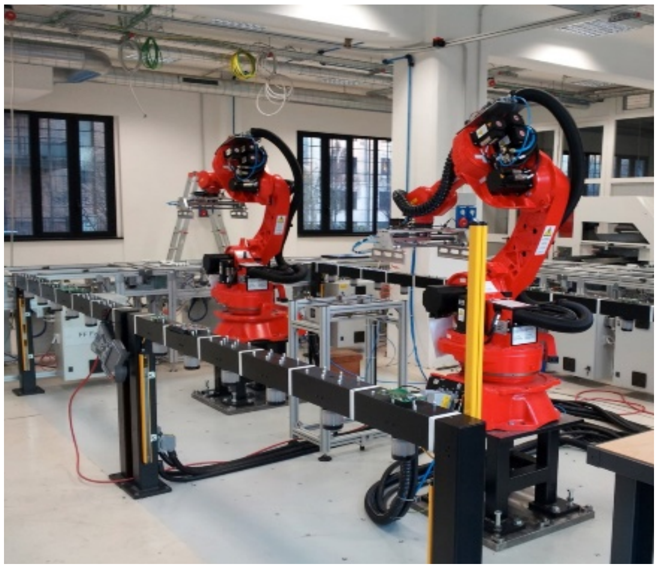


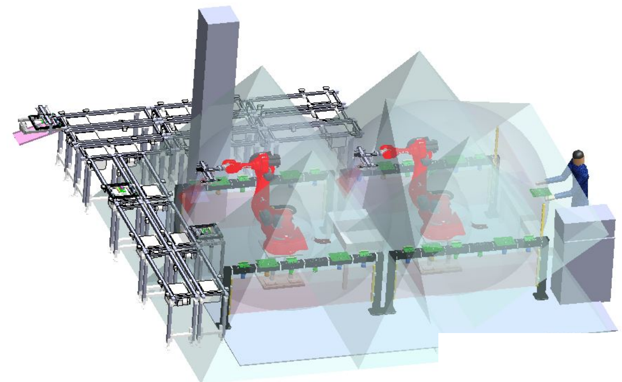
Cell 1: Disassembly

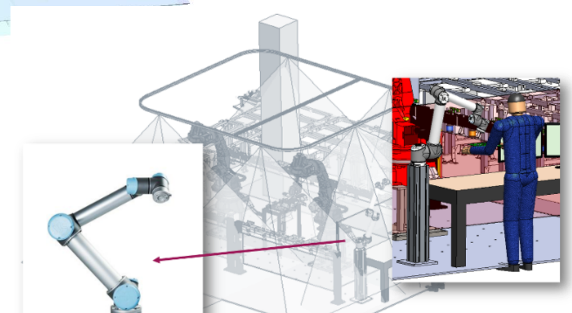
Cell 1: Robotic Disassembly

Challenges and limitations:

- High variability and uncertainty on the status of the product.
- High cost and rigidity of automated solutions (*“Sony Minidisc”, “Fuji single-use camera”*).







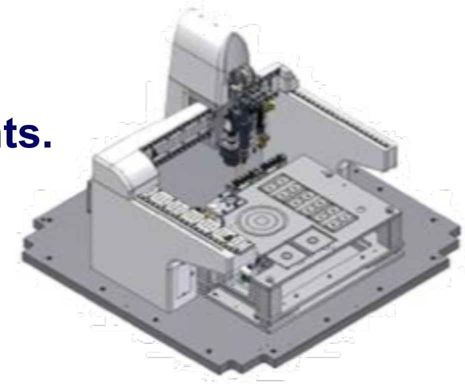
Robot-Human Cooperation in PCBs disassembly

Objective:

- To disassemble the mechanical part from the electronic part of the mechatronic component by exploiting man-machine cooperation.
- To re-assemble the component after the treatment.

Key Issue: man-machine cooperation.

Cell 2: Selective electronics disassembly and rework

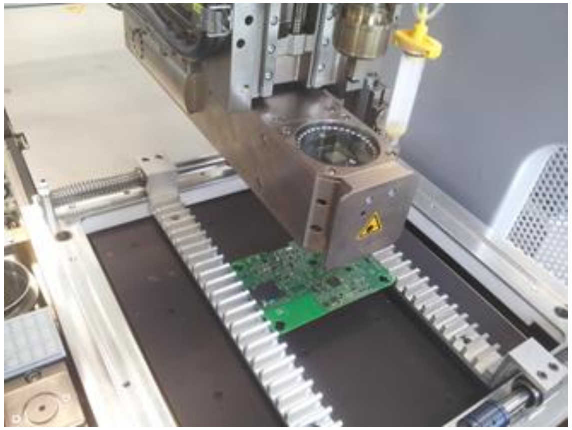


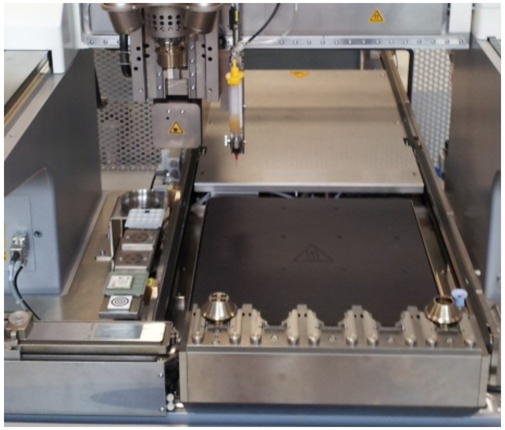
Requirements:

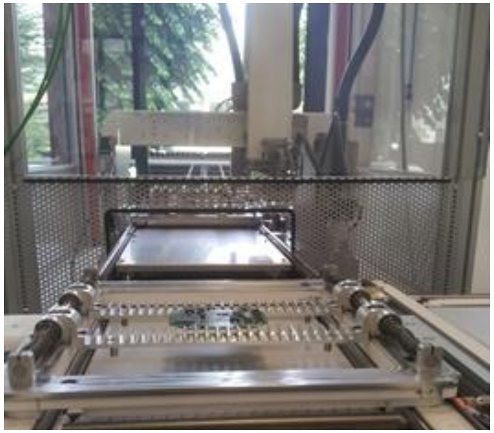
- Need to automatically treat **heterogeneous PCBs and components.**
- Strong requirements on **cycle times**.

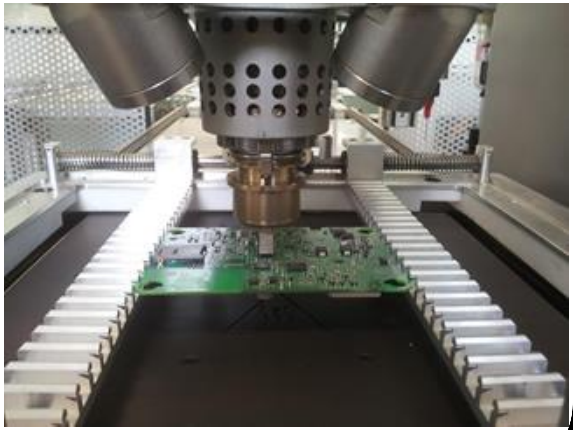
Features:

- **Gantry architecture**, based on linear motors.
- **Vision system,** for X-Y automatic compensation.
- **Force control** in Z, to prevent damages on PCBs.
- **Automatic tool change.**
- **Automatic pallet load/unload.**
- **Automatic flux and soldering paste dispenser.**





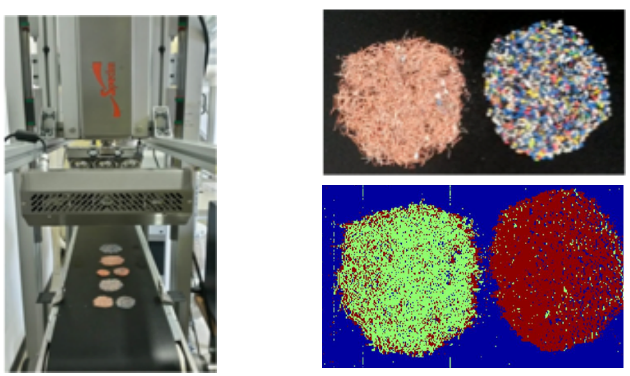




Cell 3: “Intelligent” Recycling Processes

Challenges: Rigid processes, the process parameters remain unchanged independently on the product properties. As a result, mechanical processes are poorly adopted for complex products (e.g. PCBs).

Objective: To develop flexible mechanical recycling processes and systems for optimal pre-treatment of complex material mixtures.



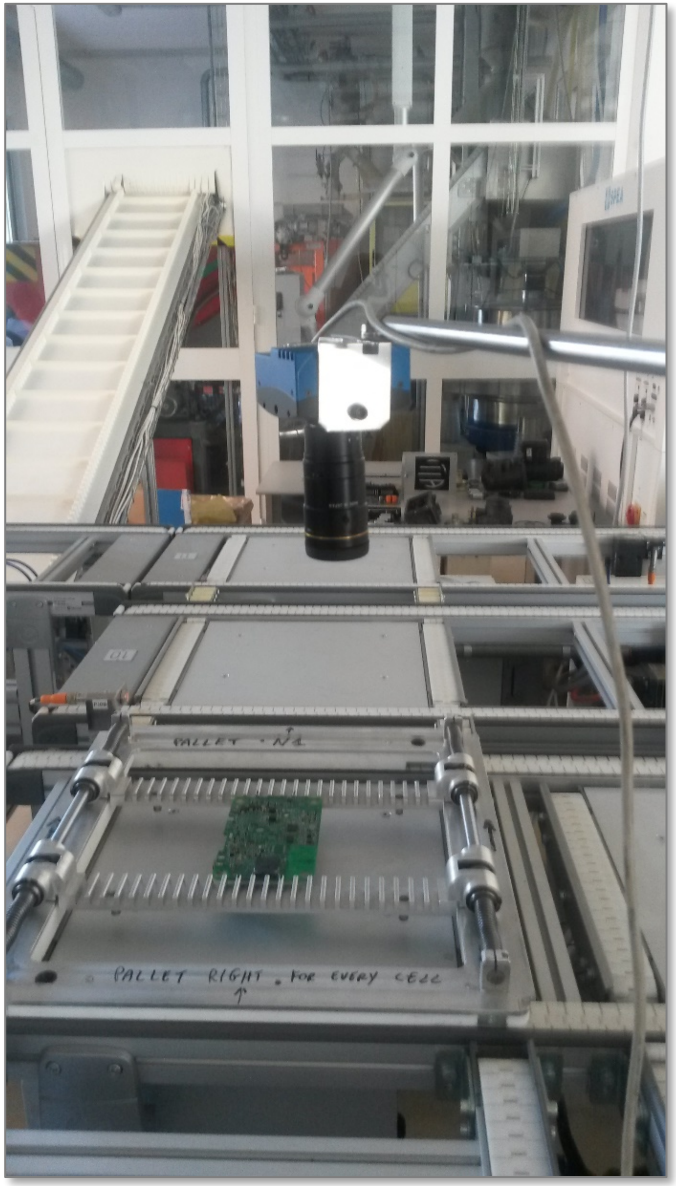
Hyperspectral imaging to perform the on-line classification of product conditions and mixtures.

