rEUman: Digitally-enhanced multi-level solution for smart human-centric remanufacturing

List of participants:

No	Name	Type	Short	Country	Role
1	**Politecnico di Milano** Project Coordinator: Prof. M. Colledani.	RTD	POLIMI	IT	human-centric disassembly, human empowerment, Cyber-Physical System for re-assembly, cold-spray, training, core collection schema and reward, pilot implementation and validation.
2	**Karlsruher Institut fuer Technologie**	RTD	KIT	DE	Function-oriented assembly, inspection and data gathering, reverse network configuration.
3	**Institute for Computer Science and Control**	RTD	SZTAKI	HU	Robotics visual inspection of post-use electronics, collaborative robotics, remanufacturing factory simulation/optimization.
4	**University of Bristol**	RTD	BRI	UK	Business dynamics, modeling and remanufacturing strategy.
5	**Flexis AG**	SME	FLEX	DE	IT company, design and implementation of reverse BoM and circular production planning for remanufacturing.
6	**Simplan AG**	SME	SIM	DE	IT company, design and implementation of Circular Value-Stream Mapping and demand-supply forecasting.
7	**Borg Automotive**	IND	BORG	PL	End-user, ind. automotive reman. (e-drives, inverters, e-turbos).
8	**CPI Belgium**	IND	CPI	BE	Affiliated partner of Borg, remanufacturing business strategy.
9	**Arcelik A.S.**	IND	ARC	TR	End-user, home appliances mfg., refrigerator remanufacturing.
10	**Automotive Parts Remanufacturers Association Europe**	SME	APRA	BE	Association, dissemination leader, legislation compliance, standardization and skill development (APRA Academy).
11	**Convergent Photonics**	SME	CONV	IT	End-user, optoelectronics manufacturer, remanufacturing of diode laser multi-emitter modules.
12	**Hepenix Muszaki Szolgaltato KFT**	SME	HEPENIX	HU	Technology provider, semi-automated, human-centric disassembly.
13	**Olimpia Splendid S.p.a.**	IND	OS	IT	End-user, home appliances mfg., heat pumps remanufacturing.
14	**Knorr-Bremse Systeme für Nutzfahrzeuge GMBH**	IND	KB	DE	End-user, OES automotive remanufacturer (electronics, control units – (H)ADAS).
15	**Syxis VSI**	SME	SYXIS	LT	Service integration, IoT, production data modelling and transfer, link with OpenDEI, interoperability.
16	**Enginsoft SPA**	IND	ES	IT	Digital tool integration and optimization suite. Skill development.
17	**CR&C**	SME	CR&C	IT	Technology provider, electronics remanufacturer.
18	**Core Innovation**	SME	CORE	GR	Technology provider, AI for return product characterization.
19	**Karl Zeiss**	IND	ZEISS	DE	Technology provider, inspection technologies for remanufacturing.
20	**Giacomelli Media**	SME	G-Media	SL	Exploitation leader, market uptake, financing, IPR management.

Glossary

Acronym	Meaning	Acronym	Meaning	Acronym	Meaning
AI	Artificial Intelligence	ET	Enabling Technology	OES	Original Equipment Supplier
BoM	Bill of Materials	EV	Electric Vehicle	OEM	Original Equipment Manufacturer
CPS	Cyber-Physical System	Fd, Fo	Factory Design / Operational tools	OSS	Open-source Software
CVSM	Circular Value Stream Mapping	ICEV	Internal Combustion Engine Vehicle	SME	Small and medium-sized enterprise
DMP	Data Management Plan	IPR	Intellectual Property Rights	VCd / VCo	Value-Chain Design / Operational tools
DPP	Digital Product Passport	MES	Manufacturing Executions System		

Key Terminology [*Apra Europe*]:

- **Remanufacturing (or Reman):** Remanufacturing is a standardized industrial process by which cores are returned to same-as-new, or better, condition and performance. The process is in line with specific technical specifications, including engineering, quality and testing standards. The process yields fully warranted products;
- **Core (or Post-use product):** A core is a previously sold, worn or non-functional product or part, intended for the remanufacturing process. During reverse logistics, a core is protected, handled and identified for remanufacturing to avoid damage and to preserve its value. A core is not waste or scrap and is not intended to be reused before remanufacturing.
- **Remanufactured part:** A remanufactured part fulfills a function which is at least equivalent compared to the original part. It is restored from an existing part (core), using standardized industrial processes in line with specific technical specifications. A remanufactured part is given the same warranty as a new part and it clearly identifies the part as a remanufactured part and states the remanufacturer.

1. Excellence

1.1. Objectives and ambition

Remanufacturing is the most valuable circular economy option, providing relevant economic returns to European manufacturing companies, contributing to the creation of knowledge-intensive jobs and new skills. Remanufacturing also reduces the dependency on the extraction and supply of critical raw materials in Europe, evidenced by the environmental benefits in terms of material consumption (-80% on average) and CO_2 emissions (-90%) with respect to new manufacturing operations. However, modern high-added value consumer products manufactured in Europe are evolving into high-complexity smart products, embedding sensors and intelligence to provide an improved set of customized functions to users and to reduce the environmental footprint. This product transformation is posing additional burden on the implementation of safe, economically and environmentally attractive remanufacturing business cases aiming at reusing functions and materials from post-use high-added value products.

For example, the automotive industry, the most important manufacturing industry in Europe providing jobs to 12 million people with a turnover of about € 780 billion Euro and a value added of 140 billion, is undergoing a fundamental transformation pervaded by the transition from traditional fuel cars to Electric (EV) and Hybrid (HEV) vehicles. It is predicted that, by 2035 the majority of newly sold vehicles will be electric. This revolution is accompanied by a fundamental transformation in the car design, featuring a substantial evolution in the critical car components and materials, pervaded by electrochemical, mechatronics and electronics components.

Remanufacturing operations are currently performed within complex industrial process-chains entailing disassembly (manual), cleaning and regeneration (semi-automated), and re-assembly (manual or automatic) stages. Differently from manufacturing operations, in remanufacturing product variations and uncertainties are generated within the use-phase and observed by the system in the input flow of post-consumer products (cores). The main objective of the remanufacturing process is to smooth the propagation of the product variability throughout the remanufacturing value-chain and factory stages. The quality requirements from the recovered parts are extremely demanding, since "as good as new" critical product characteristics have to be guaranteed. The regeneration rate in remanufacturing is usually between 50%-70%. The main limitations in the current remanufacturing practices are summarized below:

- *Lack of automation:* Post-use product disassembly is always manual, affecting operational safety, throughput and quality. High variability in the post-use product conditions bound the possibility of full automation in disassembly.
- *High-dependency on human activities with poor adoption of human-centered solutions:* In spite of the massive dependency on human tasks, frequently complex, articulated and involving high loads, and knowledge-intensive decision making, specific technologies and tools in support of humans are poorly adopted in remanufacturing.
- *Poor traceability:* Design and in-use product data and knowledge is poorly exchanged among manufacturers and remanufacturers, leading to information asymmetry and poor transparency along the value-chain stakeholders.
- *Stability of core collection, storage, and supply:* Post-use product collection and transportation is not supported by ad-hoc technologies, resulting in high variability in quantity and quality of collected cores, thus making the analysis and planning of remanufacturing business models more uncertain.
- *Poor adoption of digitalization:* Decision making and operations along the steps of the process-chain are not supported by digital tools, making the remanufacturing value-chain and factory less flexible in implementing different circular routes depending on the residual characteristics of the collected cores. There is a lack of digital tools targeting remanufacturing operation design, management, and control and poor operators' knowledge formalization and human-oriented decision support tools.

The empirical research on 91 members of APRA in North America, reports that more than 60% of companies don't use qualitative or quantitative models for remanufacturing optimization. As a matter of fact, today remanufacturing is applied only to relatively simple components in the automotive, aeronautics and consumer goods. A digitally-enhanced methodology for design and operation of remanufacturing is needed for a wide diffusion of remanufacturing in the European industry, i.e. a Twin-Transition to sustainable business, enabled by digitalization.

rEUman aims at developing and demonstrating a novel paradigm of human-centric remanufacturing approach for the European industry, acting at value-chain and factory levels, that is:
- **Intrinsically human-safe:** able to reduce human risks and increase workers' satisfaction and efficiency along the entire remanufacturing process-chain through human-centric technologies and decision support digital tools;
- **Target-driven:** able to produce remanufactured products at high regeneration rates, meeting certified product function retain or upgrade specifications;
- **Flexible:** able to adapt to variable input post-use product conditions;
- **Robust and replicable:** applicable to a wide variety of business sectors, at different levels of reman maturity;
by encompassing innovative digitally-enhanced automated technologies compounded by the implementation of Digital Product Passport and the related data-model and digital services.

The rEUman consortium, involving 20 partners from 10 EU Member States and the UK, of which 15 companies, 8 SMEs, 4 research centres and universities and 1 leading association in the remanufacturing business, believes that this is the key solution for a sustainable transformation of the European industry towards remanufacturing. To accomplish this overarching objective, the ambition of rEUman is:

- To design and develop specific pre-process and in-process vision inspection technologies for remanufacturing, to gather information about the post-use product critical quality characteristics in order to increase traceability in remanufacturing, improving reman product certification/compliance and the customer willingness-to-buy.
- To design and develop safe, human-centric remanufacturing technologies, including smart manual disassembly, human empowerment and hybrid automation collaborative solutions, to increase efficiency and flexibility of remanufacturing factories.
- To develop and validate innovative electronics and mechanical component regeneration solutions, by Visual servo-based robotics and cold-spray, to increase the technical capabilities of remanufacturing a larger set of post-use components, significantly increasing the quality of remanufactured products.
- To develop and validate function-oriented re-assembly strategies, able to adapt the selection of components to be reassembled in remanufactured products based on their inspected characteristics and the functionality required by the specific reman product model, for both function retain and upgrade business cases.
- To investigate, introduce, validate a Digital Product Passport-compliant data management platform for traceability in reman, by leveraging on existing standards, specifications, data-spaces (notably IDSA, Catena-X, AAS, GAIA-X). The platform will be developed based on open specifications and leveraging Open-source software (OSS), in synergy with recent Digital Product Passport projects (e.g. the CircPass CSA).
- To enrich the Digital Platform with data-enhanced digital services, for supporting design and operation at factory level, enabling the process-chain adaptation to the post-use product conditions for high regeneration rates, and at value-chain level, favouring stable, in terms of quality and volumes, post-use product collection and return to the reman factory through AI-based remote core characterization and incentive schema.
- To validate the novel remanufacturing paradigm in 3 industrial pilots within automotive, household appliances, and optoelectronics sectors, strategic for the Critical Raw Materials [18], the EU Net-Zero Industry [19], and the Chips Acts [20], in 5 specific demo-cases in both mature and emerging remanufacturing business cases, assessing the achievement of the target KPIs and verifying the benefits derived from the rEUman adoption.
- To set-up innovative training mechanisms and learning resources, to fulfil the existing skill gap towards digital technologies in remanufacturing and prepare future generation of reman experts to the rEUman adoption.

The objectives and the ambition rEUman are fully compliant with the general requirements of the call "Climate neutral, circular and digitised production HORIZON-CL4-2023-TWIN-TRANSITION-01, and with the specific requirements of the topic "HORIZON-CL4-2023-TWIN-TRANSITION-01-04 — Factory-level and value chain approaches for remanufacturing (Made in Europe Partnership)", as shown in the following Table 1.1.

Table 1.1: Project adherence to the work-programme and call: objectives, expected results and means of verifications.

<table>
<tr><th>Call HORIZON-CL4-2023-TWIN-TRANSITION-01-04</th><th>Adherence to the call</th><th>Objectives and expected results</th><th>Means of verification (KPI of the solution)</th></tr>
<tr><td rowspan="2">"This calls for both remanufacturing technologies at the factory level and their integration into circular value chains, including the streamlining data to support remanufacturing"</td><td rowspan="2">rEUman will develop a novel remanufacturing approach coupling two pillars namely (i) smart hybrid automation and (ii) digitalization, elaborating on the concept of Digital Product Passport. It will include digital and physical technologies at factory (WP3, 4) and value-chain levels (WP5), that will be integrated under a human-centric approach. Both design and "real" product data in the DPP, gathered by visual inspection, at the point of collection and in the factory, will be integrated in a data management system to enhance the solution (WP2).</td><td colspan="2"><u>Integration of rEUman in 5 circular demo-cases</u></td></tr>
<tr><td>Validate the DPP concept, 6 new reman technologies, and 11 digital solutions, 6 at factory and 5 at value-chain levels, within 5 circular value-chains.
Achieving stable quality and volumes of post-use parts as well as high regeneration rates at factory level.</td><td>The detailed pilot KPIs are reported in the impact Section 2. In summary:
● At least 95% regeneration rate, or production yield, for remanufactured parts.
● At least 90% of collected cores correctly classified and re-used in remanufacturing operations.</td></tr>
<tr><td rowspan="2">"Remanufacturing should not be focused only on the reuse of raw materials but should be aimed at reusing and upscaling components, valorising them and retaining or upgrading their functionality. Components, products and/or functions can be updated with new technology and improved beyond their initial functionality."</td><td rowspan="2">rEUman will deal with both "remanufacturing for original function restore" (3 demo-cases) and "remanufacturing for function upgrade" (2 demo-cases on heat pumps and optoelectronics multi-emitters). Indeed, the developed hardware technologies for mechanical and electronics reman (e.g. cold spray), and function-oriented re-assembly will support the upgrade of the original functions through additional sensoring and assembled product re-configurations integrating new technologies for upgraded functions (WP3).</td><td colspan="2"><u>Cold spray, CPS for re-assembly – ET7, ET8. Business strategy design - VCd.</u></td></tr>
<tr><td>Development of cold spray technology for mechanical regeneration and function upgrade.
CPS for function upgrade through optimal selection of new/reman parts.
Remanufacturing for upgrade business models.</td><td>● Remanufacture at least 70% in weight of the original product components.
● 100% of reman products with functionality retain.
● At least 30% reman products with functionality upgrade.</td></tr>
</table>

