POLITECNICO
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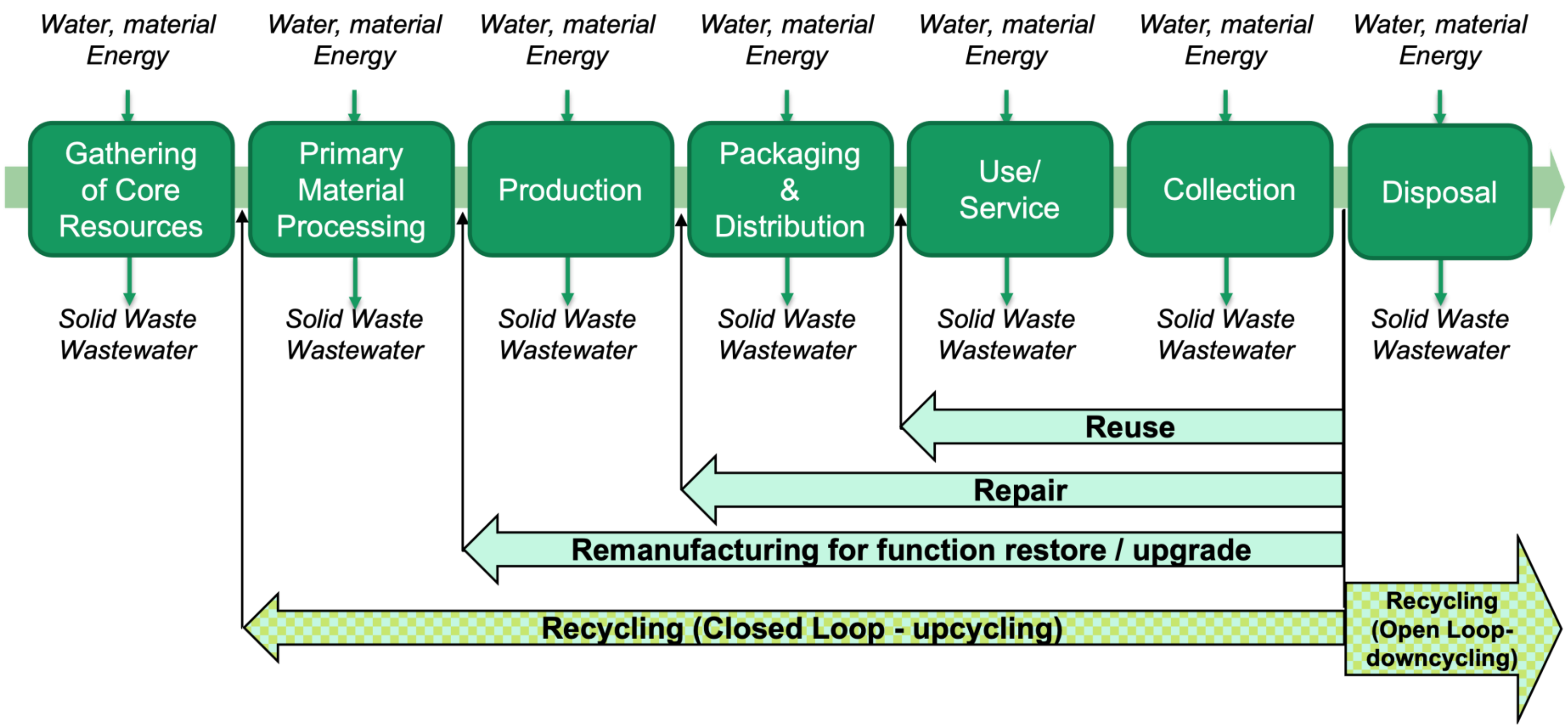
Towards innovative manufacturing-centric circular economy value-chains

Prof. Marcello Colledani: Dipartimento di Meccanica, Politecnico di Milano

Towards Circular Value-chains - Manufacturer Centric vision



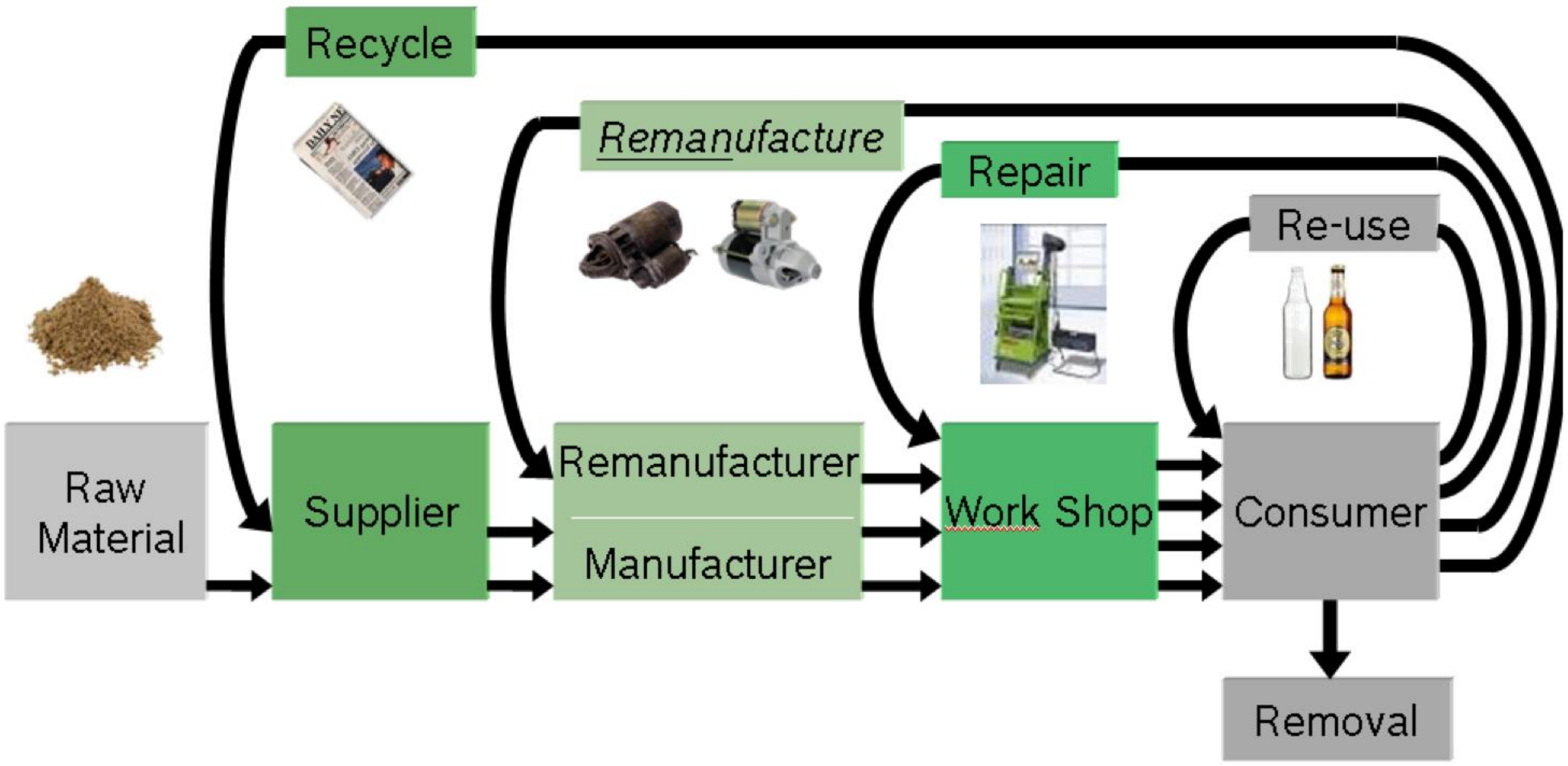
What are the implications for the manufacturing industry in the transition towards new Circular Economy business cases?

WHAT IS REMANUFACTURED?

- Remanufactured parts fulfill a fuction which is equivalent to new parts
- Restored from an existing part (called "core")
- Standardized <u>industrial</u> processes
- Fulfilling specific technical specifications
- Same warranty as new part
- Clearly identified as „remanufactured" + mention of remanufacturer
- Remanufactured is different from reused, repaired, rebuilt, refurbished, reworked, reconditioned etc.

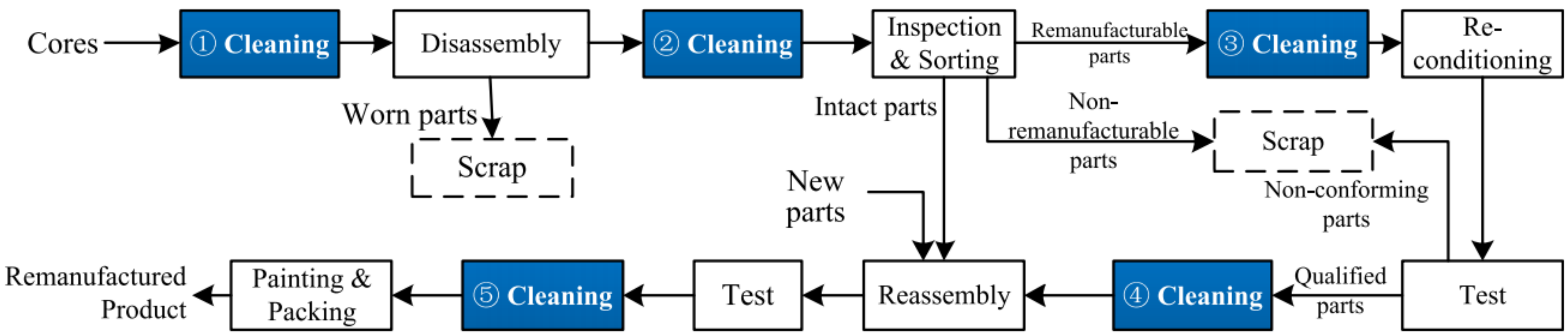
(Common definition of ACEA, APRA Europe, CLEPA, FIRM)

WHAT IS REMANUFACTURED?