In-line optimization of the process parameters to adapt to the material characteristics.

Technical enablers

Knowledge-based vision system

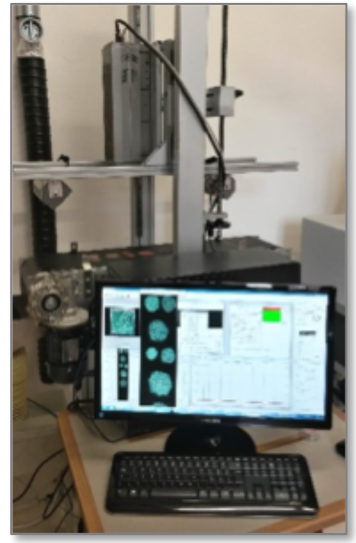
Technology ability	Detection (image)
	Pattern recognition (objects)
	Identification (group assignment)
	Prediction (material composition)
Contribution to processes adaptability	EoL products value prediction
	Process flow configuration
Current TRL	TRL: 5
Limitations and challenges	- Requires a reference EoL products database (material declarations) - Generalization of recognition algorithms. - Slow recognition analysis for in-line applications.

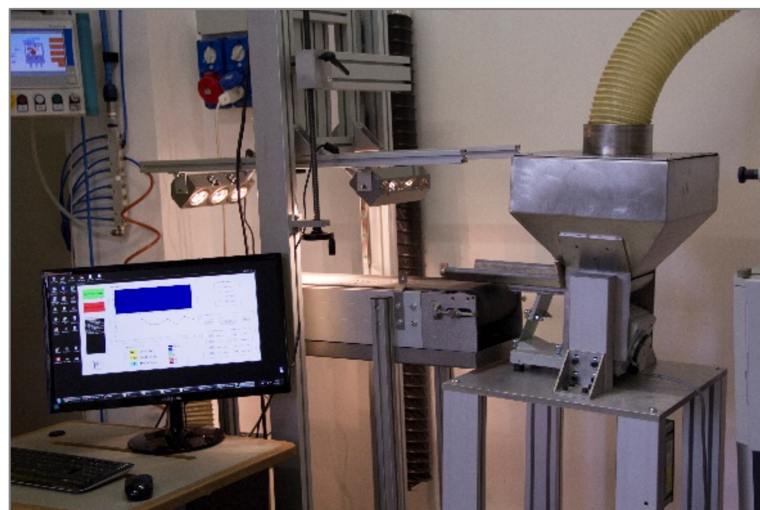


Technical enablers

In-line material characterization

Technology ability: HyperSpectral Imaging	Detection (signal)
	Recognition (objects)
	Classification
	Characterisation
Contribution to processes adaptability	On-line material characterization: full material data storage and traceability
	Remote monitoring and control of the process
Current TRL	TRL: 9 (few sectors)
Challenges and limitations	- Algorithms customization - Fine particles characterization - Detection problems: shadows, specular reflection, edge effect



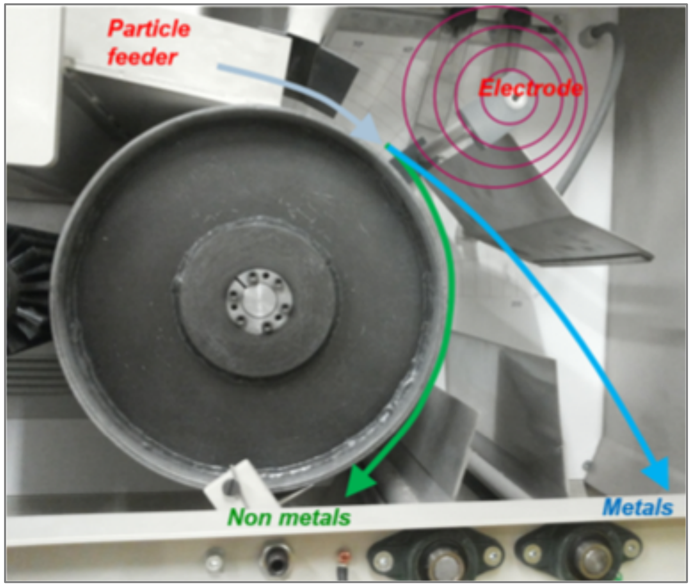


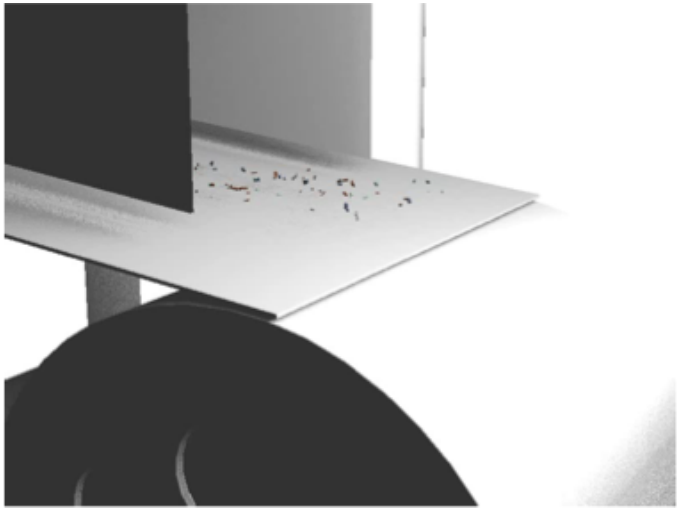
Technical enablers

Process modelling and simulation

Technology: Multi-body simulation	Process physic simulation
	Simulation of impacts between particles in motion
	Short time simulation of very complex systems (millions of interacting particles)
Contribution to processes adaptability	Prediction of output processes
	Process parameters optimization
	Model-based control of process parameters
Current TRL	TRL: 5
Limitations and challenges	- Difficult to model particle mixtures. - Computational times.

Example for Corona Electrostatic Separator





Technical enablers

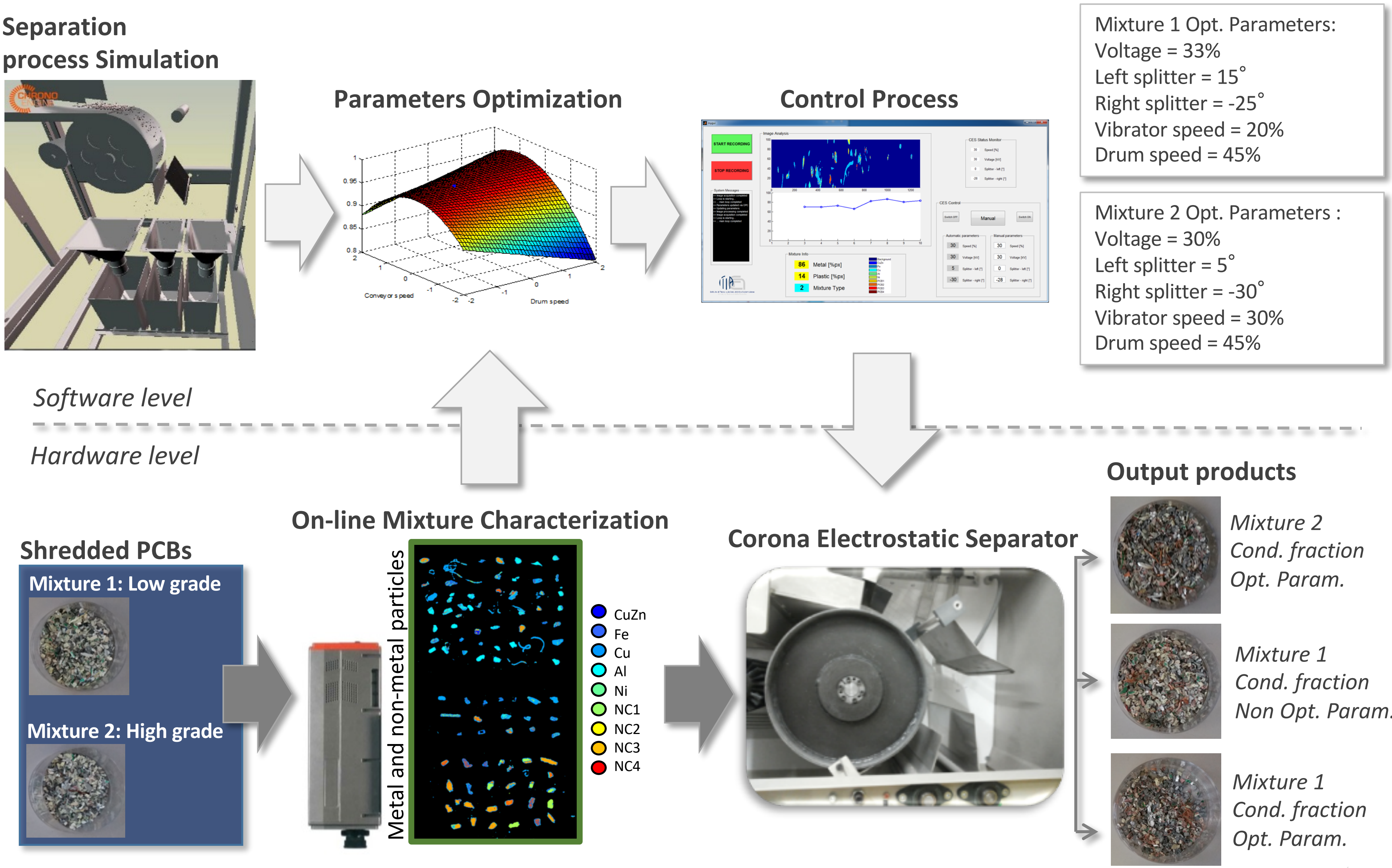
System-level material flow simulation

Technology: Virtual deman system model	Test of alternative material flow solutions and process chains
	Integration with process modelling
Contribution to processes adaptability	Analysis of optimized process flows during the flow adaptation phases.
Current TRL	TRL: 8
Limitations and challenges	High fidelity representation of the system