“Demonstrate remanufacturing processes that retain components functionality in at least three user cases;”.	The rEUman human-centric solution will be tested and validated in 3 strategic industries (automotive, home appliances, optoelectronics), fundamental for the European sustainable development for different reasons (transformation to e-mobility, Net-Zero Industry, Critical Raw Materials, and Chips Acts). 5 industry led demo-cases, and 8 product models previously non remanufactured, in more than 15 variants, will be demonstrated (WP6).	**<u>Pilot validation and demonstration – WP6</u>**	
		New reman cases: ● Automotive industry towards e-mobility; ● Home appliance industry increasing its energy efficiency. ● Optoelectronics, maintaining components in EU.	●>15 new business cases for new remanufactured product models (e-drives, inverters, e-turbos, control units, heat pumps, refrigerators, multi-emitters diode laser modules). ●-30% reman process costs.
“Develop cutting-edge remanufacturing approaches (design, technologies, business cases) and their integration into value chains;”.	rEUman will integrate cutting edge technologies and factory (re)design and control digital solutions for disassembly, regeneration and reassembly into properly designed business models, enabled by innovative value-chain approaches. During the business strategy design phase, novel business dynamics tools, Circular Value Stream Mapping for demand-supply forecasting, and core collection strategies based on incentives and reward will be validated (WP5).	**<u>Reman strategy design, Circular Value Stream Mapping, core collection strategies based on incentives – VCd, VCo</u>**	
		Develop: ● Business strategy design tool based on business dynamics. ● Circular Value Stream Mapping. ● Reward-based core collection strategies.	●-60% new reman product introduction (NRPI) time. ●>85% willingness to buy reman products. ●+20% Core Collection rates. ● -15% Core acquisition cost.
“Introduce flexible production concepts, advanced machinery, smart mechatronics, interactive and collaborative machines, robots and systems enabling efficient factory operation and reconfiguration”.	rEUman will develop hybrid collaborative robotic solutions for disassembly, flexible pre-configuring fixture for cobotic/hybrid disassembly cells, servo-based robotic cell for electronics remanufacturing, cold-spray for mechanical parts remanufacturing, and flexible function-oriented re-assembly station that will be integrated at factory level within the pilots. These smart automation solutions will be connected to the rEUman digital platform for DPP data exchange and for decision making and control supported by factory level digital tools, including a reman factory (re)design and production planning and control solution (WP4).	**<u>Hybrid disassembly, electronics reman, cold-spray, CPS for flexible re-assembly, factory design and production planning – [ET4 – ET8], Fd</u>**	
		To develop a flexible, collaborative disassembly solution. To develop a flexible fixture pre-configuration. To develop servo-based robotic cell for electronics remanufacturing. Cold-spray for mechanical part remanufacturing. CPS for re-assembly.	●Core disassembly time reduction (>40%); ●+ 30% of reman product regeneration rate (target 95%). ●>60% remanufacturable electronics. ●<10 sec for optimal CPS-based selection for re-assembly. ●-15% energy in cold spray.
“A human-centric approach to remanufacturing should be integrated, with appropriate contributions from Social Sciences and Humanities (SSH)”	As humans in remanufacturing play a crucial role, specific technologies for supporting them during disassembly, by worker empowerment solutions for improved ergonomy and through proper human-centric workstation design and process support solutions, as well as during decision making, through DSS tools for informed remanufacturability analysis (WP3).	**<u>Human-centric disassembly process design and support, Worker empowerment– ET2, ET3.</u>**	
		To design and validate worker empowerment and human-centric disassembly processes and workstation for improving efficiency and ergonomy.	●-20% task execution errors. ●-10% lumbar injury occurrence. ●-40% accidents and safety issues in reman.
“The introduction of traceability aspects, quality control and a regulatory validation need to be considered”	The novel pre-process and in-process multi-sensor data gathering and inspection network designed by Zeiss (WP2), compounded by the AI-based remote core characterization by Core and the traceability solutions integrated by Syxis during the dismantling, regeneration and re-assembly operations, will make it possible to develop AI tools for fast qualification and certification of the reman parts, in view of the release of a new or updated product ID and DPP data, according to the ESPR guidelines.	**<u>Visual inspection, AI-based remote core characterization, DPP-enhanced data management platform for traceability – ET1, ET9, VCo</u>**	
		Develop and validate Zero-Defect reman solutions by novel inspection, traceability, CPSs for process adaptation and AI for reman certification.	●<30 seconds for core inspection and clustering in quality classes. ●<10 seconds for part remanufacturability analysis. ● <30 sec for AI-based certification
“as part of this, a strategy for skills development should be included, associating social partners where relevant. This may include augmenting technologies and skills to strengthen the capabilities of the European workforce”.	rEUman will prepare new learning resources and training mechanisms for fulfilling knowledge gaps, by (i) exploiting the availability of teaching and research factories (e.g. CIRC-eV, EcoCirc), (ii) exploiting digital twins for gamification; (iii) executing ReEUmanuthon, an hackathon for future remanufacturing challenges, in cooperation with the EIT Manufacturing; (iv) launching the APRA Academy for reman operators; (v) running the RemanChallenge and RemanMasterClasses organized by Borg (WP8).	Reduce the knowledge gap and increase the adoption rate of human-centric and digital technologies in the remanufacturing industry through ad-hoc designed learning resources and training mechanisms.	●Organize and execute 2 ReEUmanuthon editions, hackathon for reman. ●>10 hands-on workshops in learning factories at Polimi, KIT, Sztaki. ●>2 editions of the APRA Academy. ●>5 gamification workflows
Proposals should take the relevant EU-regulatory framework into	rEUman will develop the concept of label-based Digital Product Passport (DPP) for electronics	**<u>Data-model and Product ID solution for Digital Product Passport – ET9</u>**	

account such as the Ecodesign Directive and the forthcoming Sustainable Product Framework (SPI)[1]. Proposals should take into account any relevant international standards (such as the Asset Administration Shell) and activities supported under the Digital Europe programme, e.g. in the area of Manufacturing Data Spaces and the Digital Product Passport initiative	components/materials identification and traceability, providing remanufacturers customized data and metadata on component features (in line with the ESPR). The DPP and the identification system will be enhanced with a proper data model that represents electronics and their interrelationships based on data-spaces (e.g. IDSA, AAS, Catena-X, GAIA-X), and grounded on open specifications and open hardware, in synergy with Product Passport projects (e.g. the CirPass CSA, as Polimi is WP3 Leader of CirPass) (activity in WP2 of rEUman).	To develop and interoperable Data Model, achieving quick identification of electronics component data and related metadata. To develop DPP prototype for remanufacturers, ensuring decentralized, trusted and secure information tracing.	• Automatic & error free label-based Identification for new DPPs (>99%); • Tampered proofs and certified digital data about electronics (100%); • 100% electronics in pilots modelled in the DPP knowledge-graph. • >+15% in operational efficiency directly linked to the DPP.
Research must build on existing standards or contribute to future standardisation. Where relevant, proposals should contribute to standardisation of relevant technologies	rEUman has thoroughly revised existing standards, including recent actions towards remanufacturing standardization (e.g. ISO 26262, DIN SPEC 91472). The developed Key Enabling Technologies will be monitored within a *Completion Toolsets* with recommendations to contribute to standardisation processes, in synergy with CEN-CENELEC (T7.4)	To develop technologies that are aligned with existing standards and provide opportunities for contributing to future standards, linking with ongoing standardization initiatives.	• At least 3 innovative technologies potentially contributing to remanufacturing standards. • >3 workshops with standardization initiatives in remanufacturing, facilitated by APRA.
Interoperability for data sharing must be addressed, leveraging on existing ontologies and metadata and though the implementation of the FAIR data principles	The rEUman digital platform will be made interoperable with existing industrial data spaces solution through IDSA-like connectors. In addition, links with existing digital platform projects (i.e. DigiPrime, Trick) will be set up to share data, tools, and methods. The design of the data management platform will be compliant with FAIR data principles. The interoperability among digital tools and the existing data sources (PLM, ERP) will be considered (WP2, WP6).	The DPP-compliant data management platform will be designed and implemented in WP2. Then it will be validated within the pilot and continuously updated along the entire project duration, and released at M48.	• Development of 100% IDSA compliant connectors. • Collection of structured feedback from pilots and fine-tuning of the platform for future uptake. • Release of 100% of the tools expected at the TRL described.
All projects should build on or seek collaboration with existing projects and develop synergies with other relevant European, national or regional initiatives, funding programmes.	rEUman, through its dissemination and communication, plan will create synergies with ongoing projects (e.g. DigiPrime, CircularTwAIn), and will identify uptake opportunities within Vanguard De-and Remanufacturing, EIT manufacturing, and I3 Inter-regional Innovation Investments (T7.5).	To liaise with ongoing initiatives and defining synergies and complementarities at Regional, National and EU level.	• >5 financial mechanisms and funding synergies for further technology uptake. • >8 initiatives at EU level within EIT, Vanguard, Next Gen EU, and I3.

The main progress beyond the state-of-the-art for a sub-set of key technologies in rEUman is summarized below.

ET1: Pre-process and in-process visual inspection for remanufacturing: Pre-process and in-process are fundamental steps that today are performed mainly manually through visual inspection. [1] demonstrated through a vast experimental campaign performed on automotive engines, that an in-depth pre-process inspection, although time-consuming, can support adjustment and fine tuning of the downstream remanufacturing process-chain parameters, thus leading to considerable time savings in remanufacturing, also gaining in regeneration rates. Automatic inspection of end-of-life components carries many challenges not seen in traditional production/manufacturing. Surface wear, micro-cracking, and deformation can all affect how the subcomponents perform and may lead to premature failure upon re-use. ZEISS will study adapting existing well established inspection systems, combined with multi-spectrum vision and intelligent data analytics to provide essential data to the decision-making parts of the full consortium systems. While similar technology is used in production today (TRL 9), adapting it to the specific use-cases and end-of-life returning products is currently at **TRL 4**.

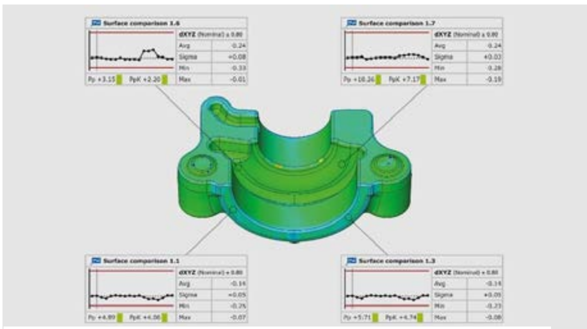


Figure 1.1: 3D scanning and vision system or inspection.

rEUman innovation beyond the state of the art. The technical focus will be on pre-process inspection of parts, and in-process inspection of mechanical and electronics components. For each of these, traditional and novel approaches will be tested to establish the best technical and workflow fit. For mechanical inspection, high-resolution 3D scanning in combination with ML powered vision systems will be evaluated to measure the components, the assembly alignment, and scan for potential defects. Individual sub-components wear and defects will be measured by multi-spectral vision and ML defect identification. For electronic inspection, thermal mapping will be evaluated to identify defects which may cause premature failure. The required resolution and mechanical setup needed for high throughput, high accuracy analysis will be studied. Limitations may arise based on component geometry, component reflectivity, and accuracy requirements. Each of these may limit the useability of specific measurement technologies. Between 3D scanning, intelligent multi-spectrum vision systems, and thermal mapping - it is the aim to demonstrate what is required for a flexible, high throughput characterization solution. The work outlined will be conducted on the remanufacturing of electric drive motors (BORG), and industrial laser systems (Convergent Photonics) in WP2. Current market solutions have a focus on production and manufacturing, potentially unsuitable for the remanufacturing space. It is the aim of this work to evaluate and demonstrate viable technical solutions that can spot the defects that arise in end-of-life components, reaching **TRL6**.

ET2 – Human-centric disassembly process design and support. Human labour has a crucial role in remanufacturing, in particular disassembly, due to its flexible capability and adaptability. Digital technologies can support the development of novel methodologies to monitor and facilitate manual processes, however they are currently still in an early development stage (**TRL 3-4**). Traditional modelling approaches for monitoring manufacturing processes fail when dealing with tracking behaviours that are not deterministic. This is a major limitation for remanufacturing processes and human-operated activities due to the high variability and uncertainty that characterize such environments, failing to catch the non-deterministic nature of a manual process. To overcome this limitation, generative models are defined using stochastic parameters estimated from input data. Hidden Markov Models (HMM) [2] and Dynamic Bayesian Networks [3] are the most commonly used generative modelling methods. HMM, in particular, are among the most suitable tools for monitoring human activities in different application areas and for gesture recognition [4].

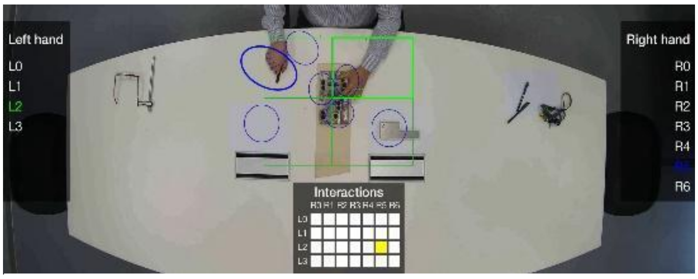


Figure 1.2: Camera-based monitoring for supporting human operations.

rEUman innovation beyond the state of the art. rEUman will develop a digital tool to support the design, control, and monitoring of human-operated disassembly processes. The rEUman approach will leverage on HMMs to provide the possibility of jointly considering the available knowledge (the ideal process) and the information coming from experiments (the output of tracking approaches), enabling mixed generative and discriminative approaches [5]. In the last 6–7 years, several AI-based frameworks for human pose estimation have been developed. These frameworks have improved accuracy and speed, opening the floor to a new generation of versatile, reliable and industry-ready monitoring approaches for human processes [6]. rEUman will use data acquired on-site from cameras, to provide: (i) adapted instructions and supporting information to the operator with respect to production targets; (ii) real-time identification of the process activities and manual operations for advanced monitoring of manual processes, increased safety and error free task execution; (iii) real-time identification of possible execution errors, warning the operator and providing supporting knowledge. **The target TRL will be 6.**

ET3 – Worker empowerment for safety in disassembly. Manual disassembly workstations and required tasks may also be characterized by ergonomic issues, including repetitive movements, loads handling, tools holding and usage. For example, studies [7] confirm that an increasing fatigue of the Quadriceps Femoris in repetitive squatting/lifting tasks alters the mode of squatting to stooping with an elevated load on the low back, thus increasing the risk of lumbar injury. In addition, the burden of re-introduction of workers after any type of injury is further increasing the need of musculoskeletal assistance for the worker. The workers in disassembly lines have to perform multiple tasks, as complex and articulated actions in sequential operations that the workers have to be prepared for.