Source: Remanufacturing Term Guideline, APRA

Typical Remanufacturng Process-chain



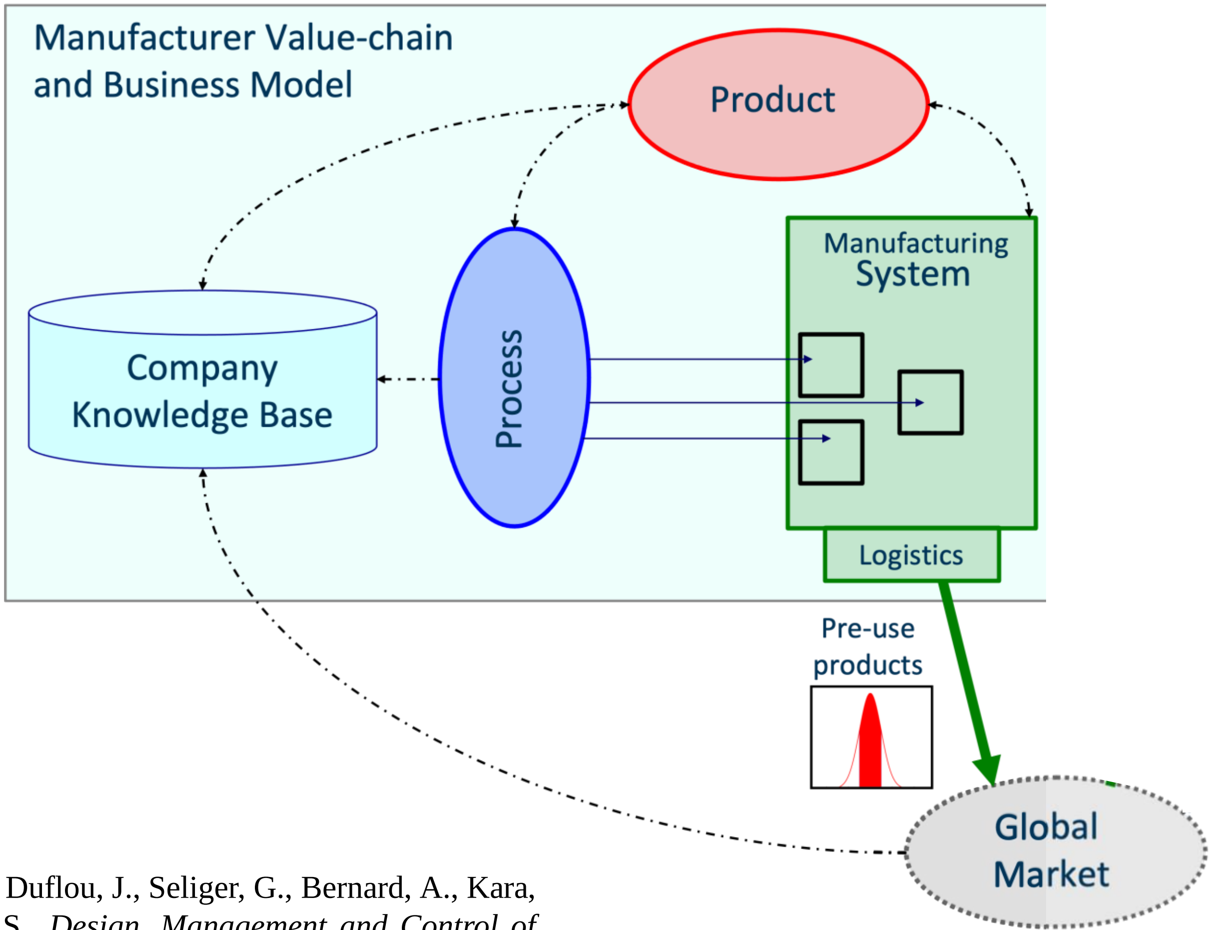
Cleaning technologies

- Organic solvents cleaning technology
- Jet cleaning technology
- Thermal cleaning technology
- Ultrasonic cleaning technology
- Electrolytic cleaning technology

Regeneration technologies

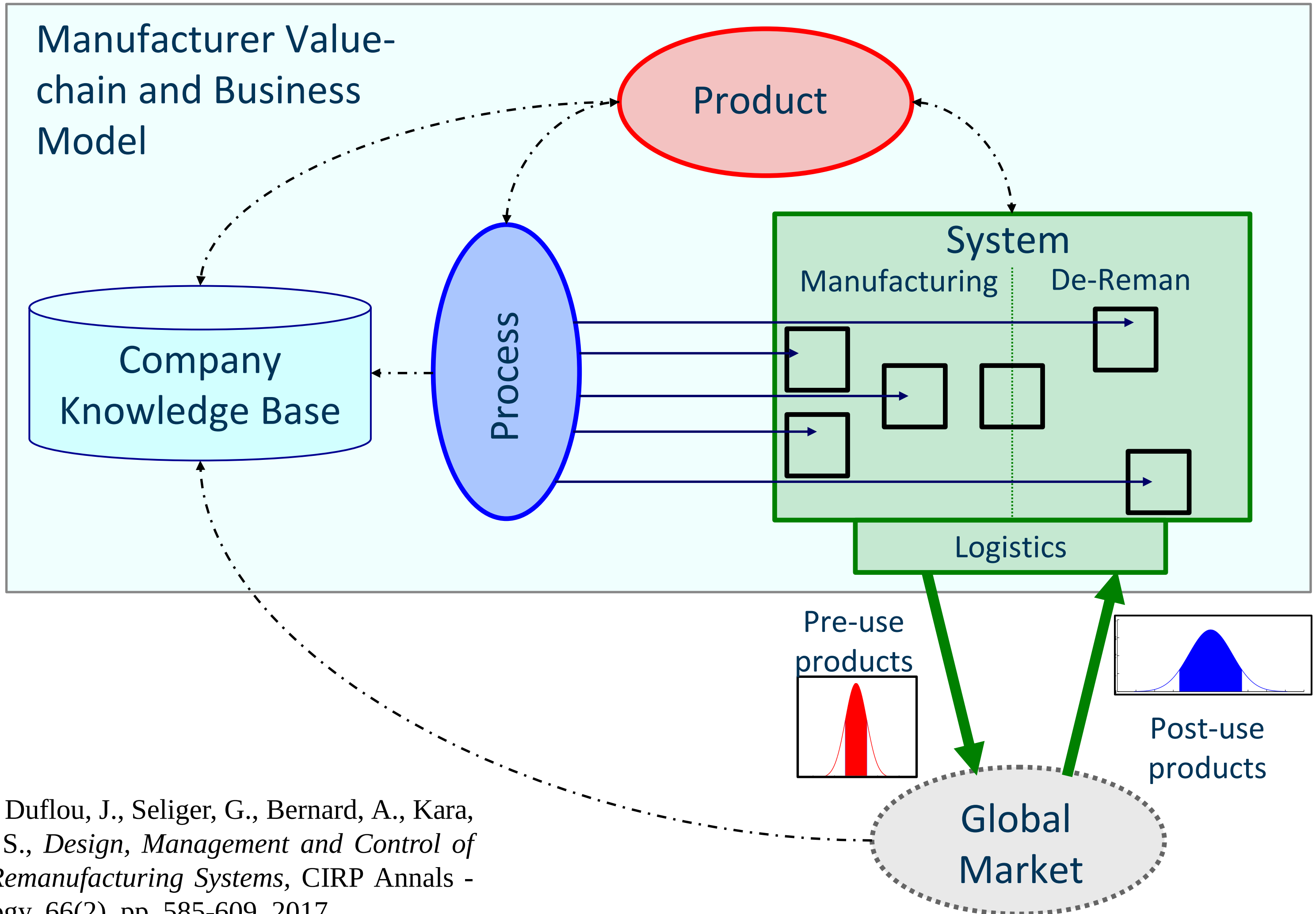
- Thermal spray
  - Conventional flame spray
    - Wire flame spray
    - Powder flame spray
  - Electric Arc Wire spray
  - Plasma spray
  - High velocity oxy-fuel coating spray (HVOF)
  - Cold spray
- Laser cladding

Implications for a manufacturing companies in the transition to remanufacturing business cases



Colledani, M., Tolio, T., Duflou, J., Seliger, G., Bernard, A., Kara, S., Battaia, O., Takata, S., *Design, Management and Control of Demanufacturing and Remanufacturing Systems*, CIRP Annals - Manufacturing Technology, 66(2), pp. 585-609, 2017.