Example for Robotic Cell at the Demanufacturing Pilot Plant

Application example

Architecture of the CPS for the on-line adaption of demanufacturing processes



Industrial Partners and Active Projects

Ongoing/Past Projects and Industrial Collaborations:

CarE-Service: Circular Economy oriented services for re-use and remanufacturing of hybrid and electric vehicles components.

FiberEUse: Large scale demonstration of new circular economy value-chains based on the reuse of end-of-life fiber reinforced composites.

FIDEAS: Fabbrica Intelligente per la Deproduzione Avanzata e Sostenibile.

Zero-Waste PCBs: Integrated Technological Solutions for Zero Waste Recycling of Printed Circuit Boards (PCBs).

WEEE ReFlex: Highly Evolvable E-waste Recycling Technologies and Systems.

National Cluster: Intelligent Factory – Project 1.3 – Demanufacturing.

Cyber-Sort: Integrated multi-sensor technologies for the identification and sorting of EoL products.

SCREEN: Synergic CirculaR Economy across European regioNs.

CircE: European regions toward Circular Economy.

FiberEUse Project

Large scale demonstration of new circular economy value-chains based on the reuse of end-of-life fiber reinforced composites.

Topic: Systemic, eco-innovative approaches for the circular economy: large-scale demonstration projects (CIRC-1-2016)

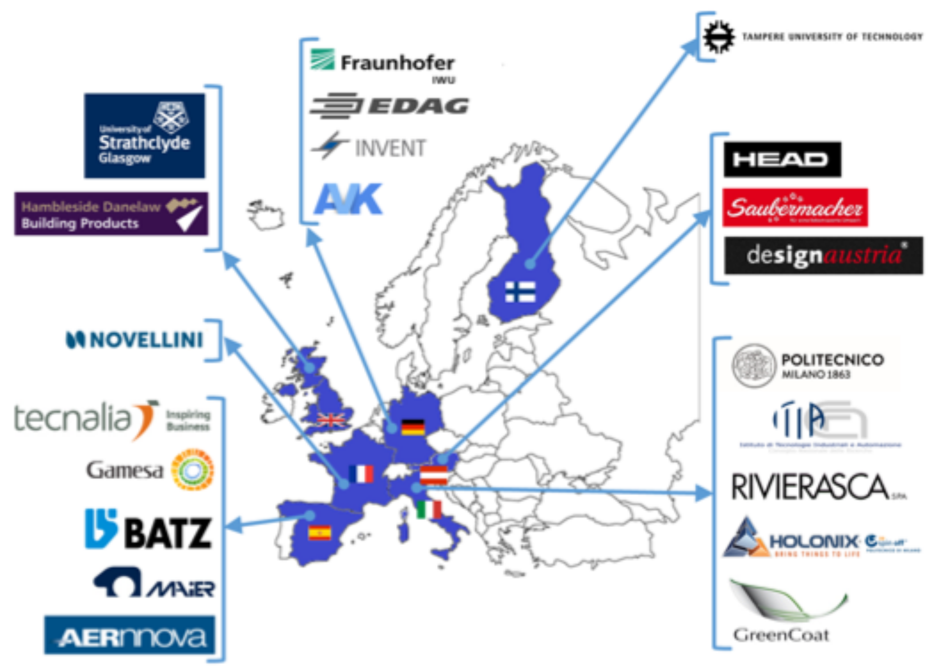
The FiberEUse project aims at integrating in a holistic approach different innovation actions aimed at enhancing the profitability of *composite recycling and reuse in value-added products.*

***Duration*: 48 months, starting on June 2017.**

Consortium: 21 partners, from 7 EU countries.

Coordinator partner: Politecnico di Milano

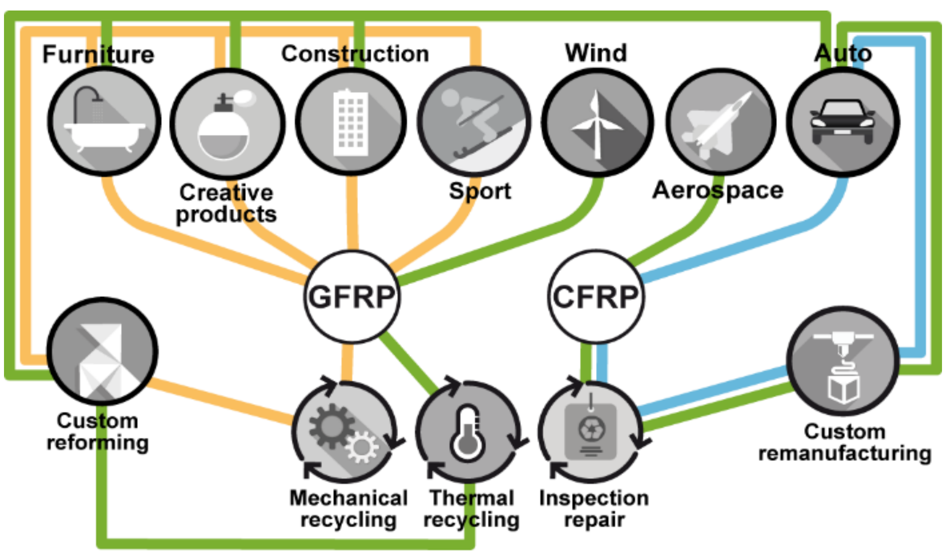
EC Funding: ca. 10 mln €.

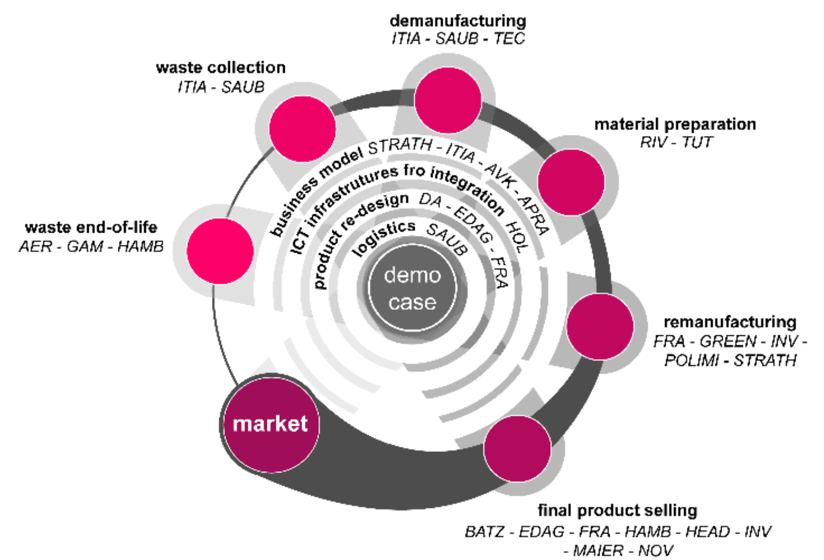


FiberEUse cross-sectorial use-cases

The FiberEUse proposal aims to develop and demonstrate at a large scale:

- The integration of ***innovative remanufacturing technologies*** addressed to develop profitable reuse options for mechanically or thermally recycled EoL GFRP and CFRP composites.
- The development of ***an innovation strategy for mobilization and networking of stakeholders*** from all the sectors related to composites.



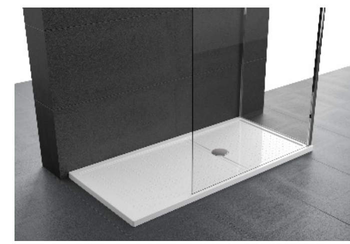


Use case 1: Demo-cases

The main technical challenges of the Use Case 1 will be:

- Optimization and automation of mechanical grinding of GFRP waste for low-cost recycling.
- Optimization of innovative 3D-printing processes for the remanufacturing of GFRP recyclates with high recyclate content and sustainable resins.
- Low cost and environmentally friendly surface finishing by UV-curing / PVD metallization of remanufactured GFRP.

Examples of output products




- **Demo-case 1.1:** Use of a fraction (at least 40% w/w) of GFRP recyclate in open mould spray applications of GFRP for *sanitary products* (bath tubs, shower trays).

NOVELLINI

- **Demo-case 1.2:** Use of a fraction (at least 30% w/w) of GFRP recyclate for prototyping *personalized and creative products* (i.e. creative packaging etc).

designaustria

- **Demo-case 1.3:** Use of a fraction (at least 10% w/w) of GFRP recyclate to strengthen PU compounds for the realization of *sport equipment* (e.g. skis).