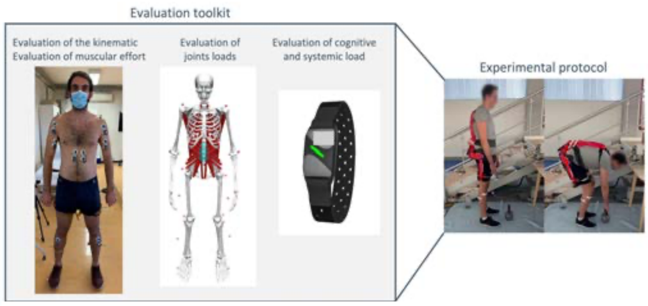


Figure 1.3: Ergonomic assessment and human support devices.

rEUman innovation beyond the state of the art. rEUman will bring innovation on ergonomy assessment methods and technologies for human empowerment during high safety risk and repetitive disassembly tasks. *Assessment methods*: actual assessment methods [8] are not specific for most of the remanufacturing activities; a first proposed solution is a revision and proposal of specific experimental protocols and metrics for ergonomic evaluation of such workplaces and tasks, which could be used to identify critical situations to be specifically addressed (by wearable technologies, cobots or other solutions). The evaluation methodology will include a dedicated sensors network (i.e., evaluation toolkit): i) evaluation of the kinematic of the movement(s) by means of IMUs, ii) evaluation of muscular involvement, effort, and fatigue by means of EMG measurements; iii) evaluation of loads applied to most relevant joints by means of inverse dynamic calculation through simulation softwares (e.g., AnyBody); iv) evaluation of cognitive and systemic load by means of heart rate variability assessment. The same evaluation can be performed before/after the introduction of actions to mitigate the workload (e.g., wearable technologies, cobots, etc.). *Technology*: wearable devices (exoskeletons and embedded and distributed sensors network) to mitigate the impact of fatigue on effort, attention and/or concentration level of the workers. These technologies are currently at **TRL4** and will target **TRL7**.

ET4 – Hybrid collaborative disassembly for remanufacturing. Disassembly cells are dominantly manual stations because disassembly is characterised with high variability of products, high variability of error symptoms, wide-ranging correction operations and lot size making the use of automation as a helper, problematic [9]. However, the quality-class based disassembly planning of rEUman, reducing the variability in post-use conditions of returning cores, unlocks the possibility of at least partial collaborative automation in disassembly. Collaborative disassembly is an active topic, driven by the need to provide effective tools for remanufacturing, despite current products that are not optimised for disassembly. Current results demonstrate feasibility of creating disassembly cells with cobots at lab scale (**TRL4**), however, there are no cell concepts dynamically driven by target KPIs [10].

Figure 1.4: Collaborative disassembly tasks.

rEUman innovation beyond the state of the art. A KPI-oriented collaborative disassembly cell will be developed to show the feasibility of the rEUman approach in cobot-assisted disassembly processes, involving a human operator, reaching usable cycle time and quality criteria at varying workflows. For the collaborative disassembly cell, an outline will be created that can be applied to multiple industries and products. Based on this outline, the actual collaborative cell of rEUman will contain 1 or 2 cobots - depending on the processes, a pre-configuring jig to receive the product to be disassembled, a set of tools that can be used either by the human operator or the robots or shared by both, sensors for the product and the human operator, standard control and safety systems including active compliance control. The design will be developed in a virtual commissioning environment to provide the advantage of checking the operation of the cell. The rEUman collaborative disassembly cell will show that based on the discovery of functional, generic structural similarities and quality clustering effective and thus viable operations can be carried out on a varying set of products. The cell will be implemented and tested at **TRL6** but it will also be shown at **TRL7**.

ET5 – Flexible, pre-configuring fixture for cobotic/hybrid disassembly cells. In order to make the rEUman approach highly efficient and consequently viable for use, the hybrid disassembly solution will be augmented by a fixture concept that does not require fixture replacements for the incoming variations of products. At a moderately higher initial investment than a fixture for a single type, but at a lower investment than the complete set of individual jigs for the targeted product portfolio, this concept also allows lower operating costs due to automatic changes that may even be performed parallel to other processes, and gains effectiveness thanks to the quality clustering. Solutions on the market are restricted to configuration possibilities at design stage resulting in a type-specific jig. Smart fixtures regularly use identification or communication functions for mass production on assembly lines with only a limited number of product types [11]. However, in order to support the large and often ad-hoc product variation in remanufacturing, a new approach needs to be introduced. The flexible, pre-configuring fixture will demonstrate that the hybrid remanufacturing operation can also be made effective by flexible fixture (current **TRL4** in reman).

rEUman innovation beyond the state of the art. The hybrid disassembly will require tooling for the process so that the operations can be carried out in a referenced manner with high potential for repeatability. The high variation in products and a lot size, coupled with the will to avoid high changeover time and thus limited output, would normally create a work environment without tooling, leaving operations to the precision of the human operator. Trustable reuse of parts requires a controlled environment targeting very high regeneration rates. The flexible pre-configuring fixture allows targeting these goals as it bridges these limitations and offers uninterrupted operations. The proposed concept is able to receive and support operations on a given product family where the members may be identified as geometrically largely different but sharing identical logical structure, analogous features and congruous processes for disassembly, assembly and testing. The fixture is able to perform measurements that can be used in confirming type identification, it contains all required prepositioning aids, positioners and locking holders for the

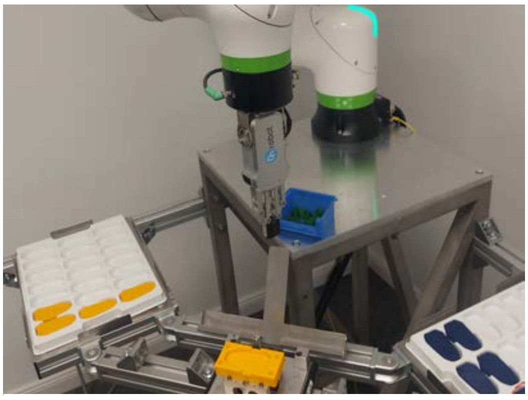


Figure 1.5: Flexible pre-configuring fixture.

process. The prototype is chosen to target **TRL6** to show the feasibility of the concept and to allow assessment of further development requirements towards industrial implementation.

ET6 – Visual servo-based robotic cell for electronics remanufacturing. Printed Circuit Board (PCB) diagnosis and repair shops are dealing with a vast amount of broken PCB products. First step of the repair process is to measure a series of predefined key points on the faulty PCB using a multimeter or oscilloscope to identify the possible failure cause, or broken, electrical component(s). PCB measurement, testing and diagnosis has a broad literature, with the most prominent areas being measurements using bed of nails, the flying probe test, and visual inspection of PCBs [12]. However, research typically focuses on the quality assurance of the mass-produced boards and less attention is given towards the diagnosis of used products. No solutions were found for repair shop or remanufacturing scenarios. To reduce the workload on the skilled experts, a robotized measuring process can be developed which allows the experts to focus on the measurement profile preparation and decision making instead of the repetitive, manual work. The automated measurement also enhances the documentation by automatically collecting and storing data from the measurement. The main challenges are the lack of digital PCB models and drawings, the high required precision (100 µm size key points), the need for fixtureless measurement, and the need for simple key point teaching on the PCBs.

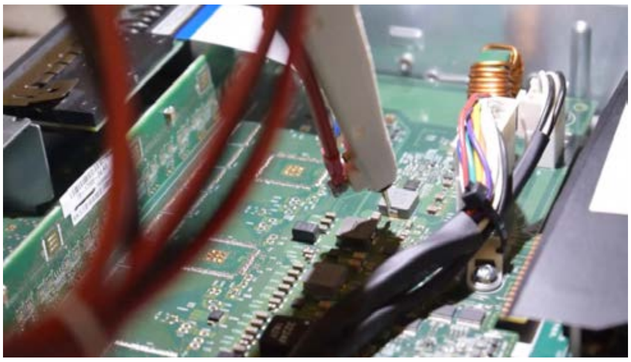


Figure 1.6: Servo-based robotic cell for electronics remanufacturing.

rEUman innovation beyond the state of the art. To be able to handle the position error, in the range of a couple of millimeters, of the measured key points using a robot, a visual servo technique was developed at laboratory scale (**TRL4**) by Sztaki. Visual serving on robot arms is applied in different fields, such as assembly or micro-manipulation. Nevertheless, no such PCB testing solution was found that is suitable for robustly checking a variety of features (key points) on used PCBs arriving in small batches, especially in case the precise geometry of the product. The idea is to observe the test-pin, together with the measured key point simultaneously using a 2D camera and gradually control the robot based on the camera image during measurement so that the test-pin tip, using a downward feeding motion, establishes the galvanic contact. In the absence of precise CAD models and drawings, key points need to be trained in manual mode for the robot. The aim is to achieve target **TRL7**.

ET7 – Cold-spray for mechanical part remanufacturing. Cold spray is a solid-state powder process that exploits the high velocity impact of powder against a target to get the adhesion of powder and progressively obtain a theoretically unlimited coating. Thanks to the peculiar characteristics of the process (no melting of powder, no need of protected atmosphere, almost no limitation of the processable metals and ability to consider mixture of powders for functional deposits) cold spray can satisfy the issues related to remanufacturing and regeneration of mechanical components [13]. The high deposition rates (up to 20 kg/h), no dimensional limits for the part to be processed, ability to upgrade the original performance by considering customized powder composition, make cold spray ideal for remanufacturing mechanical components with surface damage induced by wear, corrosion or other damage mechanisms. However, the present state the cost of cold spray makes it suitable just for rework of high value parts, while more investigation is needed for application of cold spray to post-use parts (present **TRL: 4-5**).

rEUman innovation beyond the state of the art. In rEUman, cold spray technology will be considered and developed for the applications of interest in Borg and Knorr Bremse. The application of cold spray will be designed by defining the right process parameters able to guarantee the desired performance and, at the same time, minimize the energy consumption thus reducing the cost. The advancement in cold spray is expected to raise to industrial application level, proving the ability of cold spray for sustainable industrial remanufacturing of exercised parts (**TRL 7-8**).

ET8 – Function-oriented re-assembly. The functionality of complex assemblies strongly depends on the interaction capability of its constituent components. For this reasons, Cyber-Physical Systems (CPSs) for function-oriented assembly have been recently proposed in the literature to exploit in-process data to cluster parts and select only compliant parts with good matching for the assembly in order to increase assembly quality [14] (**TRL5**). However, this challenge is even more evident in remanufacturing, where reman products are obtained by mixing regenerated and new sub-components in the same assembled part, depending on a remanufactured product BoM and with different quality characteristcs.

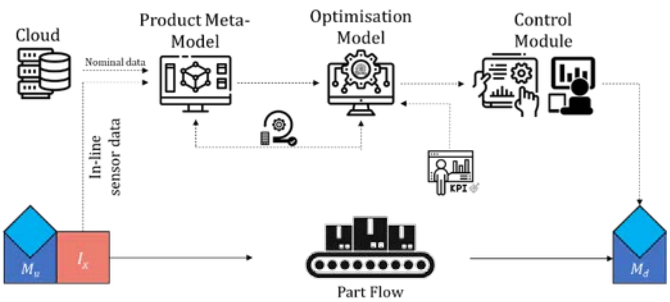


Figure 1.7: Cyber-physical system for function-oriented re-assembly.

Therefore, the re-traceable introduction of regenerated components in a reman product and the need of finding the right balance of component mix, both regenerated by remanufacturing and newly manufactured, within final assembly to meet the functional specifications, identical to the equivalent new product or upgraded, requires a dedicated decision support tool [15] and an hardware station equipped with the right network of sensors and flow control devices to implement, upon operator check, the optimal decisions of the intelligent algorithm within the CPS.

rEUman innovation beyond the state of the art. rEUman will develop both the hardward and digital intelligent parts of the CPS for re-assembly, in particular for the Convergent case. The proposed function-oriented Cyber-Physical System (CPS) for re-assembly is based on (i) Classification and sorting of components based on quality characteristics measurements, (ii) product meta-model to link the component quality characteristics to the quality features of the assembled product, integrating data analytics and/or physics-based model, (iii) optimization model that dynamically searches the solution domain defined by the available component mix in inventory and their quality characteristics in order to constantly provide an optimal selection vector for re-assembly, (iv) control module, which consists of GUI to incorporate human-in-loop paradigm, shows the necessary actions to be implemented to shop-floor operator. The **target TRL will be 7**.

ET9: DPP-enhanced data management platform for traceability in remanufacturing operations. The ESPR [16] "*includes the creation of a digital product passport to electronically register, process and share product-related information amongst supply chain businesses, authorities and consumers. This is expected to increase transparency, both for supply chain businesses and for the general public, and increase efficiencies in terms of information transfer*". Remanufacturing is mentioned in the document among the business cases gaining benefits from the introduction of the DPP. Also, although not yet officially regulated, the leaning is towards the creation of a new product ID once a core is remanufactured and puts back on the market as a reman part. According to the ongoing discussion at EU level, the DPP will be experimented first in three sectors, i.e. batteries, textile and electronics, this last being very relevant for automotive remanufacturing. In line with Cirpass, the DPP shall be structured as: A unique persistent ID for the product (including batch and/or serialization as necessary) (1); A persistent data carrier (RFID, QR Code, digital watermark, Bluetooth tag, etc.) (2); A Digital connector between physical product and the digital place of information on the product (3); An IT architecture for facilitating the data exchange (6). Cirpass in its deliverable D3.1 "Benchmark of existing DPP-oriented reference architectures" [17], led by Polimi, mapped 32 ongoing DPP pilot initiatives, at different level of implementation maturity. Typical **TRL is 4-5**.

rEUman innovation beyond the state of the art. rEUman will advance on the perspective of the remanufacturing industry towards the DPP, in line with the position paper that APRA Europe is publishing on the topic. The rEUman consortium will focus on the development of the data-model, or knowledge graph, for the electronics remanufacturing and will implement a first DPP compliant data management platform enabling traceability, together with its own stakeholder-dependent interaction layer, embedding several digital services to exploit the DPP data for enhancing efficiency at value-chain and factory levels. It will be the first-of-a- kind DPP-compliant implementation facilitating the operations of the remanufacturing industry, both considering OES and independent remanufacturers (**TRL6-7**).

1.2 Methodology

1.2.1 The rEUman Concept

Human-centric and Digitally-enhanced multi-level rEUman solution. In order to fill the aforementioned gaps and in compliance with the identified objective, the rEUman consortium aims to achieve a breakthrough innovation in the European remanufacturing industry by developing and demonstrating a novel smart and human-centric remanufacturing paradigm that will drastically improve the current poorly formalized and traceable remanufacturing operations, by acting at both value-chain and factory levels and affecting the design and operational phases of remanufacturing business cases. The rEUman concept, is represented in Figure 1.8.

The rEUman approach is based on the coupling and inter-twinning between the value-chain and factory levels, integrating physical and digital enabling technologies within a comprehensive multi-level framework.