Manufacturer Centric CE model –
Integrated product, process and system view for the circular economy transition



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Manufacturer Centric CE model – Cross-disciplinary, multi-level, cross-sectorial innovation

Enabling technologies and processes
(collaborative disassembly by robotics, remanufacturing, inspection, demanufacturing, re-processing, coating and recovery)

Digital Innovation
(IoT, smart products, cloud-based platforms, Things Lifecycle Management, data analytics, process and system simulation)

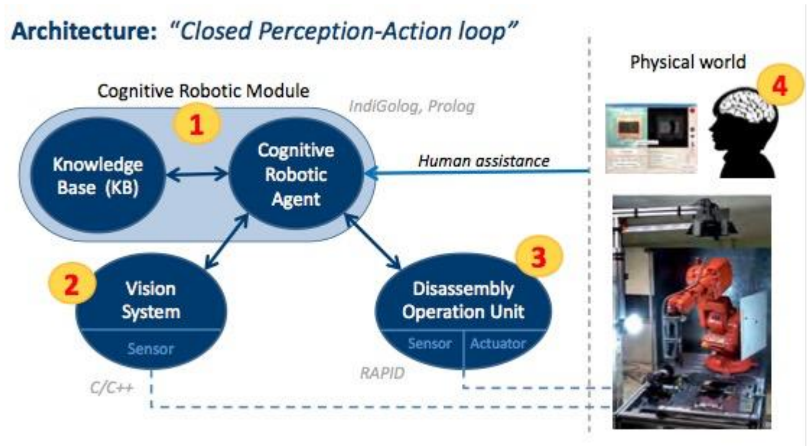
Innovation in eco-products, processes and business models

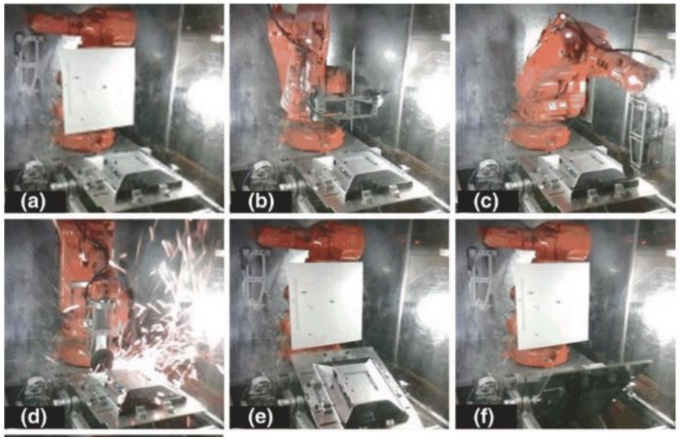
Value-chain building
(new service-oriented business models, open innovation, product re-design, cross-sectorial industrial symbiosis, ecosystems)

An effective transition to new circular economy businesses in Europe requires a systemic approach and cross-KETs innovations, in traditional and emerging sectors.

Towards smart remanufacturing systems of the future - Enabling Technologies: (semi)-automated disassembly

Emerging Technology: Cognitive Robotics	Integrates a vision system, a knowledge base, and an actuation system
	Self-learning capabilities
	Supports human assistance
Contribution to smart de-and remanufacturing systems	Easy system reconfiguration
	Process plans adaptation to parts type and condition variability
	Applicable to small lots
Current TRL	TRL: 7-8
Limitations and challenges	- Time consuming during the learning process - High installation cost - Need skilled operators



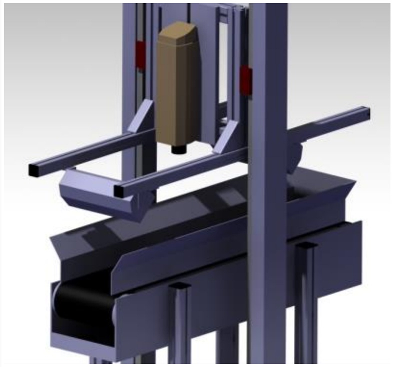


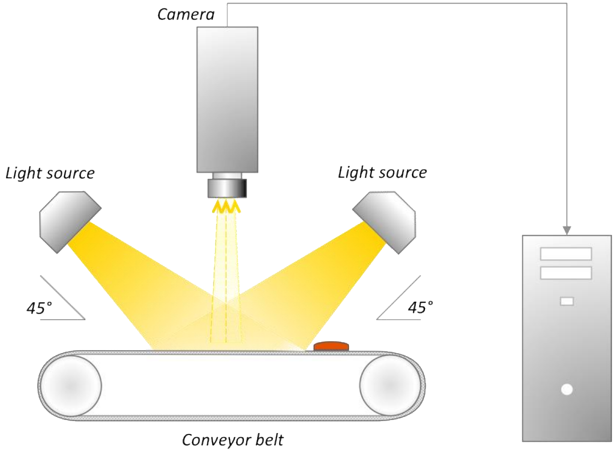
Vongbunyong S, Kara S, Pagnucco M, 2013, Application of Cognitive Robotics in Disassembly of Products" CIRP Annals - Manufacturing Technology 62/1:31–34.

Vonbungyong, S., Kara, S., Pagnucco, M., 2012, Basic Behaviour Control of the Vision-based Cognitive Robotic Disassembly Automation, Journal of Assembly Automation, 33/1:38-56.

Towards smart remanufacturing systems of the future – Enabling Technologies: In-line inspection

Emerging Technology: HyperSpectral Imaging	Detection (signal)
	Recognition (objects)
	Classification
	Material Characterisation
Contribution to smart de-and remanufacturing systems	On-line material characterization: full material data storage and traceability
	Enables in-line monitoring and process control by CPSs
Current TRL	TRL: 9 (few sectors)
Challenges and limitations	- Algorithms customization - Fine particles characterization - Detection problems: shadows, specular reflection, edge effect





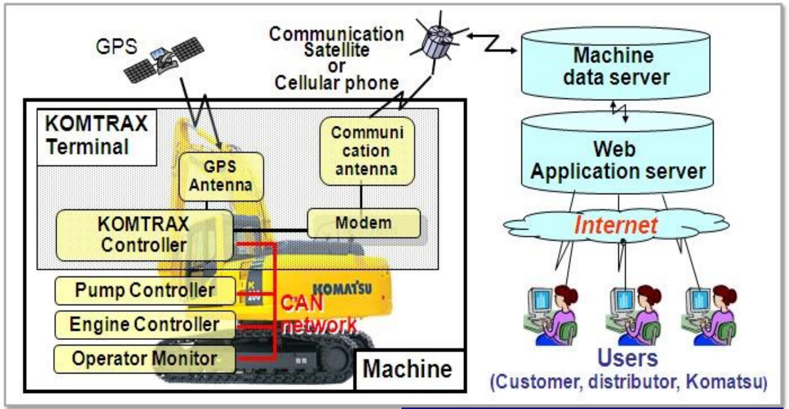
Picón, A., Ghita, O., Bereciartua, A., Echazarra, J., Whelan, P.-F., Iriondo, P.-M., 2012, Real-time hyperspectral processing for automatic nonferrous material sorting, Journal of Electronic Imaging, 21/1.

Picón, A., Ghita, O., Whelan, P.-F., Iriondo, P.-M., 2009, Fuzzy Spectral and Spatial Feature Integration for Classification of Nonferrous Materials in Hyperspectral Data, IEEE Transactions on Industrial Informatics, 5/4:483-494.

Towards smart remanufacturing systems of the future – Enabling Technologies: in-use product monitoring

Enabling Technology: Sensors embedded in products and IoT	Collect data from the product use-phase
	Provide product related data to the post-use de-and remanufacturing processes.
Contribution to smart de-and remanufacturing systems	Enables to adapt the process chain based on the information gathered on the product. Pre-process inspection savings.
Current TRL	TRL: 8-9
Limitations and challenges	Not all the products can be sensorized. Involvement of the manufacturer.

Komatsu system for in-use monitoring and data collection

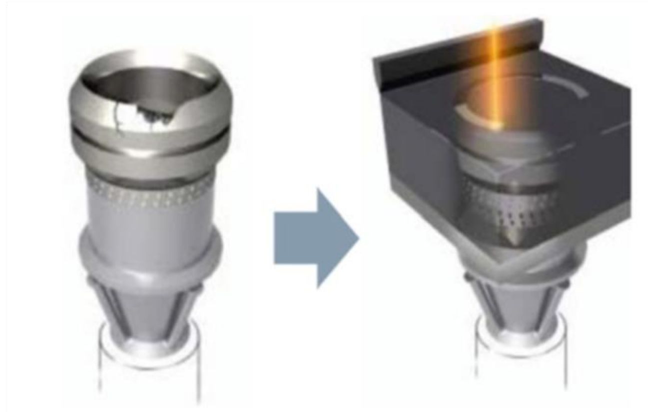


KOMATSU

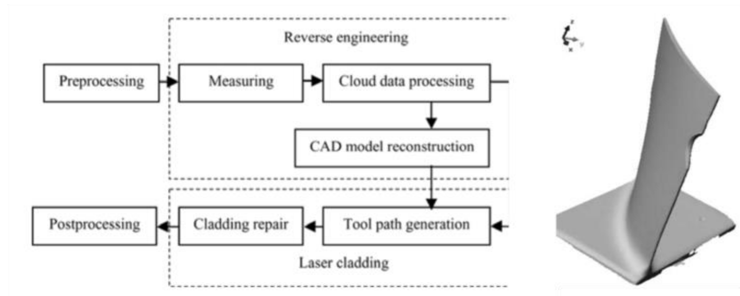
Bilge, P., Badurdeen, F., Seliger, G., Jawahir, I.-S., 2016, A novel manufacturing architecture for sustainable value creation, Annals of the CIRP, 65/1:455–458.
Ilgin, M.-A., Gupta, S.-M. 2011, Performance improvement potential of sensor embedded products in environmental supply chains, Resource, Conservation and Reycling, 6:580- 592.