HEAD

Use case 2: Demo-cases

Thermal recycling of long fibers (glass and carbon) and re-use in high-tech, high-resistance applications. The input product will be EoL wind turbine and aerospace components the re-use of composites in automotive (aesthetical and structural components) and building will be demonstrated by applying controlled pyrolysis and custom remanufacturing.

- **Demo-case 2.1** use of a fraction (at least 20%) of thermally recycled *GF for structural components in automotive*. BATZ
- **Demo-case 2.2** use of a fraction (at least 20%) of thermally recycled *CF for structural components in automotive*. MAIER
- **Demo-case 2.3** use of a fraction (at least 30%) of thermally recycled *GFRP for the building industry* (roofs). Hambleside Danelaw Building Products

Examples of output products

Use case 3: Demo-cases

FiberEUse

Inspection, repair and remanufacturing for EoL CFRP products in high-tech applications. Adaptive design and manufacturing criteria will be implemented to allow for a complete **circular economy demonstration in the automotive sector**.

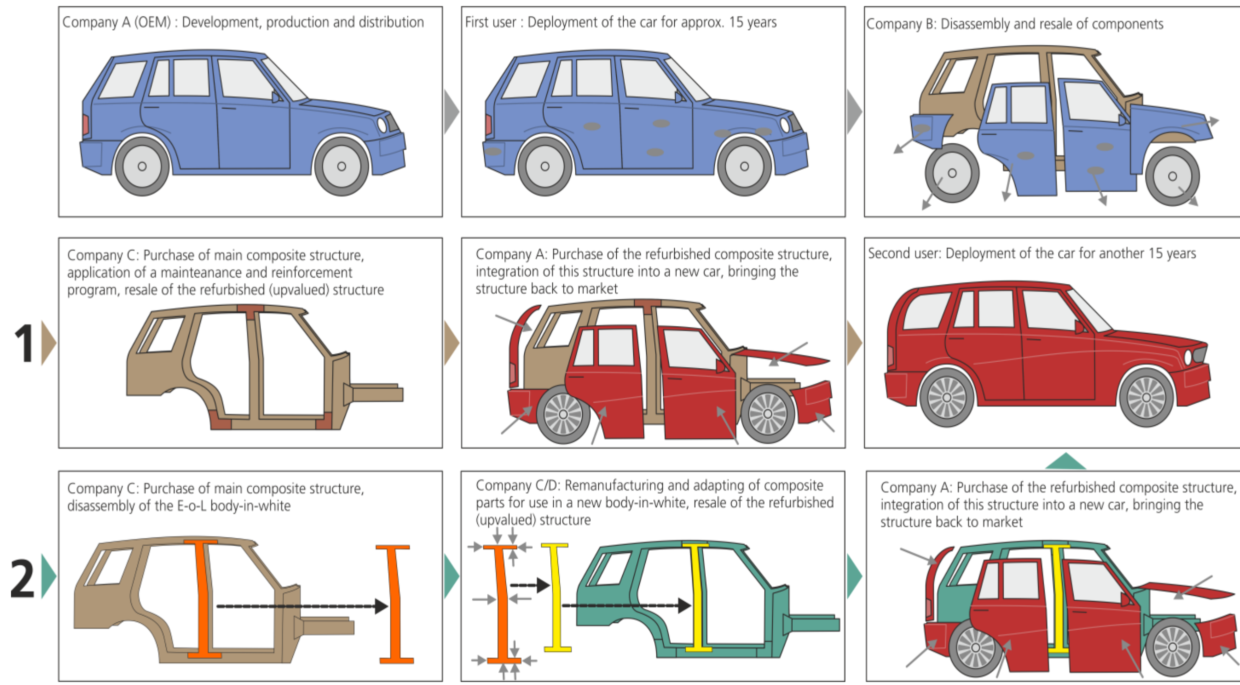
- **Demo-case 3.1:** design and remanufacturing of a CFRP *chassis component* (synergies with use-case 2).

EDAG

- **Demo-case 3.2:** design and remanufacturing of inner *body car structure* with refurbished CFRP.

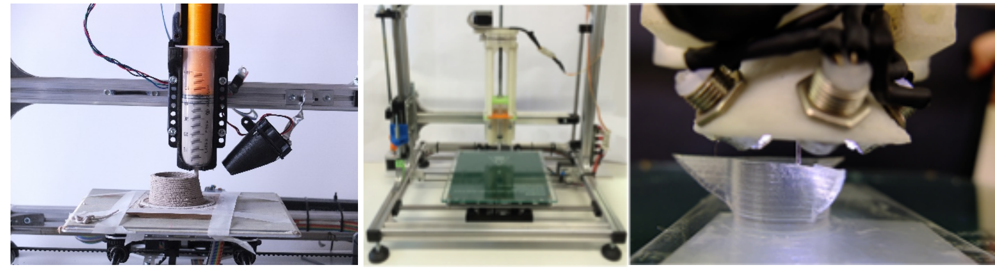
INVENT

Examples of output products

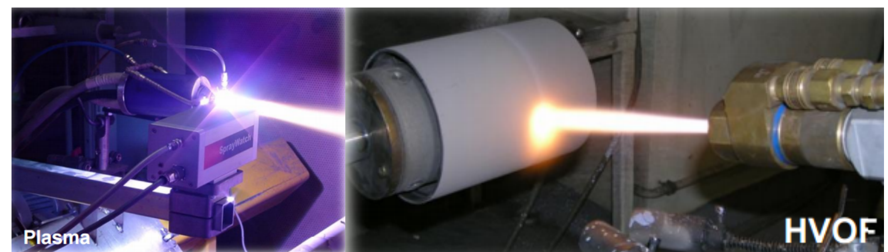


Example of Innovative Processes and Technologies

BATZ – In-line compound technologies.



POLIMI - 3D printing of clay-based compounds, LDM, UV-assisted LDM.

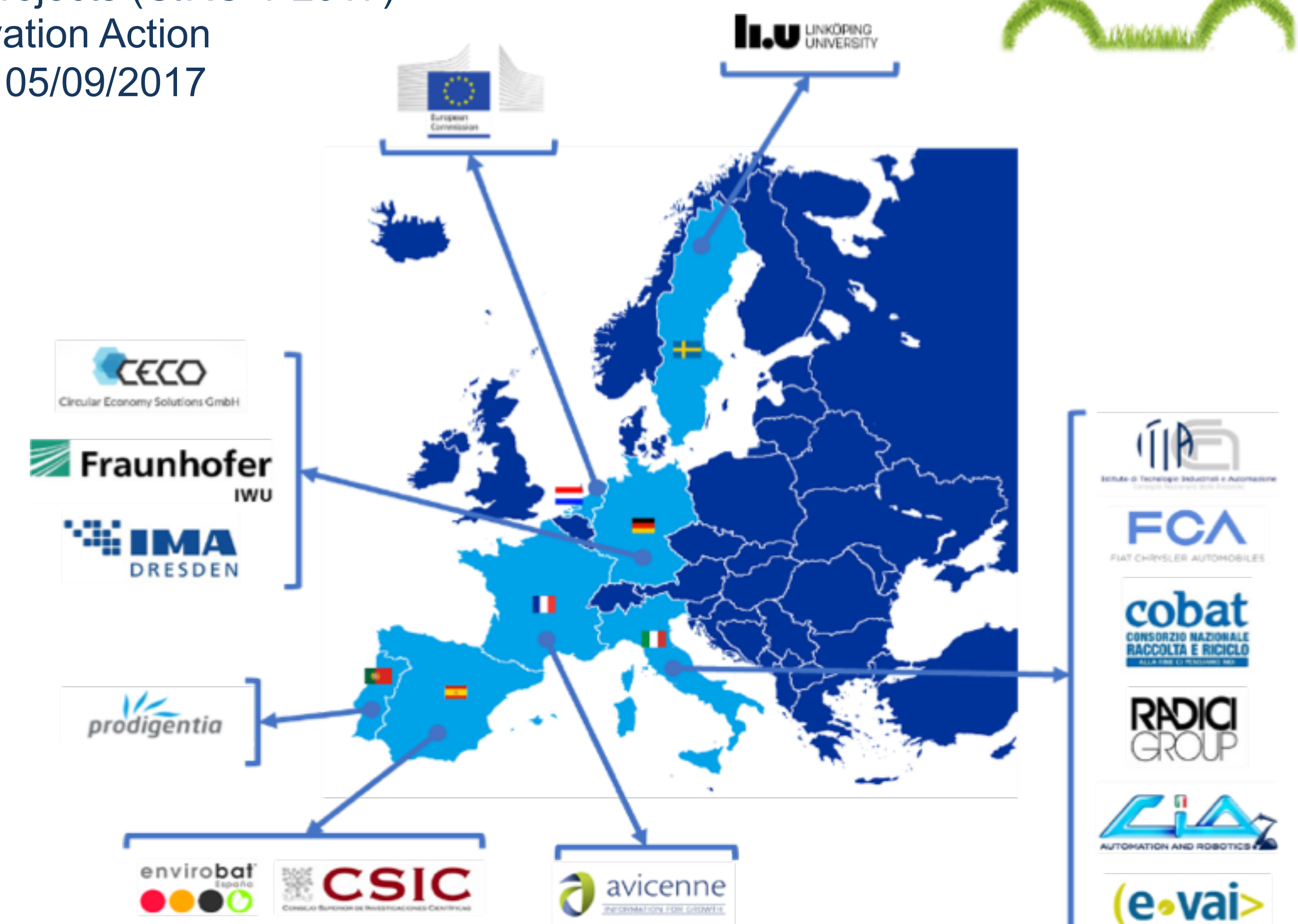


TUT - Advanced thermal spray technologies

ITIA-CNR: Disassembly and Recycling Cells.