The Factory Level: the factory level solutions are conceived with the objectives to:
(i) Support the (re)design and planning of the novel hybrid, human-centric, remanufacturing factory.
(ii) Increase the regeneration rate of remanufactured products, while systematically smoothing incoming post-use product variability.
(iii) Improve the traceability of the remanufacturing process-chain to facilitate certification, compliance and the DPP generation before releasing the product to the market.

This is achieved through three main pillars acting at Design (d) and operational (o) levels including: (Fd) novel digital tools to (re)design and plan the remanufacturing factory, when a new remanufacturable product model emerges; (Fo1) a novel Cyber-Physical remanufacturing process-chain, coupling a series of digital tools and human-centric physical technologies, to smooth the variability in conditions of the incoming cores and provide the human decision maker concrete solutions to increase the explainability of tools and traceability of the process; (Fo2) novel pre-process and in-process inspection solutions to gather product and component data along the stages of the remanufacturing process-chain, and store them in a data management platform, compliant with the DPP data model.

The Value-Chain Level: the value-chain level solutions are conceived to:

(i) Assess the economic and technical viability of a remanufacturing business case and design the remanufacturing business strategy and reverse logistics architecture.
(ii) Enhance the stable return rate of high-quality cores to be remanufactured.

This is achieved through two main pillars acting at design and operational levels, including (VCd) remanufacturing business strategy design digital tools, and (VCo) value-chain operational digital tools, for enhancing core returns.

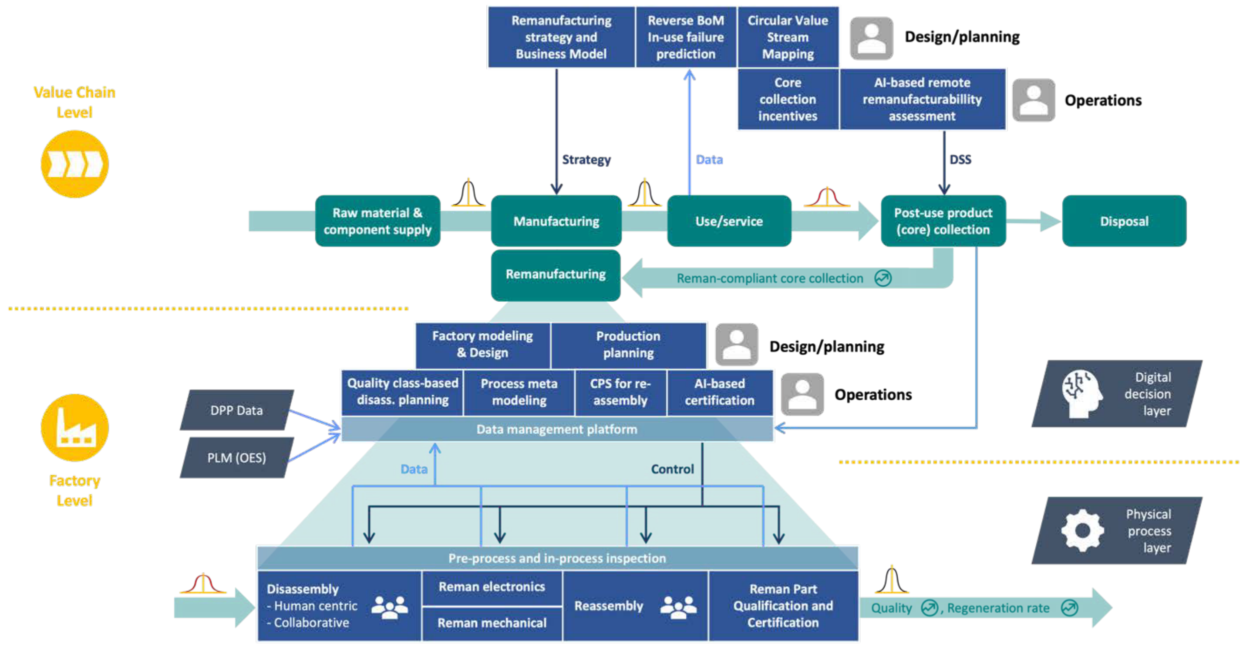


Figure 1.8: The human-centric and digitally-enhanced multi-level rEUman solution.

The rEUman solution modules. At each level of the rEUman solution, a suitable set of digital tools and services will support users in taking informed, agile, resilient, and context-aware decisions in operating the high-added value remanufacturing process-chain embedding the rEUman human-centric enabling technologies. The brief positioning of the digital tools and hardware modules with respect of the aforementioned concept, objectives and pillars is reported in Table 1.2. Given the modularity and flexibility of its hardware and digital solutions, the rEUman remanufacturing paradigm is applicable to both reman mature and emerging sectors and business cases, to both OES and independent remanufacturers, featuring different availability of product data, and to any product sold in Europe.

Table 1.2: Multi-level rEUman digital tools and enabling human-centric hardware technologies components.

Level	Objectives	Pillars and components
Value-chain	(i) Asses the economic and technical viability of a remanufacturing business case and design the remanufacturing business strategy.	**VCd - Remanufacturing business strategy design digital suite (WP5)** ● Circular business dynamics modelling and remanufacturing strategy design. ● Circular Value Stream Mapping for demand-supply forecasting and value-network configuration. ● Reverse BOM and component failure prediction.
	(ii) Increase quality and volume of return cores to be remanufactured.	**VCo - Value-chain operational digital toolkit (WP5)** ● Post-use product procurement, consumer interaction and reward system. ● AI for remote post-use product remanufacturability assessment.
Factory	(i) Support the (re)design and planning of the novel hybrid, human-centric, remanufacturing factory.	**Fd - Novel digital tools to (re)design and plan the remanufacturing factory (WP4)** ● Hybrid-automation remanufacturing factory modeling and simulation; ● Hybrid-automation remanufacturing factory (re)design; ● Mid- and short-term circular production planning and control.
	(ii) Increase the regeneration rate of remanufactured products, smoothing incoming post-use product variability.	**Fo1 - Cyber-Physical remanufacturing process-chain. (WP3 / WP4)** ● Quality class-based, hybrid disassembly planning. ● Product meta-modeling. ● CPS for function-oriented re-assembly. ● AI-based certification. ● Human centric disassembly. ● Human empowerment. ● Collaborative disassembly. ● Electronics and mechanical reman. ● CPS- based re-assembly.
		Fo2 – (Pre)in-process inspection and DPP compliant data mgmt platform (WP2)

	(iii) Improve the traceability of the remanufacturing process-chain	• DPP data modeling for remanufacturing. • Data acquisition and management platform.	• Pre-process inspection technologies. • In-process inspection technologies.

A decentralized architecture of the rEUman digital platform will be developed with the objective to provide the user the capability to dynamically select the best set of digital tools to support the specific decision-making problem, organizing customized workflows. A set of reference user-journeys and use-scenarios will be formalized and defined through in-depth interaction with the end users (WP1) targeting the platform development to the specific requirements of user personas, in line with the approach fostered by the Connected Factory2 project. An example of operational workflow is reported with its economic, social and environmental impact is quantified in Section 2.

1.2.2 rEUman Methodology

The rEUman methodology is structured in 4 pipelined phases: **Baseline**. The requirements, specification, needs and drivers for the specific developments are defined and the human-centric, data-enhanced remanufacturing approach requirements are gathered. **Developments**. Based on the inputs from the baseline, innovations regarding methodologies, technologies (disassembly, regeneration, re-assembly, certification and traceability) at individual level are developed and optimised. Enhanced digital tool to be integrated in the digital platform are designed and validated. Intermediate validations are conducted with the stakeholders. **Validation**. In this phase the innovations from the previous phases are validated in 3 industry-led pilots and 5 demo-cases to assess the achievement of the target KPIs of the developed solutions and the overall impact. **Exploitation, Communication, Dissemination and Business Upscale.** In parallel with validation, actions will aim at guaranteeing upscale and future uptake of the rEUman approach, assessing robustness of the methods (AI in particular), scalability and replicability of solutions from the pilot scenarios, for large-scale adoption in the European remanufacturing industry.

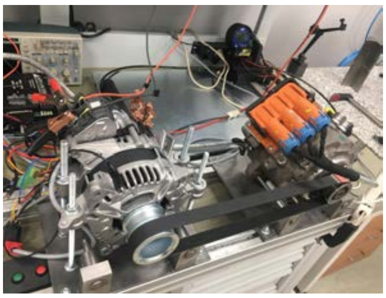
1.2.3 rEUman Pilots Demonstration and Validation

Three pilots, further differentiated into 5 demo-cases, will have a capillary validation of the rEUman system through several user journeys and within 8 product related use-cases, to validate the flexibility and robustness of the approach.

Demo-case 1.1: **Electric motors, inverters and e-turbos remanufacturing.** Involved sectors: **Automotive.** Industrial Lead Partner: **BORG Automotive, CPI**

BORG Automotive is the largest European independent automotive remanufacturer, yearly processing more than 2 million units from 9 product groups, across its plants in Poland, Spain and United Kingdom. BORG currently has a portfolio of 9 product groups and 16,000 active references, regularly evolving due to the carpark dynamics.

Current remanufacturing strategy: BORG Automotive serves two different customer profiles: large multi-brand distributors and the OES channel, made of car, truck manufacturers and Tier1s. The remanufacturing process starts with the reception of the cores, including identification, inspection and storage. Following a production order, cores are picked and moved to the disassembly area. Afterward the components undergo different steps of cleaning and inspection. Eventual regeneration activities are performed to reduce the scrap rate of the process-chain. Once all components have been either reused, repaired or exchanged, the unit is re-assembled, tested and put on stock.



Existing limitations and drawbacks: The current remanufacturing will be under pressure when starting to develop a reman concept for new components of electrified vehicles. On the process side, it is due firstly to the multitude of electrified platforms, hence a fragmented carpark, which in terms of production it will mean lower volumes for each technology / product family and therefore lower process efficiency. Secondly, the high cost of the cores (an e-motor core for instance costs between 1.000€ to 3.000€) and few established remanufacturing methods, will cause a high scrap value, bounding the profitability of the business case. Moreover, high re-engineering cost are expected, driven by embedded software, in practice related for instance to the analysis of communication protocols (CAN and Flexray need between 1 to 2 months FTE). Finally, there is a high uncertainty related to size and timing of the demand. Whilst on traditional automotive business there is awareness that the demand needs 6-7 years to appear in the aftermarket, for such new components, it is unknown how and when they will fail.

New opportunities of the rEUman enabled pilot: The pilot is meant to prove how the deployment of specific value-chain and factory level solutions can secure a high competitiveness of remanufacturing during the whole transition to electromobility and the subsequent evolving demand in automotive aftermarket. In order to demonstrate it with future-proofed concrete examples, the pilot will the set-up remanufacturing activities for e-mobility components, like the (i) electric motors, (ii) inverters and (iii) electric turbochargers. Exploiting the rEUman solution, the pilot

objective is to have for each electrified platform type (MHEV, HEV, PHEV and BEV) at least one remanufactured e-motor, inverter and e-turbos.
Strategic importance: The transition to electromobility is bringing new components into vehicles and with the background of the transition to climate neutrality, customers and policy makers have the expectation to see sustainable solutions in the aftermarket. Unfortunately, the business case of developing a remanufactured process for such components is threatened from high process re-engineering costs, low efficiency and uncertainty related to the volumes. Moreover, remanufacturing electric motors will reduce the demand for neodymium and dysprosium, mainly supplied from China. On the inverter side, the benefit is tantalum, palladium and lanthanum.

Demo-case 1.2: **Remanufacturing of electronics in Commercial Vehicles.** Involved sectors: **Automotive.** Industrial Lead Partner: **Knorr-Bremse Systeme für Nutzfahrzeuge GmbH**

Knorr-Bremse has an existing remanufacturing set-up for its commercial vehicle components with a dedicated remanufacturing plant in Liberec, Czech Republic and Campo de Criptana, Spain. Most products sold in the Independent Aftermarket (IAM) are sold with a core deposit for the core return to enable a circular value chain.

Current remanufacturing strategy: KB is currently remanufacturing ECUs (Electronic control Units), especially to improve the re-use of semi-conductors. It has no sense to scrap a complete ECUs where most of the electronic components and chips are ok only for a simple failure of a small sub-set of components. Remanufacturing is highly labour-intensive manual work, which requires high knowledge and physical strength.
Existing limitations and drawbacks: Remanufacturing within the commercial vehicle industry is limited by the lifetime and cycle of these vehicle. In general, an average products lifetime is between 35-45 years. Thereof, 10-15 years are OE production and 25-35 years are aftermarket deliveries after end of production. It is therefore important to develop methods with the current running process to ensure an intelligent setup for processes to come with the challenges of EV vehicles and their unknowns.
New opportunities of the rEUman enabled pilot: The pilot aims at improving the existing Knorr-Bremse remanufacturing set-up with new processes required for a circular business model for components of new generation vehicles. The goal is to improve the current remanufacturing process-chain into systematic development of (i) Human-centric solutions disassembly and reconditioning processes; (ii) Failure diagnostic of electronics cores for semi-automated remanufacturing. Concerning the first action, the focus will be on integrating human-centric future technologies into existing processes to support workers to increase efficiency and attractiveness of workplace by also reducing physical load and safety improvement. Concerning the second action, once the DPP will be regulated, it may be an option that the OEs is forced to disclose to remanufacturers the failures detected in their ECUs designs (similar to the recalls for vehicles). This way the remanufacturing industry will have tools to improve and optimise the process of remanufacturing itself and, in turn, the end user will benefit due to the possibilities to have better price and quality of reman products. Using the DPP to identify the ECU, an automatic process using cameras can be implemented to be able to resolve them.
Strategic importance: The new approach would enable 1:1 repair of electronic products. An increase of worker conditions as well as higher traceability of processes would lead to an increase of regeneration rate.

Demo-case 2.1: **Remanufacturing of Refrigerators.** Involved sectors: **Home Appliances.** Industrial Lead Partners: **Arçelik A.S.**

Products that undergo in-use failures that the after-sales services cannot solve or which come with customer complaints are collected in the Arçelik re-evaluation center. In this center, returning product visual inspection and functional inspection is made manually by the operators (takes up to 1 hour) and does not involve any automation.

Current remanufacturing strategy: The visual controls of the post-use devices are made by the operator by removing the internal components and opening the refrigerators doors. The functional tests of the appliances (e.g. cooling performance checks, electrical tests, etc.) are manually carried out by operators at different test stations. After the inspections, one of the following actions are possible: (i) if the problem in the product can be detected, the component can be replaced and sold to another customer at a cheaper price as remanufactured; (ii) otherwise, the product is recycled.