Towards smart remanufacturing systems of the future - Enabling Technologies: reconditioning

Enabling Technology: Additive Manufacturing and hybrid processes.	Defect regeneration by additive processes from digital product data
	Applied to large metal parts, typically molds and dies, turbines, or to polymeric small spare parts
Contribution to smart de-and remanufacturing systems	Flexibility in processing free-form shapes (damaged parts)
	Ability to produce functional graded materials
	Suited for parts functionality upgrades (hybrid processes)
Current TRL	TRL: 7-8
Limitations and challenges	Limited to high added-value parts. Involvement of the manufacturer Surface roughness limitations



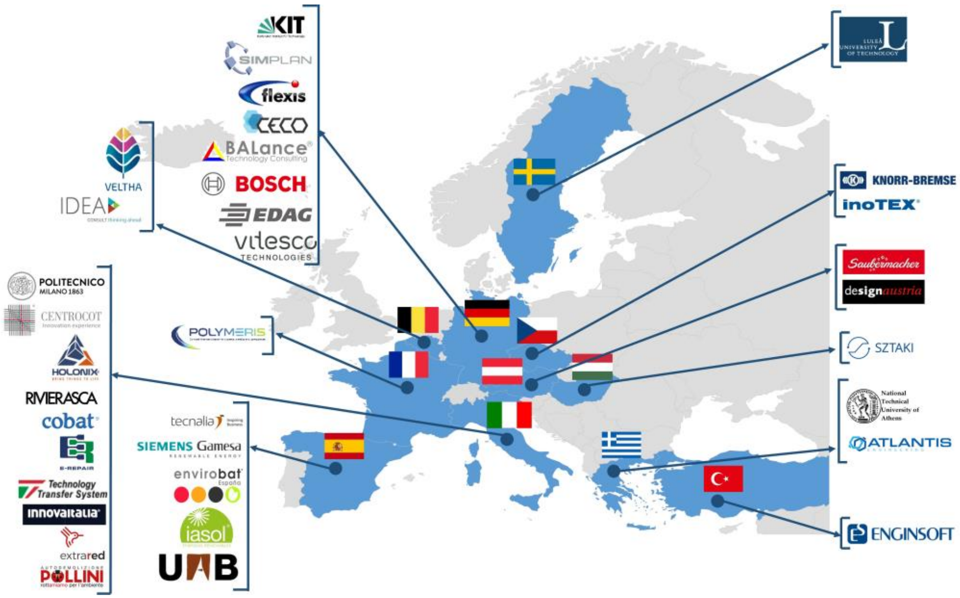
Gas turbine burner tip repair (Siemens AG 2014)



Aeronautics turbine blades

Navrotsky, 2014, 3D printing at Siemens Power Service, Siemens.
Newman, S., Zhu, A., Dhokia, V., Shokrani, A., 2015, Process planning for additive and subtractive manufacturing technologies, Annals of the CIRP, 64/1:467- 470.
Gao, J., Chen, X., Yilmaz, O., Gindy, N. 2008, An integrated adaptive repair solution for complex aerospace components through geometry reconstruction, International Journal of Advanced Manufacturing Technology, 36:1170-1179.

The DigiPrime project



- 36 European organizations from 11 EU states;
- 6 manufacturing sectors;
- 25 **industrial partners**, 18 of which are SMEs;
- 8 **research centers and universities.**

CALL

H2020-DT-ICT-07- 2018-2019

Digital Manufacturing Platforms for Connected Smart Factories

BUDGET

Project costs: *19.257.130,00€*
Funding: *15.963.173,50€*

DURATION

January 2020 – Dec 2024

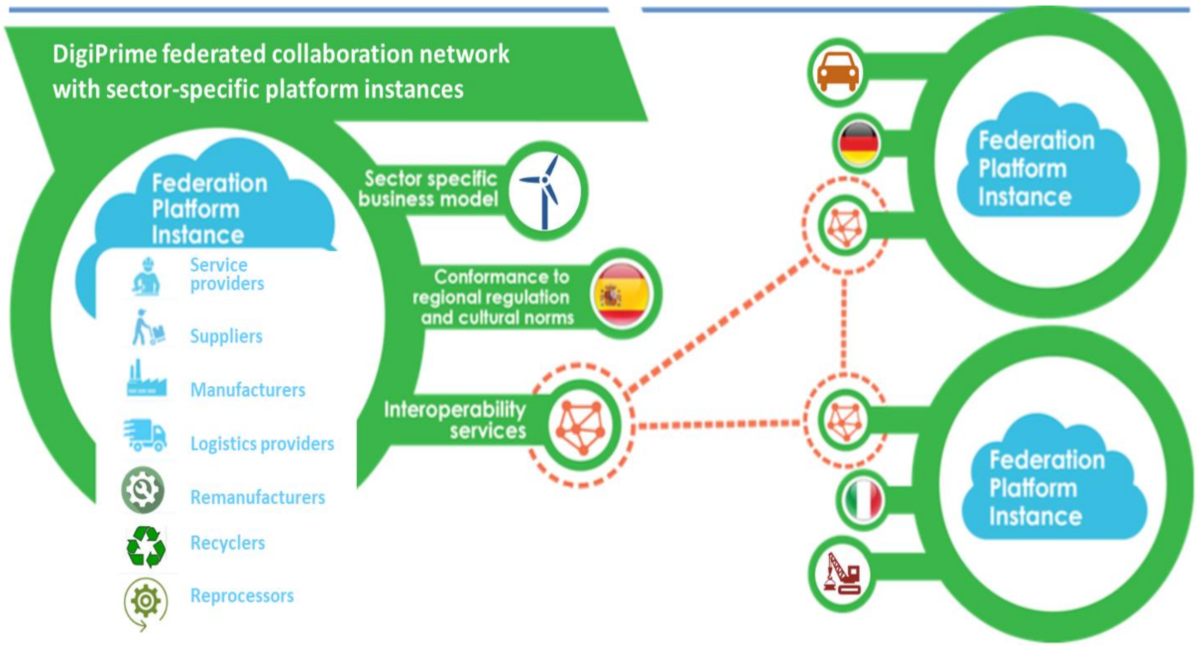
OBJECTIVE

To develop a new concept of Circular Economy digital platform overcoming current information asymmetry among value-chain stakeholders, in order to unlock new circular business models based on the data-enhanced recovery and re-use of functions and materials from high value-added post-use products with a cross-sectorial approach.

Platform Architecture: concept of federation

The overall architecture level of the DigiPrime platform includes:

- A **Multi-node federation structure**, replicable on different existing and new sectorial platform instances, which will support the future systematic creation of cross-sectorial circular value-chains.
- A **Semantic data infrastructure,** based on ontological repositories and semantic search, able to manage and standardize the Babel of information coming from heterogeneous nodes.
- A **Data Policy Framework** to ensure privacy, security, authentication and authorization policies to any information shared among registered users.

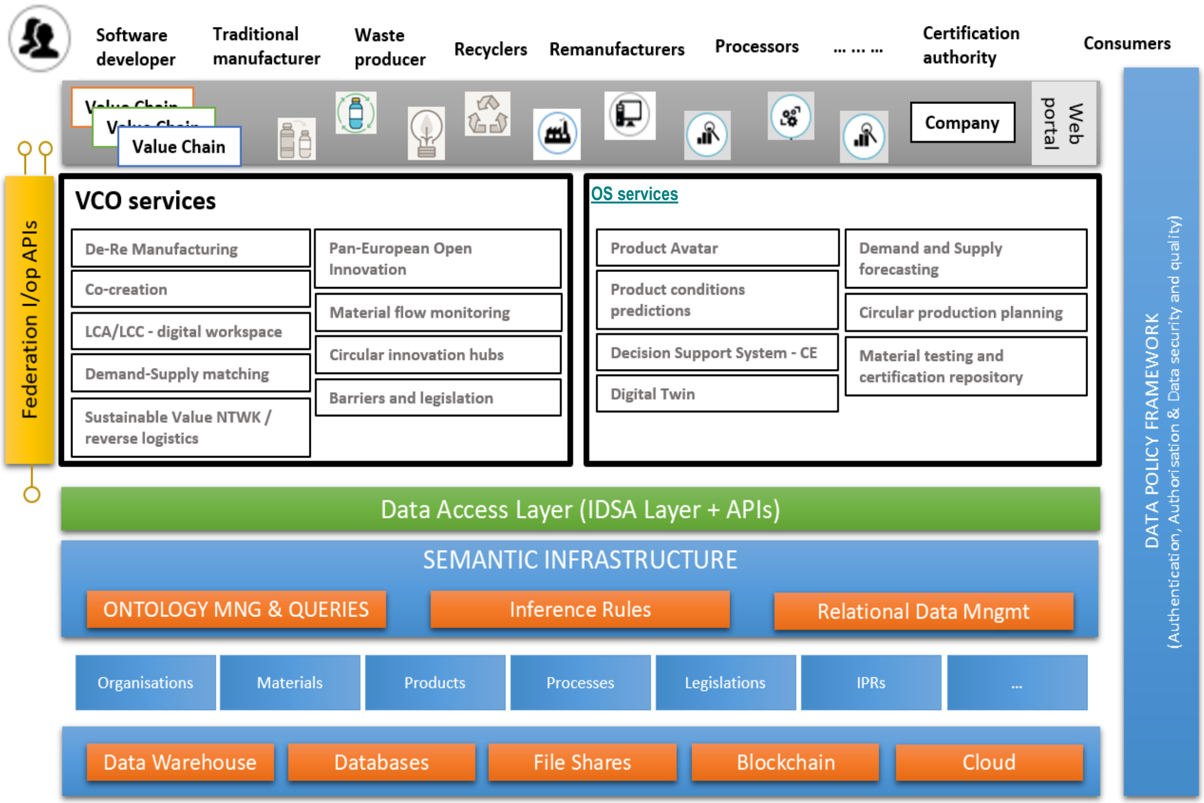


The Blockchain technology will ensure that data cannot be altered, and will keep track of any transaction taking place in the platform.