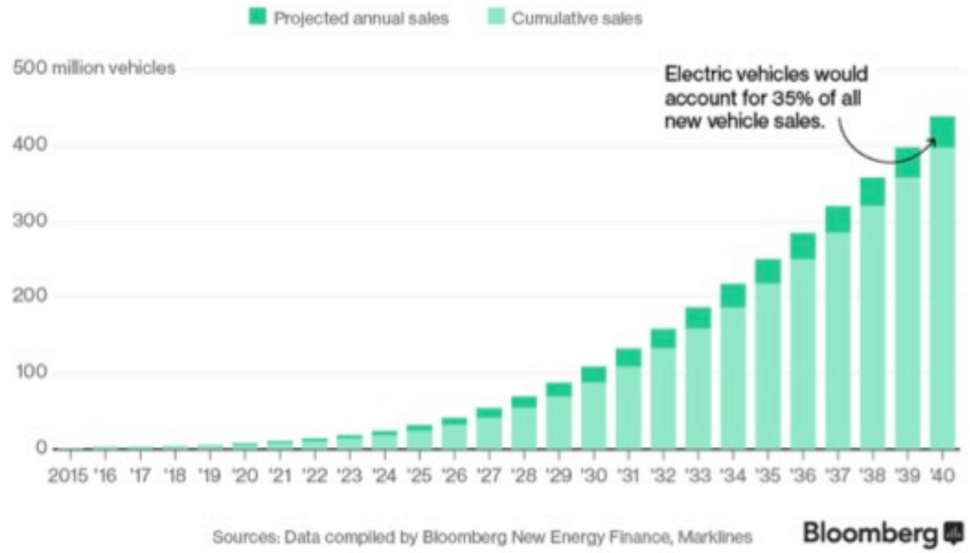
CarE-Service consortium

Title: Circular Economy oriented services for re-use and remanufacturing of hybrid and electric vehicles components through smart and movable modules
Acronym: CarE-Service
Topic: Systemic, eco-innovative approaches for the circular economy: large-scale demonstration projects (CIRC-1-2017)
Type of Action: Innovation Action
Date of Submission: 05/09/2017
Funding: 6.229.505€



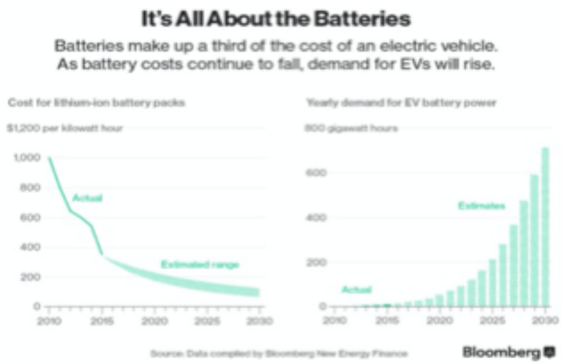
Project rationale

In Europe, 200.000 EVs and HEVs have been sold in 2015, doubling the result of 2014. Hybrid and Electric vehicles have the potential to revolution future transportation in the direction of sustainability.

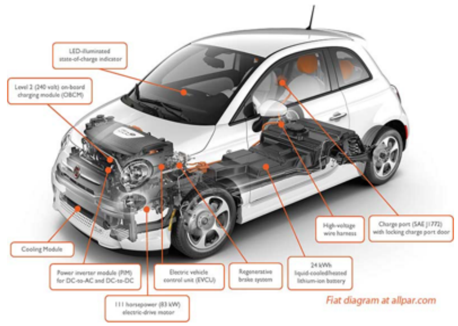


New design and high added-value components:

- Batteries
- Mechatronics
- Techno-polymers
- High-value metals



New opportunities for Circular Economy



Project goals and objectives

Demonstrate at large scale the feasibility of innovative circular business models applied to EVs and HEVs, that enable the offering of new highly customized and performance-based mobility services for European citizens

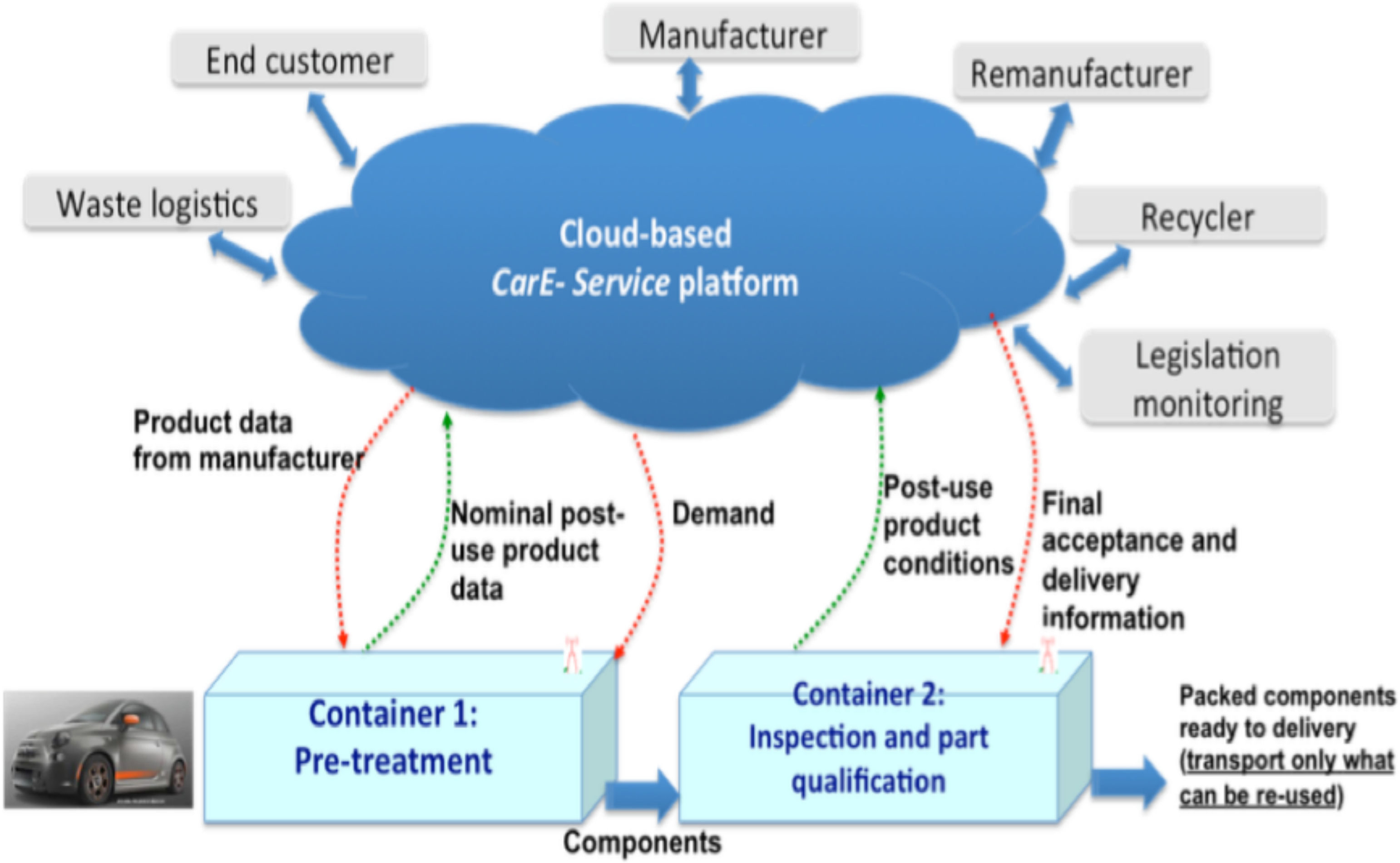
- Establish three new circular European value chains for the re-use, remanufacturing and selective recycling of high added-value parts of E&HEVs (batteries, metal and techno-polymeric components).
- Generate new service markets for the sustainable mobility of European citizens.
- Demonstrate at European scale the economic, social and environmental sustainability of new circular business models and services
- Create the conditions for a wide European exploitation of results.

Enablers developed in the project

Smart Movable Modules (SMMs) for on-site disassembly and testing/certification of E&HEVs parts

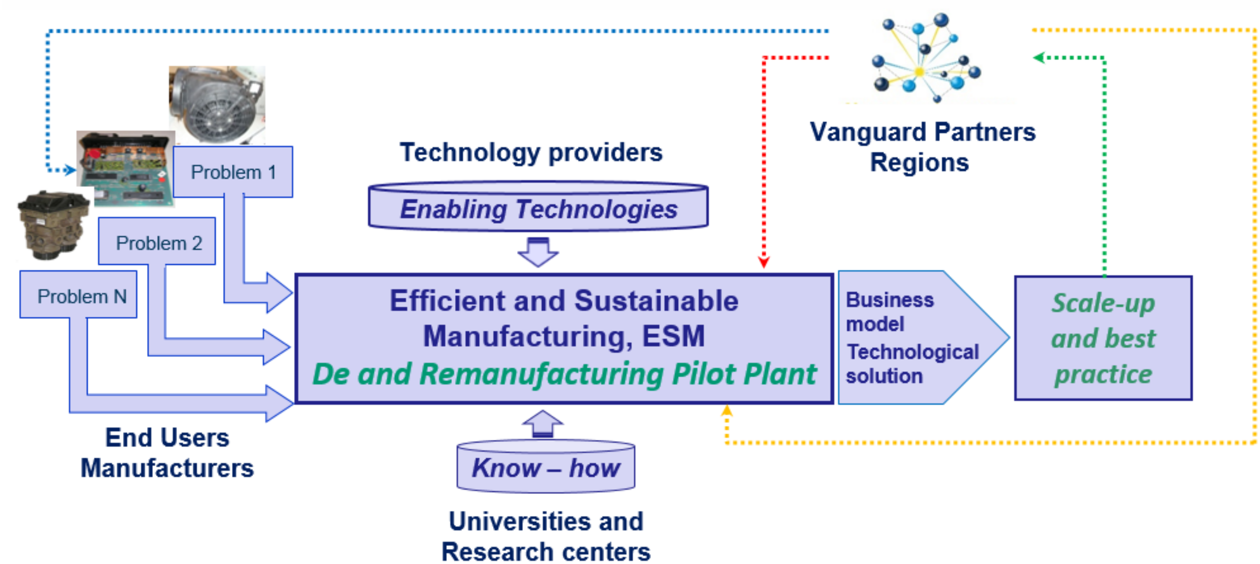
Enablers developed in the project

CarE-Service ICT Platform



VI ESM De-and Remanufacturing for Circular Economy

The main objective of the De-and Remanufacturing pilot network is to ***integrate*** a multidisciplinary set of ***advanced and innovative enabling technologies and digital innovations*** (TRL 7-8) and to exploit the ***regional Smart Specializations*** in synergic way to offer services to European end-users, mainly manufacturing companies, to solve specific ***sustainability-oriented problems*** related to their products.