Existing limitations and drawbacks: Currently inspections are done by manual operators. No traceability system is used for returning components. There is a lack of data integration between components that can be extracted from the refurbishment center and production planning.
New opportunities of the rEUman enabled pilot: The pilot will focus on (i) supporting with automation the pre-process inspection and fault diagnosis phases, (ii) support workers in their high physical load testing and disassembly activities, (iii) elaborate and formalize a new business case for the company focused on the remanufacturing of in-warranty returning refrigerators. In this pilot, visual inspection and disassembly processes will be executed with the help of a collaborative robot equipped with a camera. The robot will lift the products and open their covers. The vision-based system will evaluate whether there is damage with AI based image processing. Empowered operators will manage manual tasks. Thanks to the camera on the robot, the location of the operator will be continuously monitored for safety. After disassembly, the components will be tested with a tailor-made hardware and software unit (long performance test unit) in a short time. Throughout the whole pilot, intense human manual work will be needed, for example to perform multiple tasks, and complex and articulated actions in sequential operations. For such processes, specific experimental protocols and metrics for ergonomic evaluation of such tasks will be developed, which could be used to identify critical situations to be specifically addressed. Wearable or collaborative commercial devices (and embedded and distributed sensors network) to support the reduction of the impact of the fatigue on effort, attention and/or concentration level of the workers will be evaluated and adapted to the specific situation, or a specific design will be proposed.
Strategic importance: The purpose of the use case is to enhance the reman process-chain with human-centric and digital tools, to create a new circular economy business model, to shorten the inspection process and make it more efficient, and to create a traceability system. Currently, 200.000 household appliances come to the recycling center annually. Due to insufficient capacity, only 10-15% can be examined while the remainig are sent to recycling.

Demo-case 2.2: **Remanufacturing of heat pumps.** Involved sectors: **HVAC (Heating Ventilation and Air Conditioning).** Industrial Lead Partners: **Olimpia Splendid S.p.a.**

In 2020 in collaboration with few European client, OS began a project aimed at collecting and repairing after-market unit, an air-to-air domestic heat pump. In 2021 around 1.000 units were repaired; this number is limited due to capacity reasons and difficulties in decision making, linked to cost evaluation and planning.

OLIMPIA SPLENDID HOME OF COMFORT

Current remanufacturing strategy: The first pilot project focused on remanufacturing is currently going on. Defective units (domestic heat pumps) return from the market and are collected at an after-sale service center. Around 65-70% of the units are repaired and refurbished. The process is manual and done by operator supported with checklist. The process is made of three main steps: (i) Inspection to evaluate repairability; (ii) In case unit passes the evaluation, it is disassembled, refurbished, or repaired (which may include substitution of some components); (iii) The unit is then re-assembled, tested for safety and quality, repackaged and re-sold. If the unit is rejected because not repairable, it is anyway disassembled to re-use spare parts. Typical heat pumps components involve rotary compressor, electronic board, fan and electric DC motor, aestethics, coils (heat exchanger).

Existing limitations and drawbacks: Compared to the traditional assembly line, the remanufacturing process lacks efficiency and quality. In particular, operations are manual and not automated. Estimation of remaining life expectancy of components is based on visual inspection and some basic measurements and tests. The planning and scheduling processes are now critical. Since the lack of data and methods, also decision making is today quite complex. The current pilot project is giving some indication and estimates on business viability, but costs are hard to predict and control, either direct cost or cost along the supply chain (e.g. reverse logistic, collection from customer). It is then difficult to analyse the business case to scale-up the pilot project at stable industrial level.
New opportunities of the rEUman enabled pilot: Technologies that predict and estimate life expectancy of components are going to increase quality and reliability of the entire remanufacturing process. For example, AI tools will be applied to find defects of returning units, such as aesthetics but also compressor, electric motor and electronic parts. Automation of some disassembly and test will improve efficiency of the process increasing capacity while reducing process time and cost. Circular business model analysis could help increase feasibility of servitization of home appliances such as domestic heat pump.
Strategic importance: This project could be extended to other customer and to all other product line in Olimpia Splendid offer and could represent a best practice of re-manufacturing in the HVAC industry. This market is fast-growing because is useful to electrify and de-carbonize heating and cooling sector, in line with european plan Fit-for-55 and Re-power europe. The European heat pump market is already more than 2 million unit/year market in

2021, and it will triple by 2030; moreover, there is a stock of almost 17 million installed unit by 2021 (data and estimation by the European Heat Pump Association 2022 report).

Demo-case 3.1: **Remanufacturing of high power multiemitter laser modules.** Involved sector: **Optoelectronics.** Industrial Lead Partner: **CONVERGENT PHOTONICS Italia**

Convergent Photonics Italia S.r.l. is a manufacturer of high-power lasers for the industrial market, medical application and material processing. The main products are single diode lasers, fiber laser modules and direct diode laser systems. The demo-case is the optimization of a remanufacturing line applicable to multiemitter products.

Current remanufacturing strategy: Our product bases on modular approach: the multiemitter consists of the optimal packaging of more single diodes, collimated and located to raise the required power. This modular approach allows to be flexible on different optical requirements and to consider the replacement or remanufacturing of a component in case of failure. Currently the multiemitter have classes of damage (e.g. damage of optics, damage of connector, damage of emitter) and, based on the class, the company is able to rework up the 20% of the production defects. In the last years, a rework/reman strategy has been investigated on the manufacturing of the multiemitter and the fiber laser (iQonic EU project). In case of returned post-use/faulty multiemitter, a focused investigation has identified the damaged components, and a strategy of remanufacturing. Faulty parts can be replaced with functional components, to guarantee the same, or even upgraded, functionality of new products. The rEUman goal is to exploit this knowledge to set-up a new remanufacturing case applied to post-use products returning from the market, by sharing the same production line and resources of new parts.

Existing limitations and drawbacks: Remanufacturing in optoelectronics is very challenging, because the requirement of cleanliness and mechanical tolerances are very tight. Contamination, operating conditions, mechanical stresses and damages really affect the power and the reliability of the active parts (diodes, active fiber).

New opportunities of the rEUman enabled pilot: The purpose of the pilot is the development of new technologies and strategies to increase the regeneration rate, with the design of proper disassembly technologies based on collaborative robots. The automation in the processes is essential to guarantee high quality and decrease the cost related to the remanufacturing, at the moment quite high due to the manual processes in rework. The life prediction of components and the product is essential for the remanufacturing line. Due the complexity of the multiemitter, the standard analysis usually done to predict the reliability of optoelectronics devices is not enough (burn in test, life test or endurance test). The multiemitter is an array of different components, and analysis of the characteristics of the individual components are not sufficient to determine the functionality of the final product, due to different material, soldering and mechanical stresses that make the problem more complex. Topographical analysis based on infrared or thermal analysis are needed for accurate prediction of expected life-time, and the thermal mapping represents a good test to detect the presence of misalignment or mechanical stress, not immediately detectable with only electrical characterization. The analysis of such data consists of pictures in scale of temperatures, and need to be correlated with reliability data in working conditions. For this reason, the use of artificial intelligence tools is mandatory. Other rEUman digital tools will provide ability to improve the design of the remanufacturing line, for example the factory simulation, supporting the engineering of a structure able to process new and remanufacturing products by sharing the same production resources.

Strategic importance of the pilot: The implementation of a circular production on an optoelectronic manufacturing line is challenging: contamination, operating conditions, mechanical stresses and damages really affect the short and long-time reliability of the active parts (diodes, active fiber). A design of a circular economy business model and factory, validated with the guarantee for the remanufactured products' functionality, is very attractive.

Depending on the features of the industry, the remanufacturing maturity and the key challenges addressed by the individual demo-cases, high priority enabling technologies and digital tools, at both factory and value-chain levels, have been identified by the pilot owners, as reported in Table 1.3. This shows the flexibility of the rEUman approach.

Table 1.3: High-priority enabling technologies and digital tools for each pilot demo-case.

Enabling physical and digital technologies/Demo-case matching	1.1 - Borg	1.2 - KB	2.1 - ARC	2.2 - OS	3.1 - Conv
Human-centric disassembly process design and support					
Worker empowerment for safety in disassembly					
Hybrid collaborative disassembly for remanufacturing					
Flexible, pre-configuring fixture for cobotic/hybrid disassembly cells					
Visual servo-based robotic cell for electronics remanufacturing					
Cold-spray for mechanical part remanufacturing					
Function-oriented re-assembly					

DPP-enhanced data management platform for traceability					
Pre-process and in-process visual inspection for remanufacturing					
Quality class-based, hybrid disassembly planning.					
Product meta-modeling					
CPS for function-oriented re-assembly					
Hybrid-automation remanufacturing factory modeling and simulation					
Hybrid-automation remanufacturing factory (re)design					
Mid- and short-term circular production planning and control					
Reverse BoM and component failure prediction					
AI for remote post-use product remanufacturability assessment					
CVSM for demand-supply forecasting and value-network configuration					
Post-use product procurement, consumer interaction and reward system					
Circular business dynamics modelling and remanufacturing strategy design					

1.2.4 Relation to national and international research and innovation activities

Table 1.4 lists a selection of relevant ongoing H2020, HE projects participated by some of the Consortium partners and related to the topic of this application. Synergies and cooperation with these initiatives and with other EU projects dealing with materials circularity (including the other projects funded under HORIZON-CL4-2022-TWIN-TRANSITION-01-07) will be fostered during rEUman and implemented within a specific WP (WP8).

Table 1.4: EU funded initiatives related to the main pillars of rEUman.

List of related projects	Summary of topics and exploitable synergies
CIRPASS (2022-2024, ongoing) "Collaborative Initiative for a Standards-based Digital Product Passport for Stakeholders-Specific Sharing of Product Data for a Circular Economy". POLIMI	CIRPASS is a collaborative initiative to prepare the ground for the gradual piloting and deployment of a standards-based Digital Product Passport (DPP) aligned with the requirements of the Proposal for Ecodesign for Sustainable Product Regulations (ESPR), with an initial focus on the electronics, batteries, and textile sectors. *rEUman will interact with CIRPASS to define and understand the requirements on the data model for a DPP, with focus on remanufacturing as a high value retention strategy for Circular Economy.*
DiCiM (2022-2024, ongoing) "Digitalised Value Management for Unlocking the potential of the Circular Manufacturing Systems with integrated digital solutions**".** ARC	The aim of DiCiM is to deveope a set of integrated digital solutions that makes use of Internet of Things, Machine Learning, based Artificial Intelligence, Big Data, Image Processing and Augmented Reality to support different actors in their decision making in circular economy. *rEUman will interact within DiCiM to evaluate possible synergies in disseminating the developed ETs, assessing the DiCiM tools in the new human-centric rEUman scenario.*
DigiPrime (2020-2023, ongoing) Digital Platform for Circular Economy in Cross-sectorial Sustainable Value Networks.POLIMI, KIT, FLEX, SZTAKI, KB, ES, SYX	The EU-funded DigiPrime project develops the concept of a circular economy digital platform in order to create circular business models based on the data-enhanced recovery and reuse of functions and materials. DigiPrime will be validated through several cross-sectoral pilots and one of them is dedicated to e-mobility mechatronics. *rEUman will interact with DigiPrime to (i) understand the cross-sectorial possibilities in the e-mobility sector, (ii) elaborate on the already developed digital tools, and (iii) analysing and exploiting synergies in dissemination and exploitation.*
iQonic (2018-2022, completed) "Innovative strategies, sensing and process Chains for increased Quality, re- configurability, and recyclability of Manufacturing Optolelectronics". POLIMI, CORE, CONV, SYX	The iQonic project aimed to address quality challenges in the optoelectronic sector as increase in complexity, volume of demand and customization is ongoing. iQonic developed a holistic framework applicable both to new and existing manufacturing lines of opto-electronics to achieve flexibility, zero-defect production, and sustainability. *rEUman will elaborate on the iQonic project results to develop the Cyber-Physical System for function-oriented remanufactured products re-assembly within the opto-electronics sector pilot. In particular, the CPS developed in iQonic for increased assembled product quality during production will be enhanced to include also those reman components.*
Circular TwAIn (2022-2025, ongoing) "AI Platform for Integrated Sustainable and Circular Manufacturing": POLIMI	The EU-funded Circular TwAIn aims to research, develop, validate, and exploit a novel AI platform for circular manufacturing value chains, which will support the development of interoperable circular twins for end-to-end sustainability. *rEUman will interact with Circular TwAIn during the development of AI-based digital tools for distributed core characterization directly at the point of collection. Indeed, in Circular TwAIn a tool for the residual useful life prediction of post-use batteries is under development.*
PREHUROCO, (2021), PREdictor for HUman-RObot COllaboration, an XR4ALL project. SZTAKI	PREHUROCO utilizes interactive technologies in a new innovative way to create a cobot independent pre-collision approach for reducing these cumulative delays. The technology creates a shared virtual reality workspace for humans and robots. *rEUman will collaborate to elaborate on the innovative use of interactive technologies which can assist the human operator in disassembly tasks as a novel approach in cobot based production.*

1.2.5 Interdisciplinarity

rEUman brings together an extremely interdisciplinary team benefitting from a wide range of experts in: remanufacturing (BORG, KB), manufacturing and collaborative robotics (ARC, KB, OS, CONV, HEPENIX, POLIMI, SZTAKI, KIT), smart human and human empowerment (POLIMI), electronics remanufacturing (CR&C, KB), machine learning and AI (CORE), manufacturing system design (POLIMI, SZTAKI), inspection technologies (ZEISS), data gathering and IoT (SYXIS), Digital Product Passport and traceability (POLIMI, Dissemination, exploitation and uptake (APRA, G-MEDIA). SSH discipline will be applied to put humans in the centre: ES will coordinate the training actiivites for re-skilling and upskilling of manufacturing workforce towards the new rEUman reman concept, with experts in training and user engagement, in cooperation with the EIT Manufacturing. The methodology and the WPs are structured to allow deep innovation on each pillar, while fostering an interdisciplinary approach to achieve rEUman's ambitious objectives.

1.2.6 Integration of social sciences and humanities

One of the important objectives of the rEUman project is the design of innovative learning resources and teaching methods to enable the implementation of lifelong learning programmes for current remanufacturing employees active in the sectors of the pilots, in addition to targeting the future generation of workers at undergraduate level. To successfully address these aspects, competences in the fields of **pedagogy, education sciences as well as learning sciences and technologies** are essential. Such skills will be implemented within the rEUman project through the active participation of the "*Innovation in Teaching and Learning*" task-force of POLIMI that will act in cooperation with the team of developers of ES. It specializes in designing and testing tools and methods for learning innovation and faculty development, and will conduct activities related to the definition, validation and replication of innovative learning resources and teaching methods for future exploiters (WP8 lead by ES).