The DigiPrime platform Services

Value-chain Oriented Services (VCO) and Operational Services (OS).

- **VCO** services are horizontal services that can be made accessible to other nodes of the federation, to offer access to information of interest to stakeholders across sectors.
- **OS** services are vertical services, used by companies internally, mainly to support decision- making aiming at improving the effectiveness and profitability of the circular business processes.



The DigiPrime Pilots

The platform and the related service applications will be **adopted and validated within the DigiPrime cross-sectorial pilots**.

Executing the demonstration experiments for specific use-cases allows to test:

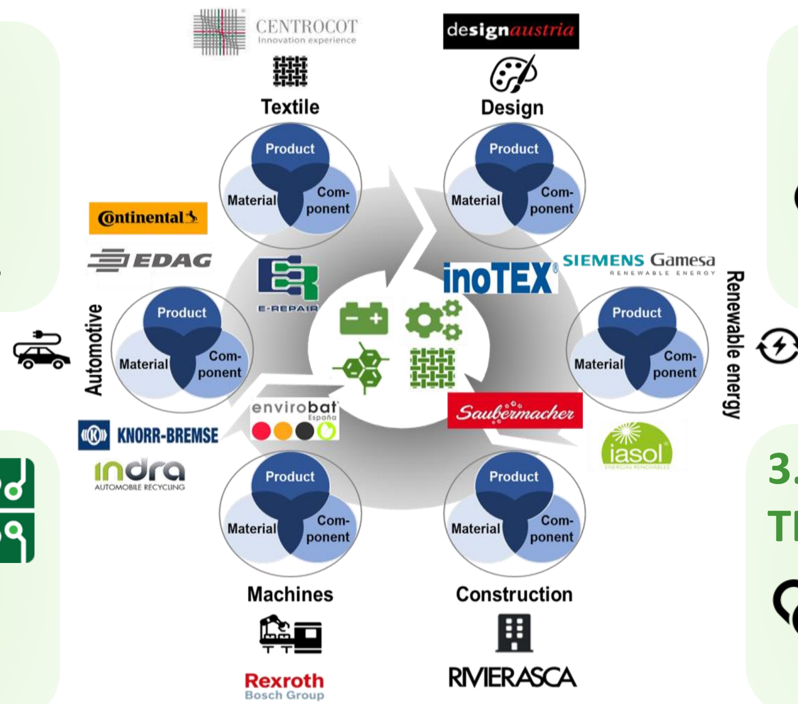
- The interoperability with the company pre-existing ICT infrastructure;
- The continuous interaction with the platform modules and services;
- The generated data to populate the platform for future business cases;
- The industrial feedback for platform maintenance and improvement.

1. BATTERIES

E-MOBILITY
RENEWABLE ENERGY SECTOR
RECYCLING&RAW MATERIALS

2. MECHATRONICS & ELECTRONICS

E-MOBILITY
SMART MACHINING SYSTEM



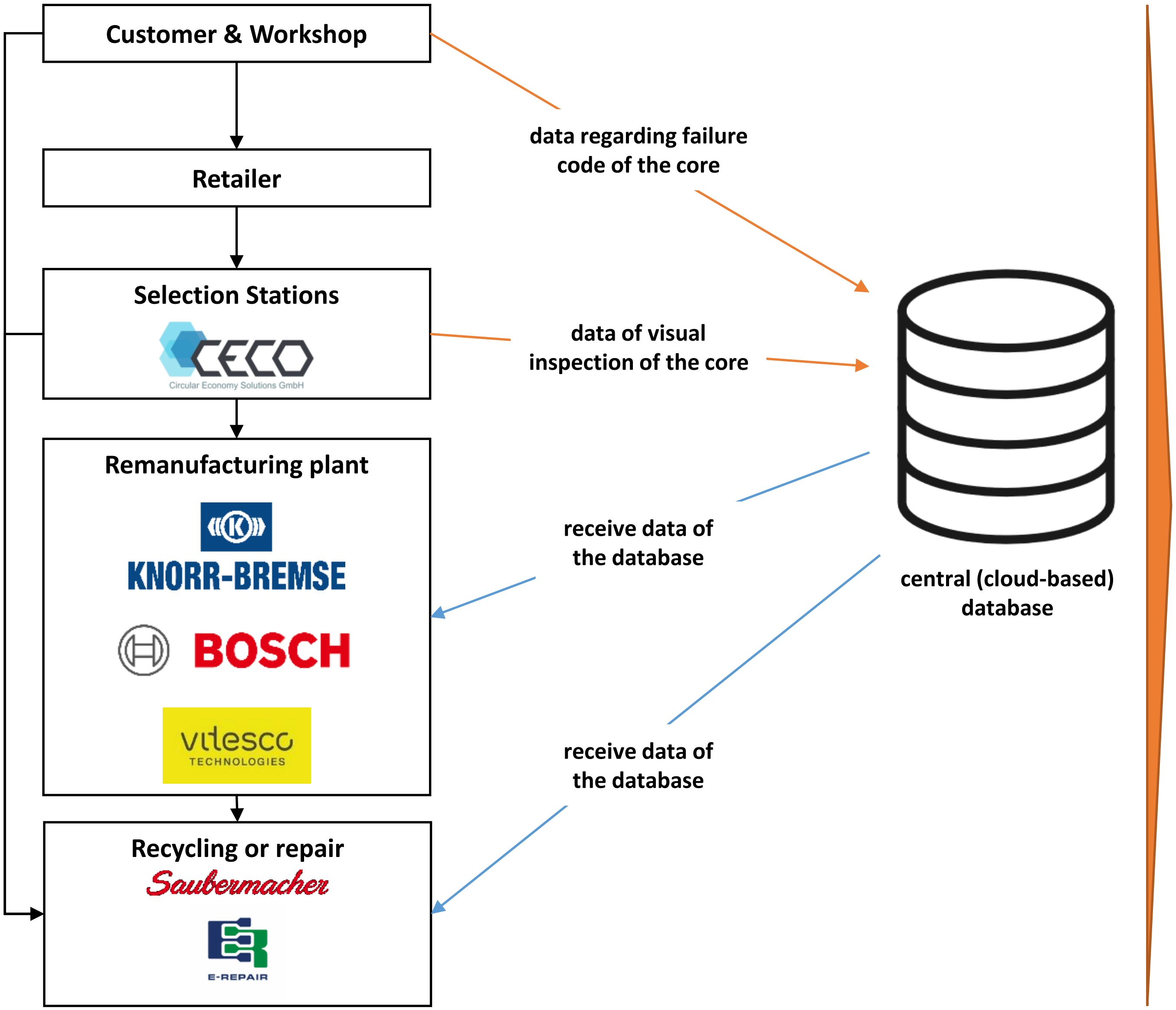
4. TEXTILE

AUTOMOTIVE
TEXTILE SECTOR

3. COMPOSITES & TECHNO-POLYMERS

E-MOBILITY
RENEWABLE ENERGY SECTOR
CONSTRUCTION
DESIGN SECTOR

Pilot 2 – Use case 1



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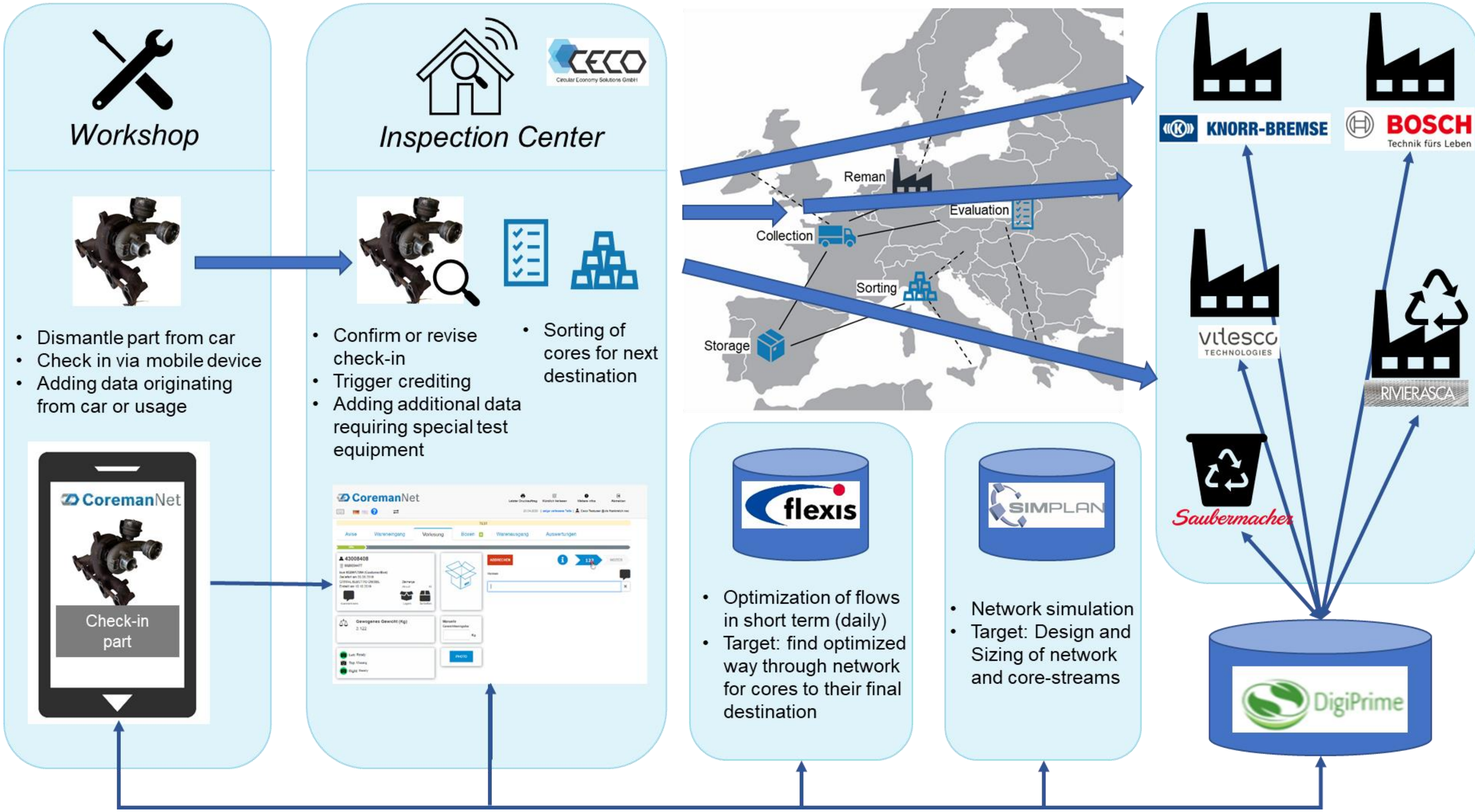
use central data base to share information across stakeholders of the value chain and create incentives for workshops and customers to increase core return rate