Selected within Pilot actions for "Interregional innovation projects" by the DG Regio

The pilot network nodes will act as ***Innovation Hubs for Circular Economy***, being a network of competence and technology centers and supporting future producer-driven replication at industrial scale (TRL 9).

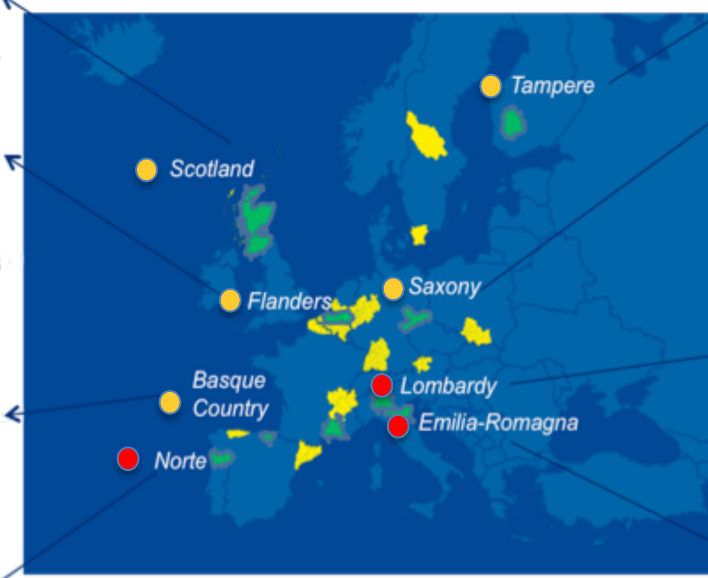
Geographic Configuration and Regional Specialization

Flexible disassembly and inspection to enable **component rebuild in** transportation and Oil & Gas.

Pre-treatment technologies for remanufacturing of photovoltaic panels **and end treatment techniques** for thermoplastics

Re-use of composites by **thermal processes** from aeronautic sector and wind energy system. **Recovery** and re-use of **metal scrap** by **plasma process.**

Moulds and dies De-and Remanufacturing and repair



Laser-based remanufacturing of the large machinery.

Design for re-use, repair and modification of aerospace, rail and automotive structure

Sustainable Demanufacturing processes including **human-robot cooperation for disassembly, electronics remanufacturing, key-metals and composite recovery and reuse by mechanical processes,** for the automotive and electronics industry

Reconditioning and **upgrade of machine tools**; conversion of aluminium and steel scraps into highly technological cellular materials

- Totally new pilot site (red)
- Upgraded existing pilot site (yellow)

Key Issue: integrated pilot plant solutions, needed by industry to ***validate high-risk investments*** in circular economy businesses before the industrial implementation.

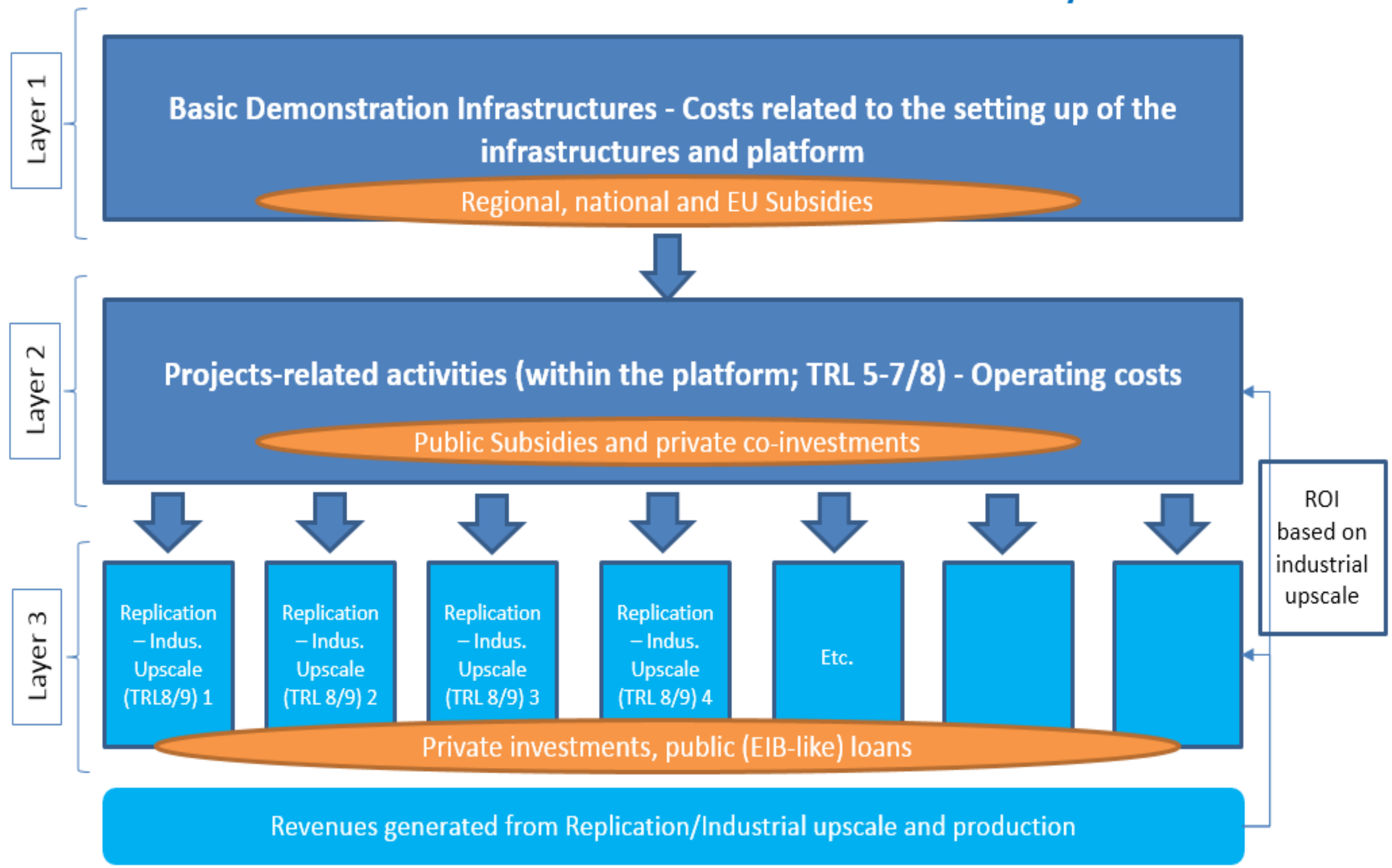
Operational and Business Model of the Pilot Network

General Financial Structure – three layers

Regional, national, EU, projects exploitable results and competences.

Industrial users (first group from use-cases)

Private investments for industrial take-up



New Circular Economy businesses in EU.
New jobs, social and environmental impact.

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Example of Ongoing Project on Remanufacturing

ROBUST planet

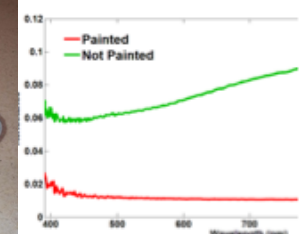
Shock-robust Design of
Plants and their Supply Chain Networks

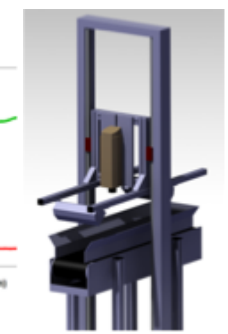
SEVENTH FRAMEWORK PROGRAMME

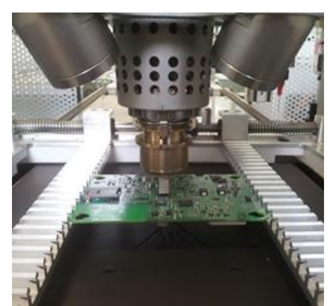
MTA SZTAKI · POLITECNICO MILANO · OMA · MARPOSS · ITConsult PRO Információtechnikai Zrt. · KIT Karlsruher Institut für Technologie · UNIVERSITY OF TWENTE. · MCM · voestalpine ONE STEP AHEAD. · FESTO · KNORR-BREMSE

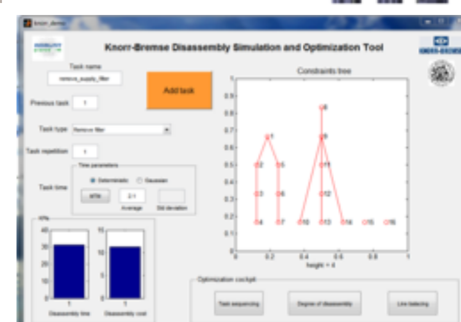
Remanufacturing Use Case at Knorr Bremse:

1. **Proposing Decision Support System**
   - Concept for a quality evaluation of EBS5 cores
   - Concept for an automatized identification of all cores.
2. **Proposing disassembly strategies** (disassembly sequence and possible technologies for different operations) for the three modules (TCM,1-channel, 2-channel).
3. **Proposing the solution for automatic remanufacturing of ECUs components.**