1.2.7 Considerations on gender dimension

The different activities foreseen in rEUman will require considerations on sex/gender dimension and on how this issue will be taken into account at each level of the project development. In this respect, the Consortium has identified two distinct levels of scrutiny and intervention. LEVEL 1 – PRACTICAL IMPLEMENTATION OF SCIENTIFIC AND TECHNOLOGICAL TASKS PLANNED IN THE PROJECT. The practical implementation of the scientific and technological activities planned is assumed to be equally perceived and participated by male and female subjects and no gender/sex-based differences are expected in the development, demonstration and validation of the proposed technologies. LEVEL 2 – DISSEMINATION OF PROJECT RESULTS. The project will take particular care of the sex/gender inclusion topic by designing dissemination material free from discrimination of any kind and by stimulating the participation of individuals with arbitrary gender orientation in the project activities and outcomes. The rEUman Consortium will take responsibility in using an inclusive language, free from sex/gender stereotypes.

1.2.8 Open Science

The project will fully comply with the HE rule of ensuring open access (either green or gold access) to all publications. In particular, Open Science practices will be implemented at different levels and different stages during the project to ensure cooperative and systematic sharing of the produced knowledge and tools, in agreement with the IPR protection strategy outlined in Section 2.2.3. In the early dissemination of the scientific results, pre-print scientific publications in suitable open access online databases and repositories (e.g., ChemRxiv, arXiv) will be considered for immediate knowledge sharing with the community. Additionally, institutional repositories (e.g., Re.Public@Polimi) will be used for immediate access to research outputs through univocal persistent identifiers (PIDs). Project results that will be provided as open-source components, will be protected under open-source licenses; analogously, project results that will be commercially exploited will be *copyright-protected*. In order to ensure clear and efficient knowledge management and exchange within the Consortium, the Project Coordinator (PC) will establish internal web resources for communication among the partners and for the dissemination and transfer of knowledge and information as required. All Consortium members will co-operate in order to reach the most efficient process of knowledge management as well as data management.

1.2.9 Data management plan

The Consortium partners have considered issues related to the management of data and research outputs as they want to ensure them to be findable, accessible, interoperable and reusable (FAIR), ultimately enabling data security, accessibility and reproducibility. **Dr. Dena Arabsolgar from Syxis, as data manager,** will take responsibility for the collection, management, sharing and curation of the data, as well as for the day-to-day quality assessment. A Data Management Plan (DMP) will be implemented which will minimize possible duplication of efforts and the risk of data loss and will offer integrity to the data. It will be periodically updated describing what type of data will be generated (e.g., experimental, numerical, graphical) and what policies apply to the data (i.e., data accessibility). Moreover, the Consortium partners will clearly describe which data will retain value after the end of the project, how their reuse will be enabled, and how the long-term preservation of such data will be ensured after the original research is completed, to ensure effective data and research output reusability. Partners will share the generated research data allowing other partners to replicate, validate, or correct their results, thereby improving the scientific record and ensure knowledge advancement. Partners will not share sensitive data whenever the achievement of the objectives may be jeopardized by making those specific data openly accessible.

2. IMPACT

2.1 Project's pathways towards impact

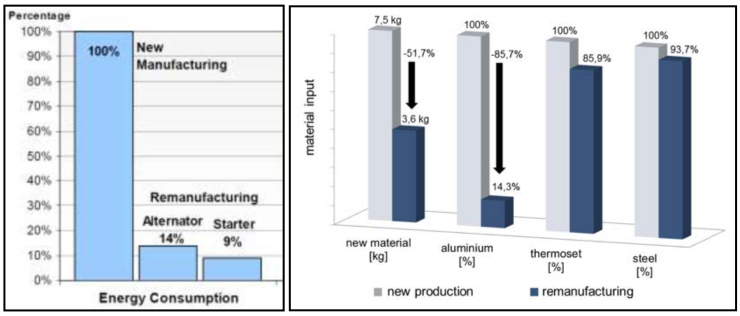


Figure 2.1: Remanufacturing benefits - Kohler D., Mechatronic Remanufacturing at Knorr-Bremse Commercial Vehicles Systems (CVS).

rEUman key challenge and opportunity: Remanufacturing is widely recognized as the most sustainable circular economy option focusing on recovering, and even upgrade, the functions of products, components, and materials along multiple use-cycles, by bringing considerable economic and environmental benefits. However, existing challenges are bounding the massive diffusion of remanufacturing business cases in a wide set of European sectors, except automotive, aeronautics, furniture, and consumer electronics, calling for a new generation of smart and human-centric remanufacturing systems in Europe. rEUman will design and develop a new Human-centric and Digitally-enhanced multi-level rEUman solution, to boost remanufacturing in a wide set of sectors and in business cases characterized by products with increasing complexity, representing a *Game Changer* for the entire transition to Circular Economy in Europe. Therefore, the economic, social andenvironmental figures derived in the following paragraphs, focused on a sub-set of sectors due to space limitation, are only conservative estimates of the potential impact of rEUman at global worldwide scale and at European scale in the next 5-10 years, in line with the European Green Deal time horizon.

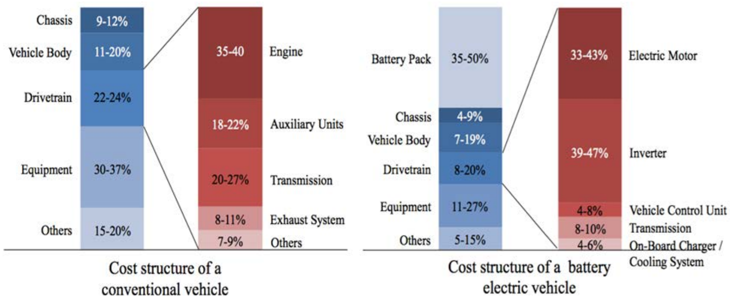


Figure 2.2: Comparison of BEVs and ICEVs cost structures.

Current status and trends of the European automotive industry. The automotive industry (NACE Group 34.1) is a strategic sector in the EU, producing 16.2 million cars, vans, trucks and buses every year. A recent report of European Automobile Manufacturer's Association (ACEA) estimated that 12.9 million people - or 5.3% of the EU workforce - are employed direct or indirectly in the automotive sector. The 3.1 million high-skilled jobs in automotive manufacturing represent 10.3% of the EU's manufacturing employment. With its 290 assembly and production plants in 25 countries across Europe, the European auto industry is a global player, delivering quality 'Made in Europe' products worldwide, and bringing in a €95.7 billion trade surplus. The transportation sector accounts for the 25% of the GHG emissions according to the IEA (International Energy Agency). According to the European Environment Agency, in 2020, more than 1.5 million of hybrid or electric vehicles have been introduced in the Europe, representing the 11% (6.2% BEVs and 4.8% PHEVs) of the overall market (European Environment Agency, 2021). It is also estimated a realistic market share up to 35% by 2040. Battery cost is the major technological and economical barrier: according to (König et al., 2021) as battery price will continue to fall, the demand for electric vehicles will rise more than linearly. In automotive 48% of the total revenues are from the aftermarket.

Baseline situation with respect to post-use e-motors. One of the critical components in EVs is the E-motor, accounting nowadays for more of the 10% of the overall vehicle cost, and expected to become even more impacting, as the price of batteries will decrease (König et al., 2021). The technologies of electric motors of the hybrid and the plug-in electric vehicles change and evolve rapidly. Consequently, no common standards in EV motor design have yet been established and many design variations currently exist. This means that the design of EV motors differs not only from manufacturer to another, but also from car model to car model even by the same manufacturer. This is one of the main reasons why disassembly processes are challenging.

Current status and trends of the home appliances industry. The heat pump European market is a fundamental portion of the domestic appliances manufacturing sector (NACE Group 29.7), employing more than 90'000 persons, 14'000 in the aftermarket, and with a yearly turnover greater than 10 billion euros (European Heat Pump Association, 2020). European heat pump sales grew by +7.4% in 2020, with 1.62 million units sold. Moreover, heat pumps adoption is expected to continuously grow in the next years, as they can be considered as one of the most energy efficient heating and cooling systems: according to many recent European legislative and policy actions (Electricity Market Design to EU 2050 decarbonisation objectives, EU Energy System Integration Strategy, 2241INI A European Strategy for Energy Integration, European Green Deal) clear objectives are set for the electrification of heating: 40% of residential buildings and 65% of all buildings in the service sector are foreseen to be heated by electricity by 2030. Heat pump systems are a key integrator technology, as they both support and benefit from moving electricity and thermal energy sectors closer together, especially if integrated with renewable and decentralized energy sources, as PV. In 2020, the biggest absolute gains were achieved in Germany +38k units, and Italy +25k units. Italy is also the second biggest European market with 232k units sold, under France, 394k units. Remanufacturing can play a crucial role in the heat pumps sector, as the availability of cores is guaranteed by the high turnover rate (>10% of installed stock per year) and because, as above presented, aftermarket and maintenance account for more than the 15% of the market overall added value, mostly affected by labour and spares costs drivers.

Baseline situation with respect to post-use heat pumps. Most heat pumps systems are nowadays sent to recycling. Remanufacturing strategies are not applied because product data unavailability (same heat pumps of different manufacturing batches can be assembled with different components, especially electronics) and labor-intensive manual disassembly lower the profitability profile of this scenario.

rEUman overall scale and significance: rEUman directly affects through its demo-cases three of the most strategic and transformative industries in Europe, i.e. e-mobility, home appliances and optoelectroics, directly contributing through their products to the quality of everyday life of European citizens. These industries are currently in their transition path towards more sustainable products, contributing to substantial emission savings during the product use-phase. For example, the heat pump stock in 2020 contributed 41.07 Mt of greenhouse gas emission savings in the building sector. Similarly, e-vehicles bring a great benefit in the use-phase compared to traditional vehicles, resulting in a total reduction of CO_2 emissions of about 20% over a 20-year lifespan. In these sectors, growing at unprecedented CAGRs, there is a need to reduce the footprint in terms of emissions during the manufacturing operations - the equivalent CO_2 emissions for an EV in the manufacturing phase are almost the double of the emissions of an ICEV, mainly due to the demanding battery production process - the consumption of critical raw materials, at the same time making products more affordable for consumers, thus further accelerating the transition.

Pathway to impact

The rEUman project has defined the following pathway to impact, further described in the next subsections.

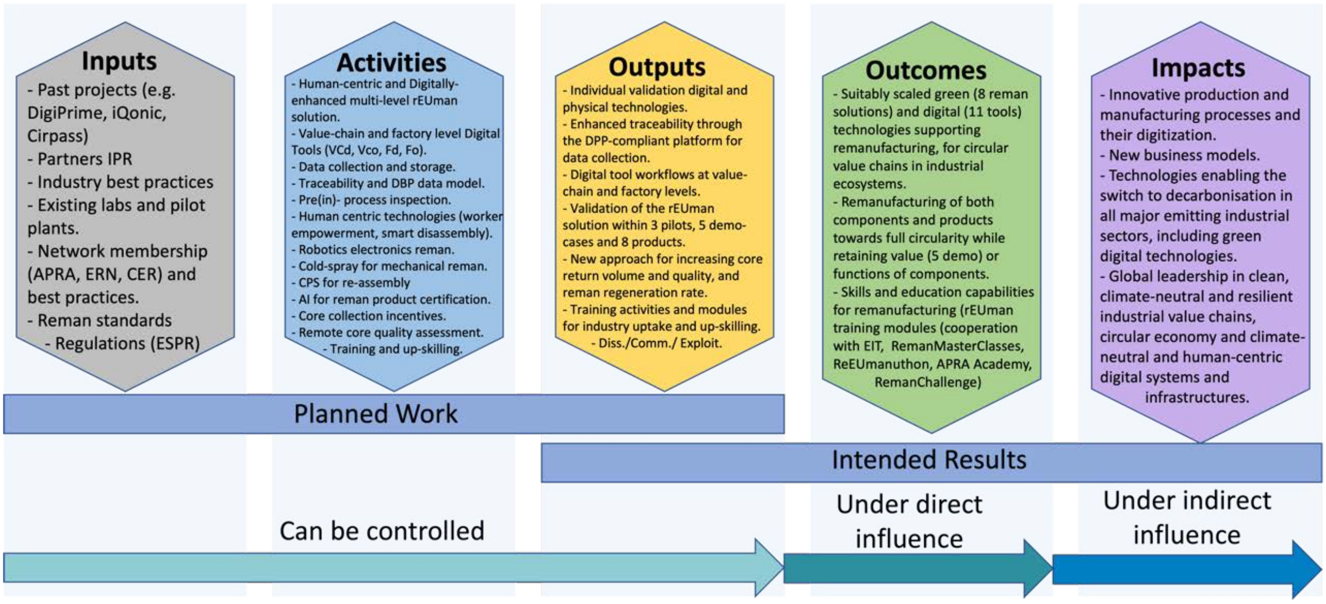


Figure 2.3: rEUman pathway to Impact: from activities to Expected Outcomes [EO] and Wider Impacts [WI].

2.1.1 rEUman impact on the expected outcomes

The rEUman cause-effect diagram towards the expected outcomes is reported in Figure 2.4, showing the impact propagation pattern, linking the project activities and outputs to the outcomes listed in the call text.