Pilot 2 – Use case 1

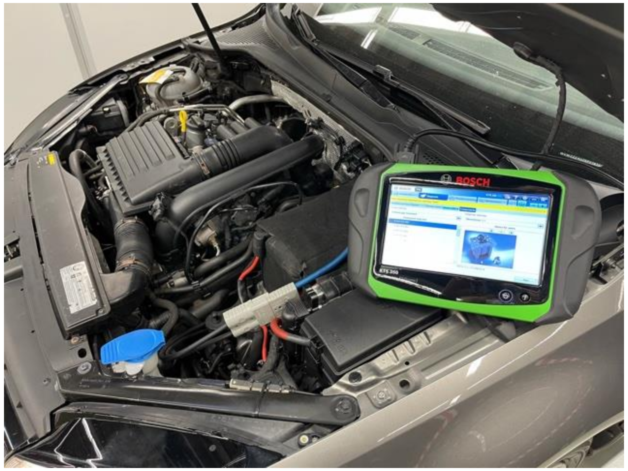


Current status

Service Component: Mobile Application

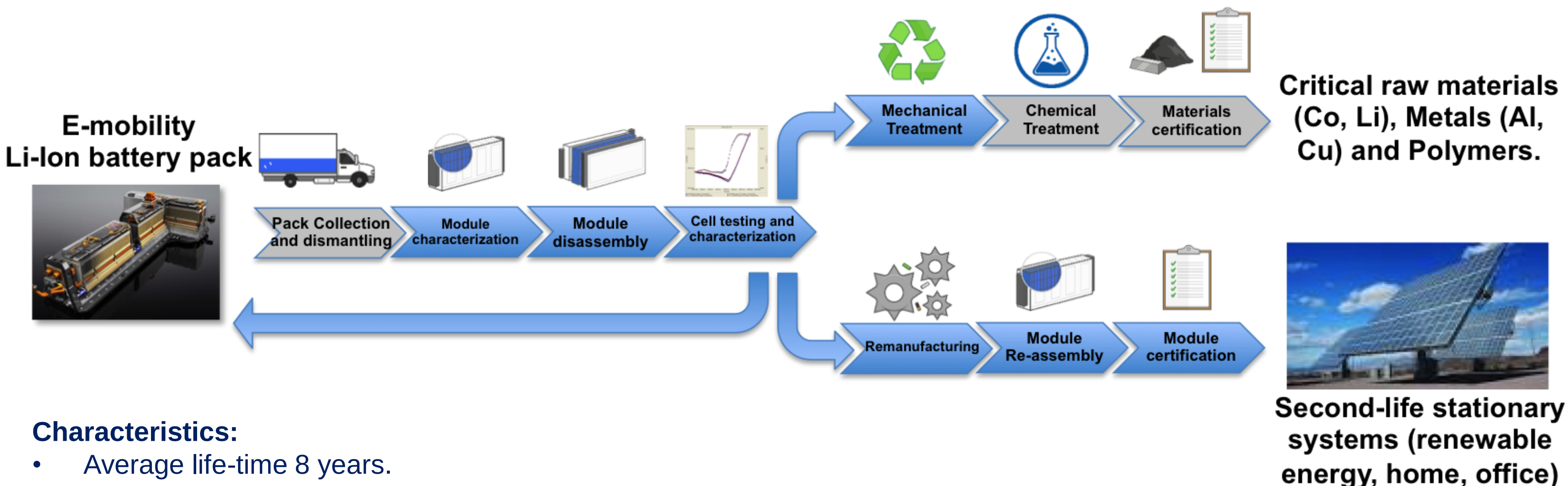
Functional scope of MVP:

- Read-in testing data from OBD-tester-protocols by OCR-technology
- Identify used parts by product-numbers
- Check-in parts for transportation
- Collect data for transfer via platform



Inter-departmental laboratory CIRC-eV

The mission of the CIRC-eV Laboratory is to develop a new concept of **Circular Factory** to support the manufacturing industry in the recovery and reuse of functions and value from post-use Hybrid and Electric Vehicles, boosting the introduction of new circular economy models for sustainable e-mobility.

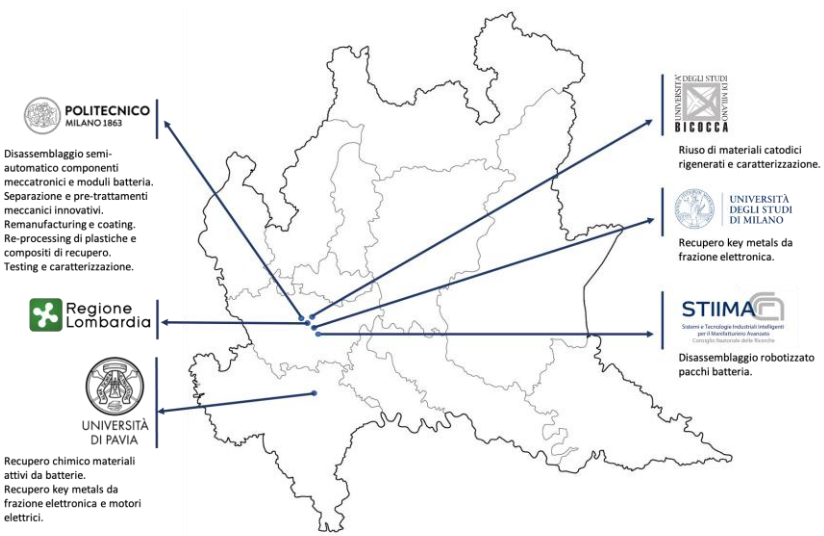


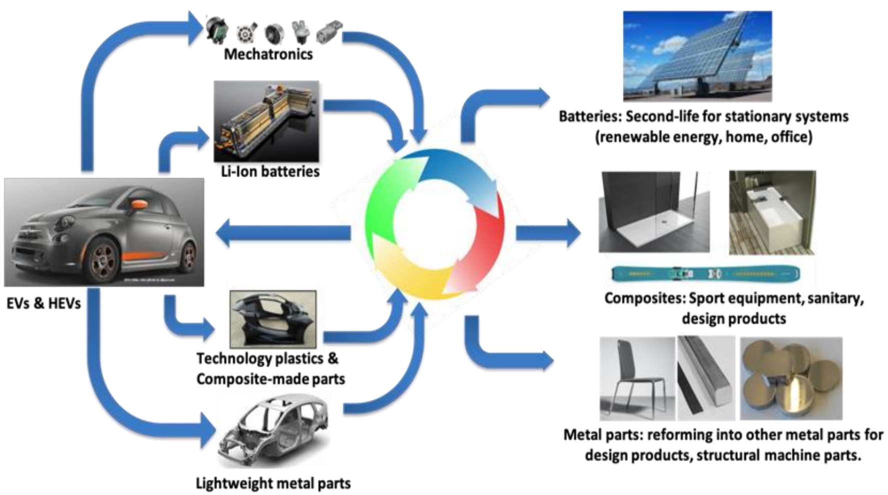
Characteristics:

- Average life-time 8 years.
- Current cost 150 Euro kWh.
- Residual capacity >80% (24 kWh on average).
- Warranty for manufacturers usually for 5 years (e.g. Tesla, Nissan).

Lombardy Region Initiative: EcoCirc

Lombardy region launched the "Accordo di collaborazione per la realizzazione di un'innovativa infrastruttura pilota regionale di supporto alla transizione verso l'economia circolare" di Regione Lombardia, focused on circular economy solutions for the e-mobility sector.





The agreement involves 5 MEuro of infrastructure co-funding for increasing the capacity of research institutes in Lombardy in view of the realization of a Regional infrastructure for supporting the circular economy transition of the Lombardy Region industrial stakeholders.