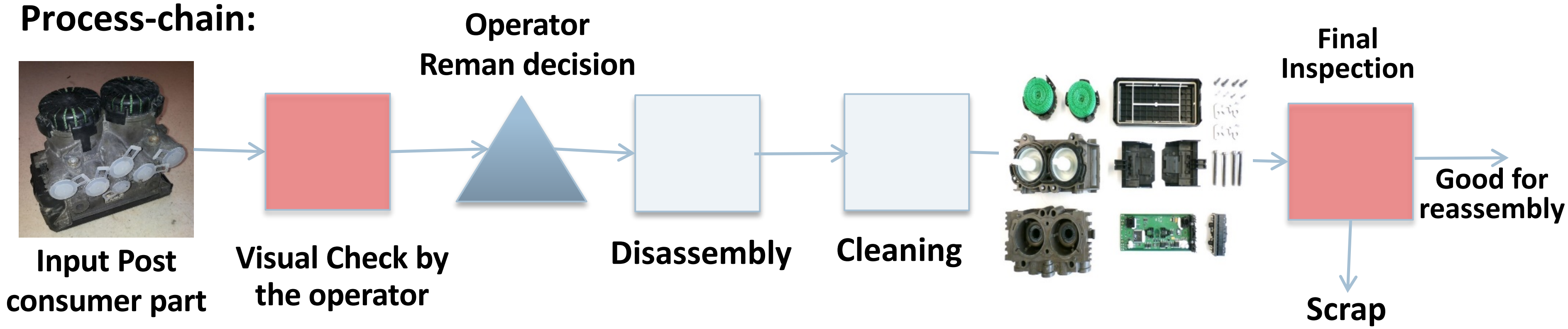






Remanufacturing of mechatronic parts for the automotive aftermarket as a sustainable circular economy business.

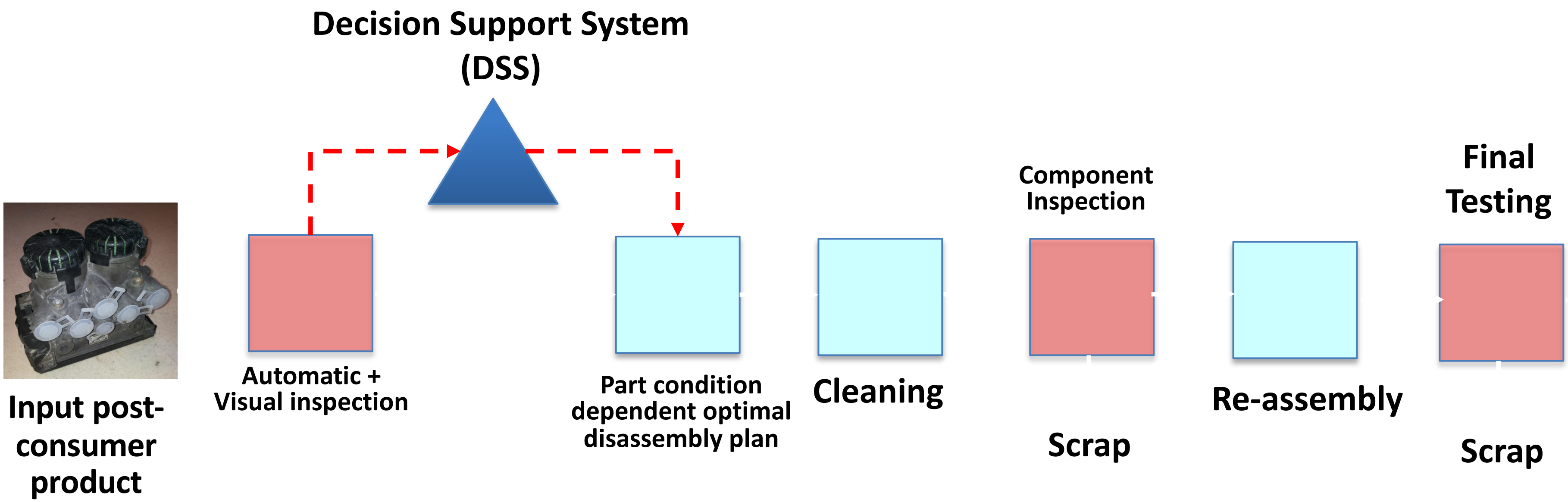
Process-chain:



Challenges:

- Large variability in the condition of the post consumer products.
- Remanufacturing decisions are taken by the operator based on Standard Operations Sheets – SOS. The resulting regeneration rate is 0.7.

To propose a **Decision Support System** to adapt the disassembly strategy in feed-forward mode, depending on the quality conditions of the input post-consumer products.



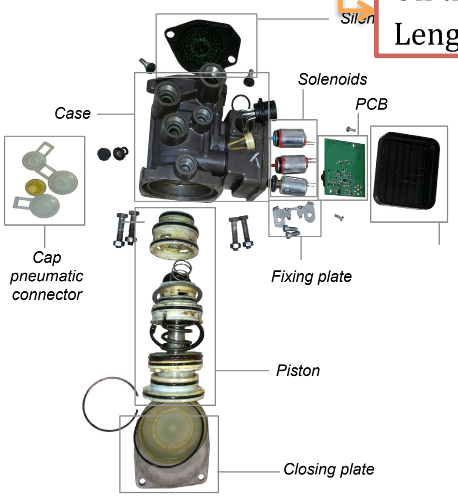
- Classification of 60 post-consumer parts according to the following criteria.
- Complete disassembly of the test parts. Analysis of the task feasibility and times and derivation of the di
- Statistical analysis of th ication of significant
  - Level of Corrosion
  - l of co on

Quality Classification Criteria

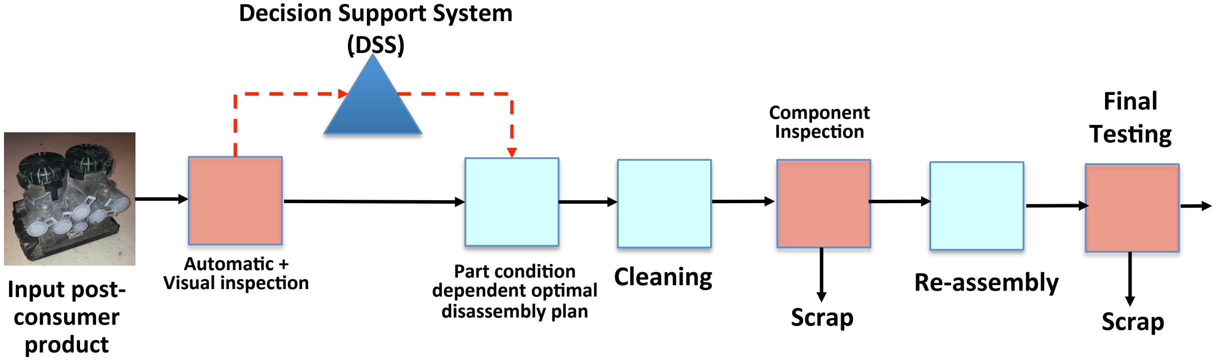
Damages on the main body	Corrosion on the screws	Corrosion on the main body	Painted / not Pained	Dirtiness	Manufacturing Date	Weight	Product number
Scratch	On the Top	On the Frame		D4: Very Dirty			
	On the Length	On the Holes					
		On the Fixing Holes					

Qu	Age	y Features	Probability
	<200		
	>2007	High	
	<2008	High	
	>2007	High	
	>2007	Low	
Q6	>2007	Low	

Corrosion on the main body



Decision Support System - architecture



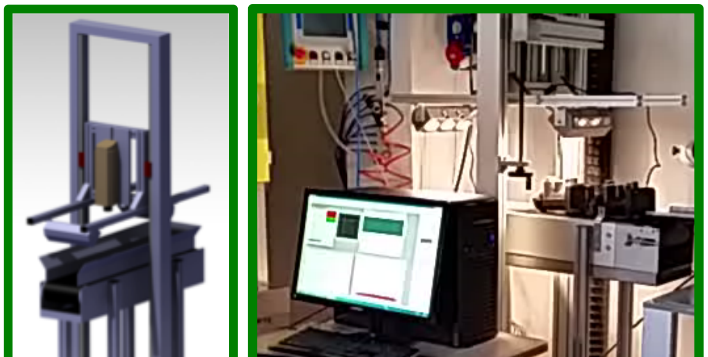
- Regeneration rate > 0.8
- Disassembly time reduction = -15%.

Part inspection and classification

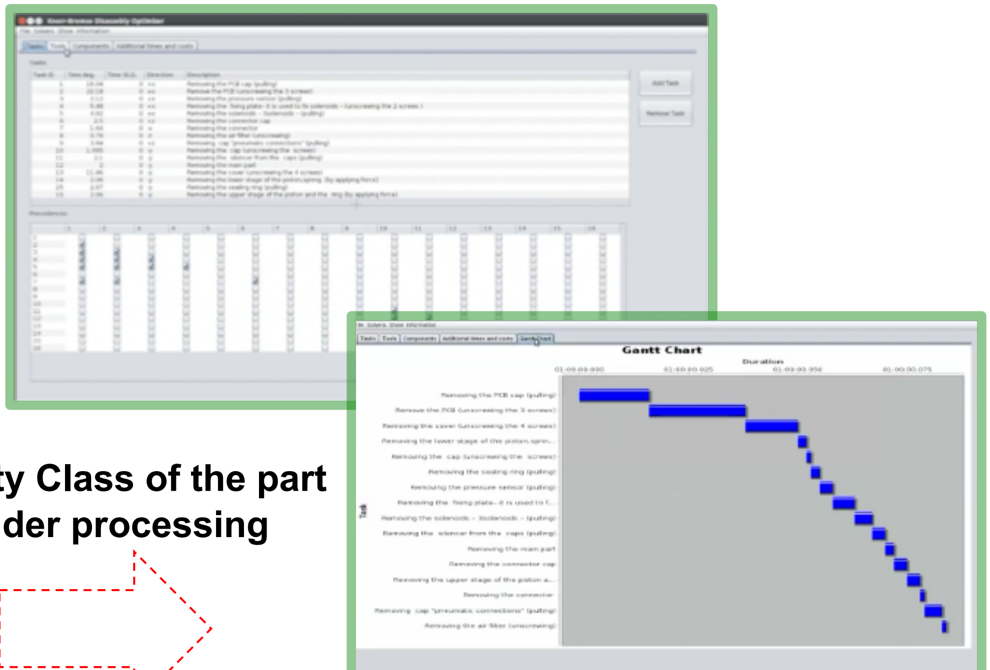
Disassembly Planning

Optical Character Recognition

Hyperspectral Imaging System



Quality Class of the part under processing



Experimental validation

Two PCB mixtures coming from high and low grade PCBs.