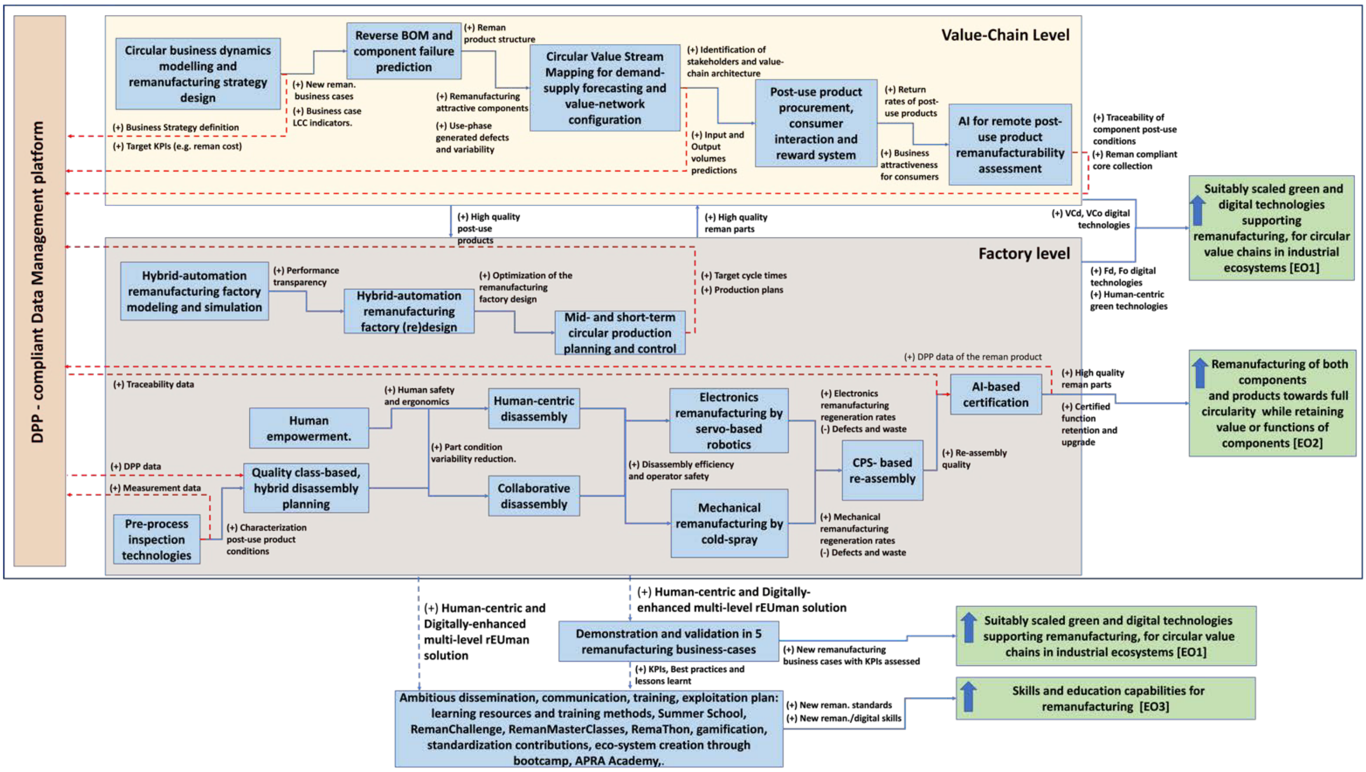


Figure 2.4: rEUman Cause-effect diagram - Technological solutions (blue), Expected Outcomes (green). Red lines: information flow; Blue lines: material flows; Green lines: direct impacts.

EO1: *Suitably scaled green and digital technologies supporting remanufacturing, for circular value chains in industrial ecosystems;*

Narrative (see cause-effect diagram in Figure 2.4): rEUman will develop breakthrough technologies at both value-chain and factory level to enhance the capability of the remanufacturing industry to (i) attract more stable volumes of high quality of post-use products back from the use-phase in the market, and (ii) increase traceability and the regeneration rate of remanufacturing process-chains. At value-chain level, a set of digital tools will be fine-tuned and upscaled acting both in the value-chain design and operational phases, grounding on the ongoing developments in the EU project DigiPrime. In the design phase, these tools support business strategy modeling, business case analysis through a reverse BoM and in-use failure prediction analysis, value-chain configuration, supply – demand forecasting, post-use core procurement, considering incentives for improved core-collection and pay-per-use service models for consumers (e.g. home appliances) to guarantee market returns. In the VC operational phase, remote and distributed assessment of the quality of return cores at the point of collection, avoiding CO2 emissions by transporting non-remanufacturable cores, will be developed. The value-chain level digital tools will be made interoperable with the DPP-compliant data collection platform, developed following the FAIR principles and properly integrated into user-centric digital workflows. At factory level, innovative digital and physical technologies will be developed and fine-tuned to the pilot needs. Digital tools will be developed to support the factory design phase, such as the by modeling and simulating the hybrid human-automated factory for performance assessment, by supporting the optimization of the factory with a KPIs driven approach, and by supporting production planning and control, considering return cores. The innovative workflow is described below.

rEUman remanufacturing process-chain operational workflow: the incoming product ID will be scanned to check design product information in the DPP (if available). Then, pre-process inspection will be applied to identify the quality characteristics of the core. The part will be sorted in a quality-class. With the quality class-based disassembly planning tool, the specific disassembly tasks will be planned and optimally allocated to manual or collaborative modes, depending on the real post-use conditions. Then smart human or collaborative disassembly will take place. The disassembled components sorted into mechanical or electronical component classes and analyzed by in-process inspection. Through the product meta-model, the remanufacturing process will be adapted and planned. The electronics component will be remanufactured through the servo-based robotics cell. The mechanical part will be remanufactured by cold-spray. Then, the remanufactured product will be re-assembled according to the nominal information in the reverse BoM, retrieved from the value-chain level and stored in the PLM, as well as through the CPS for function-oriented re-assembly, considering the real quality conditions of new and reman components. By retrieving data from the data management platform about traceability, the AI-based product certification tool will be used to certify the reman part. A new DPP can then be originated for the reman part, before sale to the market.

The rEUman technologies will be demonstrated in 5 pilots in different industries, namely automotive and e-mobility, home applicables and heat pumps, and optoelectronics and laser multi-emitter modules, strategic for the achievements of the objectives of the EU Net Zero Industry Act [18], Critical Raw Materials Act [19] and the EU

Chips Act [20]. In particular, in the first paragraph of the Net Zero Industry Act the following is reported: The resilience of future energy systems will be measured notably by a secure access to the technologies that will power those systems - wind turbines, electrolysers, batteries, solar PV, **heat pumps** and other. Therefore, demo-case 2.2 will be particular relevant for this EU strategy. Within these pilots, the benefits of rEUman in terms of energy consumption reduction, climate change and emissions, as well as technical, social, and economic will be assessed. The ambitious dissemination, communication and exploitation plan of rEUman, compounded by the high involvement of rEUman members in international associations (European Remanufacturing Council - CER, ERN, CLEPA - European Association of Automotive Suppliers), on top of APRA Europe, will facilitate transferring of results to industry and future uptake, also exploiting financial instruments at regional and national levels, such as the Next Generation EU, the opportunities within the EIT Manufacturing and the I3 EU program, Inter-regional Innovation Investments. The rEUman team is well equipped for this transition, given the active presence in the De- and Remanufacturing for Circular Economy demo-case in the Efficient and Sustainable ESM pilot in the VI.
Target Groups: Remanufacturing industry, green digital and physical technology providers, EU society
Scale & Significance: Both digital and physical green technologies at system and value-chain levels. Validate 6 new and patentable reman technologies, and 11 digital solutions, 6 at factory level and 5 at value-chain levels, within 3 pilot circular value-chains in 5 demo-cases and 8 products. Clear path for exploitation and uptake, exploiting regional Smart Specialization Strategies (I3), the EIT Manufacturing nad the Next Gen EU opportunities. Transferring the results of rEUman to the EU industry (see the next section), a potential decrease of dependency from imported raw materials can be achieved, by re-using 13819 Tons of materials in remanufactured products, of which 1819 Tons for e-motors containing Critical Raw Materials (CRMs) of critical supply from non-EU countries (Co=36, Nd=564, Dy=82, Fe=1119, Bo=18), and 12000 Tons of plastics and electronics from heat pumps. Through remanufacturing, these materials will be kept in Europe, reducing the costs of supply for the European industry, with potential of activating cross-sectorial re-use from recycling in the next use-cycle (for example cobalt in emerging EU Gigafactories).

EO2: Remanufacturing of both components and products towards full circularity while retaining value or functions of components.
Narrative: The innovations explained in the previous EO1 will be enabling both the remanufacturing of the entire product as well as of the key embedded components, following the remanufacturing for function retain and upgrade concepts. At remanunfacturing business planning level, the structure of the “as designed” product will be matched with the structure of the “as returning” product via the functionality of the “Reverse BoM” digital tool and the enhanced information of the in-use product function failure analysis data, extracted if accessible, by the remanufacturer (in the case of OES). These tools will create a matching between the components to be disassembled / remanufactured and the structure of the assembled reman product in which they will be integrated, also considering the possibility, for some components such as mechanical parts and modular sub-components, to be upgraded providing additional functionalities to the product. This tool will also generate feedback that the designer can exploit to “design multipe upgraded use-cycles” since the early product conception phase.
Target Groups: Product designers, remanufacturing strategy developers, remanufacturing industry.
Scale & Significance: Out of the 3 pilots and 5 demo-cases, 2 of them will deal with remanufacturing business models including the potential upgrade of the product functionality, i.e. the heat pump demo-case and the optoelectronics demo-case, exploiting the modularity of the product.

EO3: *Skills and education capabilities for remanufacturing.*
Narrative: “*The lack of appropriate skills in manufacturing is becoming a concern in many sectors, opening the opportunity for the use of breakthrough innovative technologies to make manufacturing jobs more attractive; and more broadly to ensure that manufacturing provides prosperity beyond jobs, while respecting planetary boundaries*”. This destination statement is particularly true for the remanufacturing industry. As mentioned in the excellence section (APRA reports that more than 60% of companies don’t use qualitative or quantitative models for remanufacturing optimization), the adoption of Digital Technologies in remanufacturing is very limited. Within the DigiPrime project this problem has been experience and tackled but the way towards acceptability of digital tools in this highly manual industry is still long. Workforce re-skilling (for example in automotive towards reman of new components) or upskilling is a fundamental lever to increase the capabilities of remanufacturing workers to increase their skills, education and capabilities for remanufacturing. rEUman will launch an ambitious program (WP8), starting from the identification of the existing skill gaps and key requirements that are highly relevant in remanufacturing, specifies and designs delivery platforms, training material formats and methodologies for training and skills development, develops and delivers specific training modules consisting of presentations, videos, self-assessment tools and questionnaires, sets-up and launches the

APRA Academy for future exploiters the core skills and competences needed for the uptake of the solutions developed in the project, and assesses the effectiveness of knowledge transfer by gamification of the basic training with stealth assessment. Taking another view point, humans are central in the rEUman remanufacturing approach. The digital and physical tools have been conceived as functional to increase the quality of manual work in remanufacturing, increase safety and provide data and information to support human-driven decision-making processes, in a business dominated by manual, human-driven operations. The "Human-centric disassembly process support" developed in WP3 is only one example of this key vision. rEUman will carefully monitor the impact of the developed services integrated in the digital suite on day-by-day work of operators at industrial level and will run specific training programs that will increase the acceptance of the developed digital service applications by workers, thus improving their ability to correctly operate the process, also supported by decision support systems and extended product data. Specific feedback from the operators will be collected during the demonstration phase to further improve usability and consciousness. This will constitute a strong motivational lever for workers.
Target Groups: Remanufacturing workforce, young entrepreneurs, scholars, engineers, practitioners.
Scale & Significance: 2 ReEUmanuthon editions. Organization of more than 10 hands-on workshops in learning and research factories. Organize more than 3 bootcamps for future adopters of the Reman Navigator suite. Develop more than 5 exploiting digital twins for gamification. Launch the APRA Academy for reman operators, and the RemanChallenge and RemanMasterClasses organized by Borg.

2.1.2 rEUman impact on long term (Wider impacts-Destination work programme)

Global leadership in clean, climate-neutral and resilient industrial value chains, circular economy and climate-neutral and human-centric digital systems and infrastructures
WI1: *Innovative production and manufacturing processes and their digitisation;*
Narrative: At process-chain level, rEUman will leverage on the most advanced Industry 4.0 manufacturing technologies and will transfer and customize these solutions to the remanufacturing challenges, characterized by the variability reduction challenge and by a massive presence of manual tasks. Collaborative robotics for disassembly, servo-based electronics remanufacturing, cold spray, CPS for function-oriented re-assembly are all technological solutions that are still not ready but could be potentially transferred to the remanufacturing sector if properly fine-tuned, digitally-enhanced, and validated. In turn, when demonstrated in remanufacturing, these technologies will be transferable into other manufacturing industries, characterized by intense human workforce presence, high variability and unpredictability in demand and specifications and strict quality requirements.
Target Groups: Manufacturing and remanufacturing industry, technology providers, innovators.
Scale & Significance: Collaborative robotics for disassembly, servo-based electronics remanufacturing, cold spray, CPS for re-assembly, human empowerment and smart human solutions demonstrated in real industry environment.
WI2: *New business models;*
Narrative: rEUman will enhanced remanufacturing not only from the physical and digital technology uptake viewpoint but also from the business strategy and model viewpoint. Indeed the DPP – compliant semantic data management platform will decrease the knowledge asymmetry between manufacturers and remanufacturers, providing opportunities to the value-chain design and operational services to foster innovation at business strategy, value-chain configuration, and, in particular core procurement sense. This last aspect is nowadays a critical activity in remanufacturing. Core availability is the essential element in remanufacturing, exactly as the availability of raw materials is essential for a manufacturer. Without cores, there is no remanufacturing business. rEUman will contribute the way cores are attracted by introducing in the market the concept of reward-based incentives. The designed core return through incentives mechanisms will be discussed and validated in workshops, service centers, dismantlers, retailers, and citizens, for example leading to the introduction of discounts on reman parts acquisition. This new element is part of a broader set of new business models that will be investigated both for independent remanufacturers and OES. For example, the feasibility of offering "reman as a service" especially for high-loyalty products, such as engines, will be analyzed. Also, more traditional but still poorly exploited business models, such as the pay-per-use and, in general, service-oriented business models, will be tested grounding on the availability of in-use product data, especially in OES conducted B2C businesses (e. g. heat pumps, refrigerators).
Target Groups: Business strategy developers, business managers, reman core procurement experts.
Scale & Significance: Transferring the rEUman results to the EU industry with the appropriate business models, the economic added-value brought in EU by 2030 will be 0.296 B€, attracting 5993 additional workers in knowledge intensive reman operations (see next section).
WI3: *Technologies enabling the switch to decarbonisation in all major emitting industrial sectors, including green digital technologies;*