Towards innovative manufacturing-centric circular economy value-chains

Prof. Marcello Colledani: Dipartimento di Meccanica, Politecnico di Milano

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)

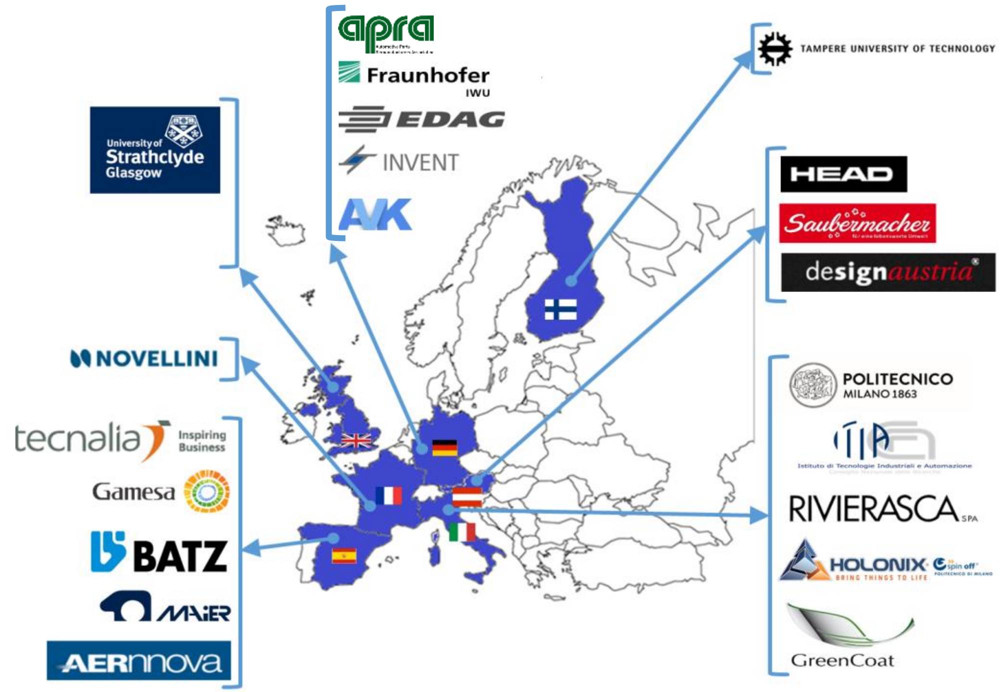
The FiberEUse project aims at integrating in a holistic approach different innovation actions aimed at enhancing the profitability of *composite recycling and reuse in value-added products.*

Duration: 48 months, starting on June 2017.

Consortium: 21 partners, from 7 EU countries.

Coordinator partner: Politecnico di Milano

EC Funding: ca. 10 mln €.

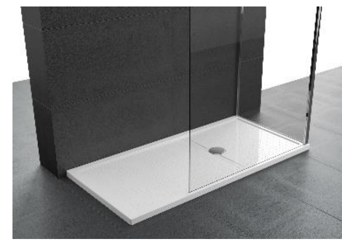


Use case 1: GFRP parts mechanical recycling and re-use

Mechanical recycling of short GFRP and re-use in added-value customized applications, including furniture, sport and creative products. Emerging manufacturing technologies like UV-assisted 3D-printing and metallization by Physical Vapor Deposition will be used.

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).

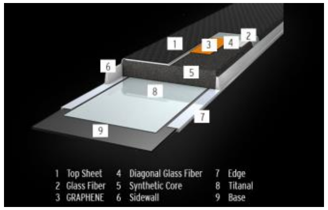


NOVELLINI

- **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).



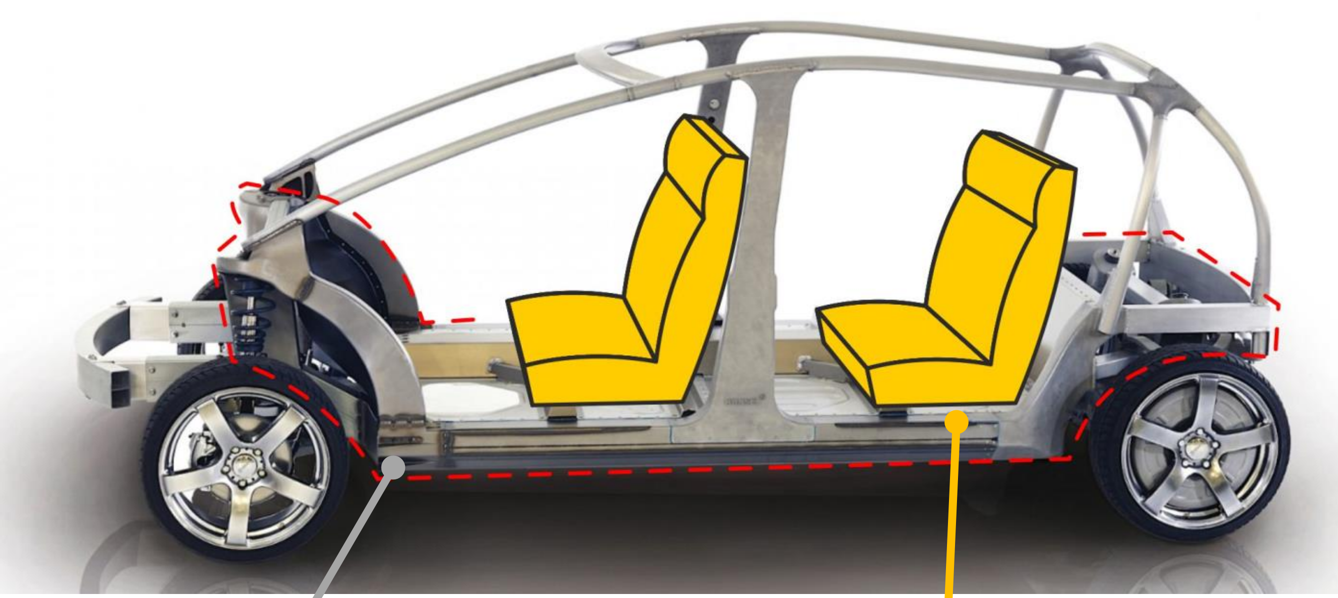
HEAD

Use case 3: CFRP parts remanufacturing

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

Example DC 7: Light Car Space Frame Concept from EDAG



Demo-Case: Body Structure
Complete New Approach
Task-Leader: EDAG

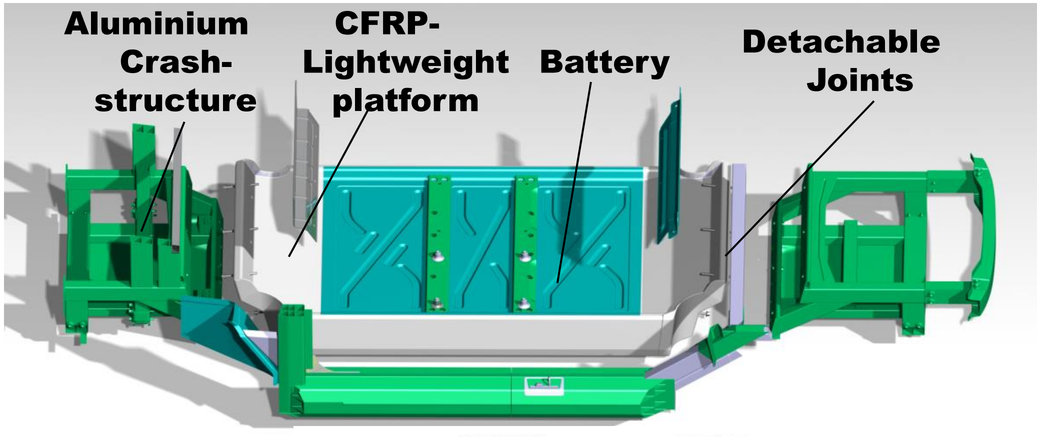
Demo-Case:
Internal/Interieur Structure
e.g. Rear Seat Backrest
Task Leader: INVENT

Use-case 3: E-vehicle re-design concept

Segment: Compact multi-purpose vehicle (MPV)

Design and proportions:

- Short hood
- Small overhangs for easy parking
- Large wheelbase for easy entering and leaving the car and for maximization of battery compartment
- Modern panelled design for easy refurbish

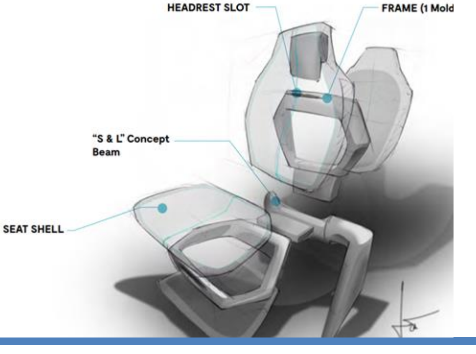


Platform features (CFRP & GFRP):

- Light
- Scalable (M, L, XL)
- Symmetrical foundation pursued
- Crash safety for passengers and battery

Requirements:

- Reusability of BiW parts
- Ultimate fatigue life of main body panels (30 years)
- Possibility of non destructive disassembly
- New detachable joining methods for FRP parts