Mixture 1

Mixture 2

Mixture	Recovery conductive mixture	Recovery non conductive mixture
1	0.953	0.975
2	0.788	0.832
2	0.973	0.982

Optimal parameters for mixt 1.

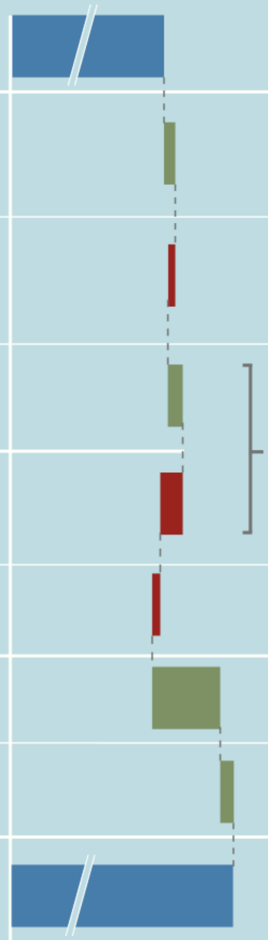
Optimal parameters for mixt 1.

Optimal parameters for mixt 2.

- Effect of CPS: +25% recovery.
- Replicability: over 10 replications the CPS always detected the change of mixture. Although false alarm have not been observed, the change happened at different time due to the random feed of the mixture.

Social Benefits at European Level: effect on jobs

FIGURE 17 **QUALITATIVE EMPLOYMENT EFFECTS OF A CIRCULAR ECONOMY TRANSITION**



Baseline	EU employment today	• 218 million jobs in EU-28, 2014 • Unemployment rate: 10.2%
Direct effects	Waste and recycling sectors	• Today ~2,3 million jobs, ~1% of EU jobs[1] New jobs from increased recycling, reverse logistics, secondary markets
	Raw material sectors	• Substitution from raw materials to secondary implies less demand for virgin raw materials • Some of the resulting employment loss outside EU
	Manufacturing sector	• Today, 30 million manufacturing jobs,~14% of EU jobs • New jobs due to upgrade, repair, re-manufacturing activities (labour intensive) • Jobs loss in new products manufacturing • Net effect likely to differ substantially between sectors and companies
Indirect effects	Manufacturing	
	Raw material sectors	• Possible price increase on materials reduce demand • Some of the resulting employment loss outside EU
Induced effects	Increased consumption in all sectors	• Increased consumption driven by lower prices
	"Eco innovation effect"	• New jobs created by innovation and investments from circular economy transition
Circular economy vision	Potential new EU employment base	• Overall positive circular economy effect on jobs • More important are general labour market policies about gender inclusion, retirement age, and structural barriers regarding entry salaries, etc.

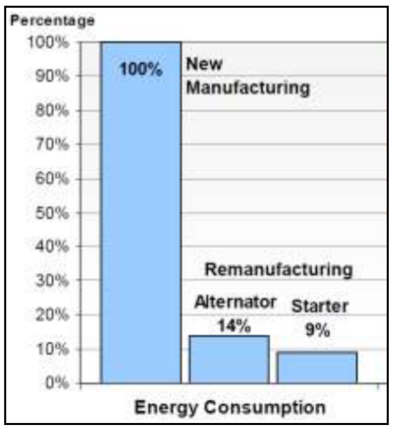
Source: Europe's circular-economy opportunity. McKinsey Center for Business and Environment September 2015

Environmental motivation

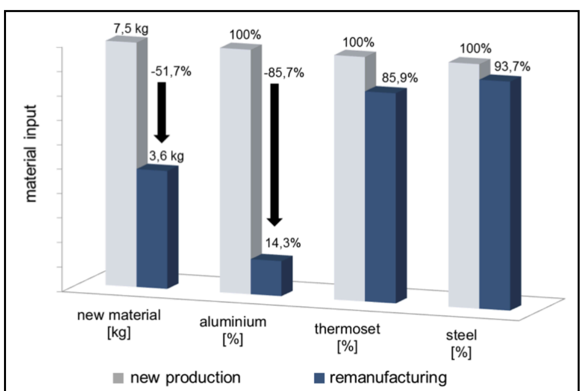
Benefits of De- and Remanufacturing

- ***Economical & strategic impacts***

Example: Benefits of Remanufacturing in the automotive industry (Electronic Air Control unit)



Kohler D., Mechatronic Remanufacturing at Knorr-Bremse Commercial Vehicles Systems (CVS)



- ***Environmental impact***

Example: Benefits of recycling

Table 1
Benefits of using scrap iron and steel

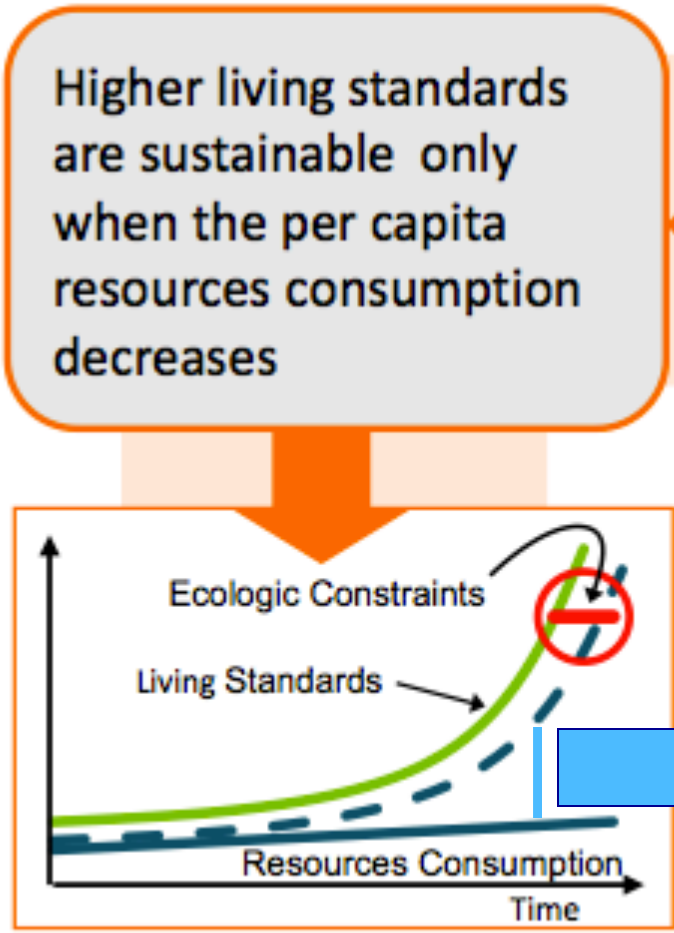
Benefits	Percentage
Savings in energy	74
Savings in virgin materials use	90
Reduction in air pollution	86
Reduction in water use	40
Reduction in water pollution	76
Reduction in mining wastes	97
Reduction in consumer wastes generated	105

Table 2
Recycled materials energy savings over virgin materials

Materials	Energy savings (%)
Aluminum	95
Copper	85
Iron and steel	74
Lead	65
Zinc	60
Paper	64
Plastics	>80

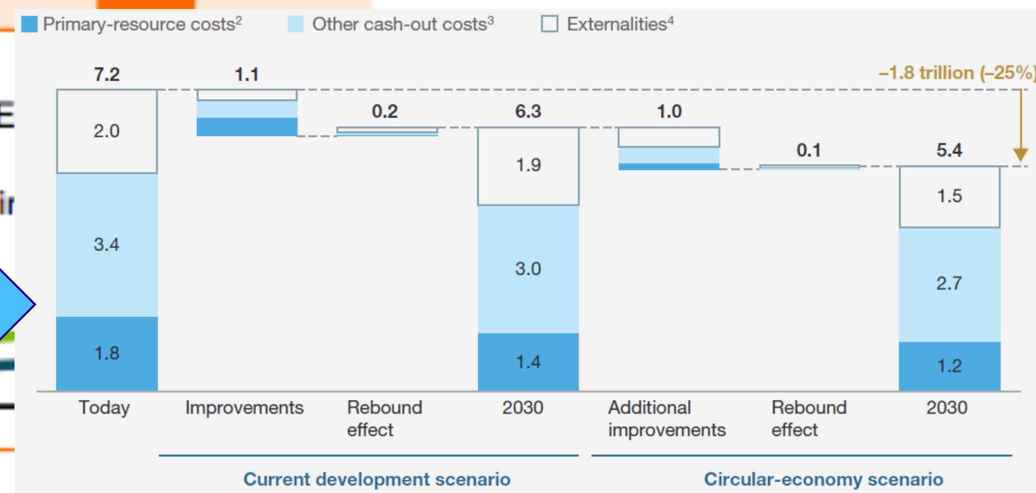
Cui, Jirang, and Eric Forssberg. "Mechanical recycling of waste electric and electronic equipment: a review." Journal of Hazardous Materials 99.3 (2003): 243-263.

De-and remanufacturing macro-challenge



Shifting toward a circular economy together with a digital transformation of manufacturing would improve resource efficiency by 25% (annual benefits of up to €1.8 trillion by 2030).

Source: Europe's circular-economy opportunity McKinsey Center for Business and Environment September 2015



A new industrial model that decouples revenues from material input, and production from resource consumption is needed for achieving a sustainable development path, both in early-industrialized and in emerging countries.