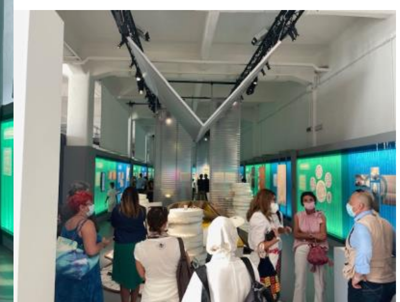
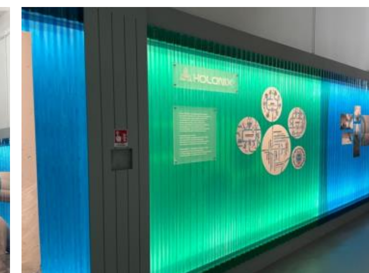
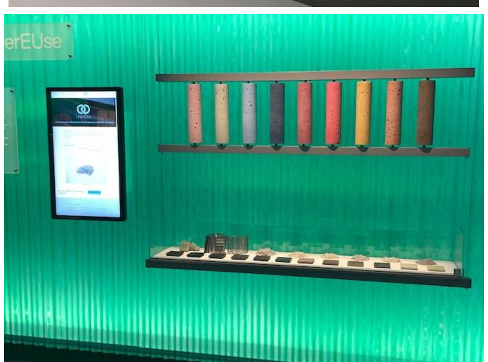
First complete prototype presented at the Milan Design Week in Sept 2021

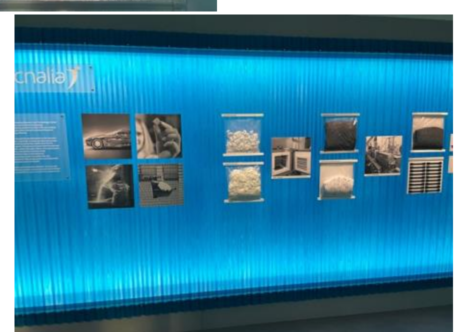
Overview of the Milan Design Week Installation in Sept 2021








Target objective of the inter-departmental laboratory CIRC-eV

Technical challenges:

- High variability of input product design
- High variability in the conditions of post-use batteries
- Lack of testing criteria and standard certification procedures:
    - SOH and residual life-time;
    - Acceptability for re-use;
    - Performance regenerated modules.
- Safety and egonomy requirements for humans.
- High quality and efficiency standards.

Requirements:

Flexible and adaptable technologies

Availability of information from producers and in the use phase

Standard testing procedures

Decision Support System for performance-driven re-assembly

Human-centric and safe-by-design systems

Automation, traceability and repeatibility

Need to develop a new generation of Safe and Smart De-and Remanufacturing systems

Manufacturer Centric CE model – Technical Challenges and Requirements

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.

In line with these requirements, methodologies, tools and enabling technologies for the next generation **smart de-and remanufacturing systems of the future** are needed.

APRA MAIN POSITIONING

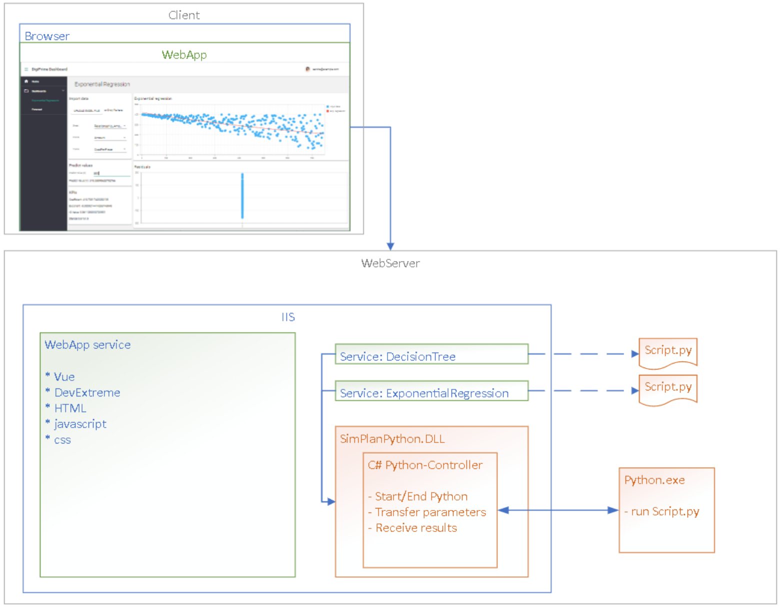
THE VOICE OF REMANUFACTURING SINCE 1941

APRA IS THE ONLY GLOBAL ASSOCIATION THAT REPRESENTS THE WHOLE AUTOMOTIVE REMANUFACTURING INDUSTRY

We are representing:
Remanufacturers, Component Manufacturers, Car Manufacturers, Core Dealers, Wholesalers, Scientific Research Institutions, Consultants & Services

OS Demand and Supply Forecast

Service application for forecasting the demand for remanufactured products and the supply of post-products in order to support de-and remanufacturers in medium-term production planning, long-term capacity planning activities, assessment of circular business cases on new products and second-life material/product pricing.



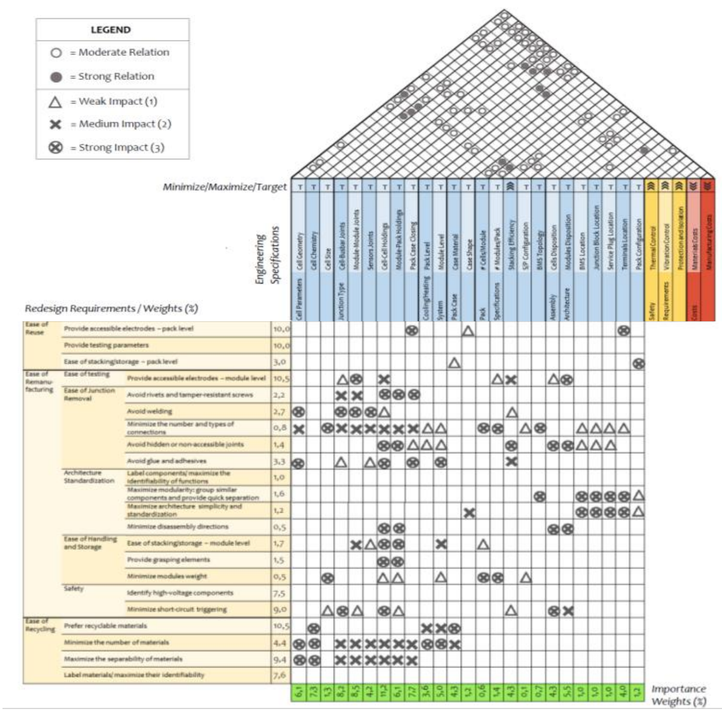
Improved data handling

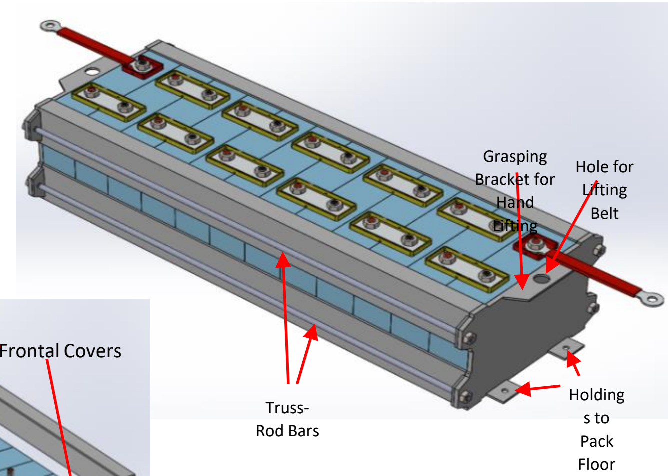
Evaluation KPIs

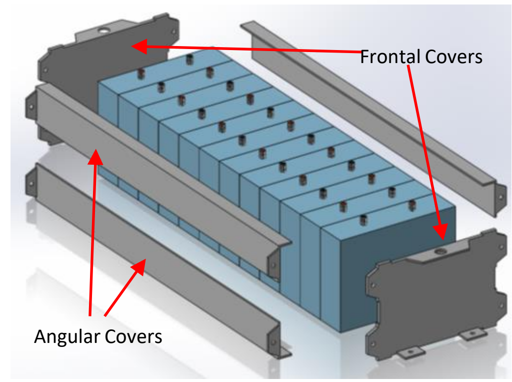
Re-design of battery packs and modules for easier disassembly and re-use

HOUSE OF QUALITY

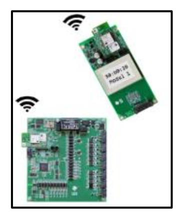
The design tool of Quality Function Deployment (QFD)

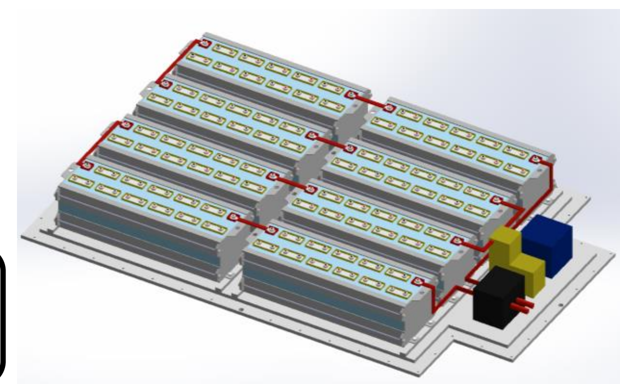






- Easy opening
- No glue
- Maximum accessibility of internal parts
- Easy testing and maintenance





"Which engineering specifications mostly impact on the Redesign Requirements?"

Gentilini, L. Mossali, E., Merati, G, Colledani, M., *Methodology and Application of Electric Vehicles Battery Packs Redesign for Circular Economy*, 30th CIRP Design Conference, 5-8 May 2020, South Africa, Procedia CIRP, Volume 91, 2020, Pages 747-751.