Narrative: Remanufacturing a product and selling it to consumers at reduced price makes it possible to decouple production and growth from the consumption of virgin resources, meeting the worldwide ever-growing demand of high-tech products with more affordable products, contributing to the financials of million of European families struggling by the current inflation and growing price of goods and energy, reducing the harm on the planet and the environment. Concretely, remanufactured products compared to the production of equivalent products, need less energy (-90% calculated with experimental data by Knorr Bremse) and consumes less virgin materials (-50% on average, -90% for metals and alloys, -20% for plastics and composites), reducing the high emissions of manufacturing operations as well as the emissions of upstream material extraction/supply processes, involving the mining and the process industry. rEUman makes remanufacturing more efficient in terms of regeneration capabilities and volumes of products collected from the market, therefore transforming the European industry from being almost linear into being sustainably and profitably circular. This transformation is enabled by the proper upscale and integration of green digital technologies, thus being perfectly aligned with the scope of the Destination Climate neutral, circular and digitised production as well as with EU policies and upcoming regulations. **Circular Economy Action Plan.** published on 11 March 2020, which is a key part of the European Green Deal and the Commission's plan to make the EU's economy sustainable. It recognizes remanufacturing as the most valuable mechanism to close the industrial resource loop, being closer to the consumer and requiring limited number of added value operations to recover not only materials from products but also function, that can even be upgraded, making the product more sustainable through multiple upgrading loops. **EU Net Zero Industry Act.** the Commission's communication on the Green Deal Industrial Plan of 1 February 2023, presented a comprehensive plan for enhancing the competitiveness of Europe's net-zero industry and supporting the fast transition to climate neutrality considering that the global market for key mass-manufactured net-zero technologies is set to triple by 2030 with an annual worth of around EUR 600 billion. The plan is articulated around the following four pillars: (i) a predictable and simplified regulatory environment; (ii) faster access to funding; (iii) enhancing skills and (iv) open trade for resilient supply chains. Two of the 3 targte industries of rEUman are directly mentioned in the act considering that "Global production of electric vehicles will increase 15-fold by 2050, while the deployment of renewables will nearly quadruple. Deployment of heat pumps will increase more than six times by 2050, compared to today and production of hydrogen from electrolysis or natural gas-based hydrogen with carbon capture and storage will reach 450 Mt in 2050. This will translate into global cumulative manufacturing investments of USD 1.2 trillion required to bring enough capacity on track with the global 2030 targets. China accounts for 90% of investments in manufacturing facilities." Therefore rEUman is perfectly positioned to supporting making this plan concrete at industrial level. **Critical Raw Materials Act.** Delivered on the 16 March 2023, this Act claims that "with the global shift towards renewable energy and the digitalisation of our economies and societies, demand for some of these critical raw materials is forecasted to rapidly increase in the coming decades" and "EU demand for the rare earth elements from which the permanent magnets used in wind turbines or electric vehicles are manufactured is expected to increase six to seven-fold by 2050.". Thus "Substituting materials and increasing material efficiency and circularity can mitigate the projected rise in demand to a certain extent, but these steps are not expected to reverse the trend". Within article 1, remanufacturing is mentioned as one of the sustainable actions to promote. rEUman is strongly contributing to this strategy being focused on CRM intense components, such as e-motors, electronics, and optoelectronics. Remanufacturing these components will reduce the dependency on the import of the contained critical raw materials from the East. **EU Chips Act.** Published in February 2022, the Act claims that "Within the past year, Europe has witnessed disruptions in the supply of chips, causing shortages across multiple economic sectors and potentially serious societal consequences. Many European sectors, including automotive, energy, communication and health as well as strategic sectors such as defence, security, and space are under threat by such supply disruptions". In response to this challenge the proposal articulates in 5 objectives "The proposal aims at reaching the strategic objective of increasing the resilience of Europe's semiconductor ecosystem and increasing its global market share." Through its activities in automotive and optoelectronics, rEUman provides a concrete contribution to this Act. **ESPR.** In its proposal dated 30 March 2022, a framework to set Ecodesign requirements for sustainable products is proposed. In this document remanufacturing is mentioned in several article, being remanufacture one on the relevant stakeholders potentially benefitting from mandatory information stored in the Digital Product Passport (e.g. Page 44). rEUmain will strongly contributing to the ESPR through its DPP-compliant data management patform and data model, in synergy with Cirpass, preparing the ground for the DPP adoption in the reman industry.
Target Groups: Industry, citizens and society, next generations, industrial leaders, think thanks.
Scale & Significance: Transferring the results of rEUman to the EU industry, the potential energy savings in EU are estimated at 4,086 TWh by 2030, with a reduction of CO2 emissions of 14031,9 kTons/CO2 and benefits in

terms ozone layer depletion of about 355,6 kg CFC-11 eq., in energy intensive industries as the e-mobility and heating systems (see next section).

Economic Impacts.

In the following, the rEUman consortium has quantified the economic, social and environmental impact of the project on the medium-long term (year 2030), for a sub-set of remanufacturing demo-cases in different sectors, due to space limitations, under the assumption that the pilots' KPIs will be met and the developed Human-centric and Digitally-enhanced multi-level rEUman solution will deliver the promised outcomes of 95% target regeneration rate and +20% core collection rates (for already established reman business cases). The considered scenarios include the remanufacturing of electric engine in the e-mobility sector (demo-case 1.1), and the remanufacturing of heat pumps in the home appliances sector (demo-case 2.2). The resulting figures are, therefore, conservative measures of the overall rEUman impact. The calculations are based on the data/assumptions reported in the following table.

Parameter	Value used in the quantitative impact forecasts	Source
Past EVs and HEVs sales profile in EU.	<2014=194822; 2015=188013; 2016=209104; 2017= 290132 ;2018=345000; 2019= 560000; 2020=1365000; 2021=2272666; This includes sales battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV) sales.	JRC report "Electric vehicles in Europe from 2010 to 2017: is full-scale commercialisation beginning?".
Average E-motor return time.	Electric motor life-time has twice the life-span of combustion engines and approximately equal to 400.000 miles (Tesla estimates). The average return time is estimated at 10 years and regulated by the car usage time (Weibull distribution used to model the use-time).	forums.tesla.com
E-motors collection rate due to the rEUman BSO services.	Increasing up to 50% by 2030 at EU level (mature remanufacturing market).	Consortium analysis.
Weight of magnets per E-motor	1.3 Kg for a Toyota Prius with a 8 poles rotor. In general, between 1kg (PHEV) and 2kg (EV).	Binnemans K et. Al. [21]
Fraction of remanufacturable E-motors over the total collected.	Estimated at 80% of the collected rotors. Undamaged magnets can be integrated directly in remanufactured electric motors. Many other components can be directly reused such as copper and electronic components. Steel rotors can be remanufactured and re-used.	Vanguard "De-and Remanufacturing for Circular Economy" demo-case business model, investment plan.
Willingness to pay a remanufactured part.	Estimated at 80% of the price. In an E-motor with 8 poles and 10 stacks the total price for new magnets and steel rotor is 750 Euro. 150 Euro/Motor will be the price reduction for a reman motor and 600 Euro the revenue from the remanufacturing operations, leading to a net profit of 180 Euro/motor.	APRA – Automotive Part Remanufacturing Association.
Critical Raw Materials in E-motors	31% Nd, 4.5% Dy; 2% Co; 61.5% Fe; 1% Bo in weight. Market price (conservative): Nd (78Euro/kg), Dy (450 Euro/kg), Co (76 Euro/kg), Bo (11000 Euro/kg).	Fyhr P. et al. [22].
Estimated sales profile in EU of less than 12kW air conditioning units.	The European heat pump market is already a 1,5 million unit/year market, and it will more than double in the next 5 years and almost triple by 2030; moreover, there is a stock of 15 million installed unit by 2020. Considering a collection rate of 10% (new business case) and an average life-span of 10 years, the number of post-use units to be remanufactured by 2030 is 750000, with a fraction of remanufacturable heat pumps of 600000 units.	European Heat Pump Association 2021 report.
Additional margin per remanufactured unit.	200 Euro/unit, disassembly cost per unit is approximately 180 Euro/unit	Olimpia Splendid analysis.
Re-usable components / sub-systems in post-use air conditioning units.	All the components except screws, hexnuts and connecting pipes, weighted on their reusability percentages.	Olimpia Splendid analysis.
Energy consumed in the manufacturing of heat pumps.	30 kWh per unit (new heat pumps), 20 kWh per unit (remanufactured heat pumps)	Olimpia Splendid analysis.
Environmental impact in the manufacturing of heat pumps.	New heat pumps: Global Warming: kg CO2 eq = 523. Ozone layer depletion: kg CFC-11 eq = 6,29E-04. Reman heat pumps: Global Warming: kg CO2 eq = 296. Ozone layer depletion: kg CFC-11 eq = 3,69E-05.	Olimpia Splendid analysis.

Economic Impact for the EU e-mobility. rEUman will directly contribute to the automotive e-mobility industry by:

- Demonstrating new digitally-enhanced solutions for human-centric and collaborative dismantling, inspection, remanufacturing and re-assembly of E-motors and their sub-components (rotor, including magnets, and stator), with the reference workflow described in Figure 2.2. In particular, this would make it possible to reuse magnets for reman e-motors applications, thus avoiding Critical Raw Materials (CRMs), such as Nd, Dy, Co, Bo being directed to complex recycling processes or, in the worst-case scenario, being disposed in landfills.
- Increasing the core collection rates, thanks to the value-chain operational services.

According to the assumptions, considering the current EVs and HEVs fleet on the market and assuming a return-time of 10 years for the E-motors, regulated by the car-life time, a total quantity of 1.399.882 post-use E-motors are expected to be collected by 2030, with a linearly increasing collection rate from 10% in 2026 reaching 50% by 2030.

By taking into consideration the long life-time and favorable use conditions of E-motors, it expected that 70% of the magnets and rotors collected from these systems will be re-manufacturable at 95% regeneration rate, while 30% will have to be directed to recycling. The total margin from selling remanufactured motors to the aftermarket will be **176'385 M€** by 2030, with a total amount of material saved from recycling/landfill of **1819 Tons** and re-used in remanufactured products, instead of virgin materials to produce new engines. This also means a cost reduction for the final customers of remanufacturing motors of about **146M€** due to the lower price of remanufactured units.

Economic Impact for the EU home appliances. rEUman will directly contribute to the home appliance industry by:

- Developing and validating the feasibility, benefits and value-chain implications of a new business case based on the remanufacturing of heat pumps, including a pay-per-use service model for consumers.
- Providing operational solutions for improved post-use parts quality characterization, human-centric remanufacturing and quality certification through traceability.
- Offering to the European consumers a more affordable, regenerated, high-tech, sustainable, and added-value product obtained in output from the remanufacturing value-chain, with a dedicated warranty and fully produced in Europe by local workforce.

According to the basic assumptions, a supply-demand for regenerated, less than 12 kW, heat pumps systems, estimated at 600.000 units by 2030 can be observed if remanufacturing strategies are implemented, with a core collection rate estimated at 10%. This would mean an additional value-added of **120 M€** by 2030 for the whole European sector, considering a value-added per unit of 200€, with a total amount of material saved from recycling/landfill of **12 kTons** in remanufactured products, instead of virgin materials to produce new heat pumps.

Table 2.1: Summary of rEUman economic impact on market value in the EU target sectors.

Sectors	Product collection rate by 2030 thanks to rEUman	Increase in value added in 2030 [M€]
EU Automotive	10% in 2025 to 50% in 2030.	176
EU Home Appliance	10% in 2030	120
Total	/	**296**
1€ invested in rEUman by the EU will translate at least into 42€ of value added for EU industry by 2030.		

Social Impacts

Impact on jobs and growth in the targeted European industrial sector:

EU Automotive sector: rEUman will increase the added value of the EU automotive sector by 176M€ by 2030. According to the actual contribution to the value added per employee in this sector (54,000€), this means 3266 new workplaces that will be required by this industry by 2030 for knowledge intensive jobs in remanufacturing.

EU domestic appliances sector: the project will increase the added value of the EU domestic appliances sector by 120M€ by 2030. According to the actual contribution to the value added per employee in this sector (44,000€, Eurostat), this means 2727 new workplaces that will be required by this industry by 2030.

Table 2.2: Summary of rEUman economic impact on market value in the EU target sectors.

Sectors	Current Employment [n°]	Increase in employment triggered by rEUman by 2030
EU Automotive	12'000'000	3266
EU Home Appliance	287'600	2727
Total	12'286'600	**5993**
1168€ invested by the EU will produce 1 new job in these industries at the end of rEUman.		

Impact on raw materials and environment in the targeted European sectors

Energy Consumption in manufacturing operations: The project will significantly reduce the energy consumption during the manufacturing operations by substituting new components produced with virgin materials with components obtained by remanufacturing. Remanufacturing e-motors for EVs requires an energy that is 90% lower than the new production energy (15GJ/motor) [Gutowski et al., 2010, MIT]. Therefore, a total energy saving during production of 14'698TJ is estimated by 2030 by remanufacturing E-motors. Concerning heat pumps, according to a company internal study, the production of heat pumps consumes in total 30kWh. In general, remanufacturing requires 90% less energy than the production of new parts, but in heat pumps the remanufacturing and regeneration of the compression unit requires additional energy with respect to the new. OS estimates a total reduction of 33% of energy in remanufacturing. The project will then bring a total energy saving of 6 GWh by 2030.

CO_2 Emissions: by re-using the calculated volume of e-motor components a total of 13897 KTons CO_2 can be saved by 2030 with respect to new production. Concerning heat pumps, the project will positively impact on the reduction of emissions during the production phase thanks to the re-use of complex electronics and mechanical components that would not need to be re-produced as new. The proposed business case will positively impact global warming since 134,93 KTons CO_2 can be saved by 2030 with respect to new production (523 kg CO2-eq/part), in perfect alignment with the EU Net Zero Industry Act.

Raw material use in manufacturing operations and reduction of waste going to landfill: under the reported assumptions, a total amount of material saved from recycling/landfill of 1819 Tons will be embedded in remanufactured e-motors. In terms of CRMs from E-motor magnets, this will mean 564 Tons of Nd, 82 Tons of Dy, 1119 Tons of Fe, 36 Tons of Co, and 18 Tons of Bo that would otherwise been required to build new e-motors for the aftermarket demand, in perfect alignment with the EU Critical Raw Material Act.
Concerning heat pumps, considering an average weight of 40Kg per machine and including the fraction of remanufacturable components, a 50% of the material can be re-used. This would mean that 20Kg of material per unit will be saved from becoming waste. The total amount of material saved from landfill is 12 kTons by 2030, mainly related to the electronics and polymeric case fractions, both containing critical raw materials and plastics. This would also bring benefits in terms ozone layer depletion of about 355,6 kg CFC-11 eq.

Table 2.3: Summary of the rEUman environmental impacts by 2030.

Sectors	Materials being saved from recycling [kTons]	Saving in Manufacturing Energy [TWh]	Savings in CO_2 emissions [kTons CO_2]
Automotive	1’819 (Co=36, Nd=564, Dy=82, Fe=1119, Bo=18)	4.08	13’897
Home Appliance	12’000	0.006	134.9
Total	**13’819**	**4.086**	**14’031.9**

Scientific Impacts: The technical work of the project and the Human-centric and Digitally-enhanced multi-level rEUman solution involves a wide range of multi-disciplinary tasks, which require partners with complementary skills and knowledge from different domains of research (see table 3.2a). This interdisciplinary approach of rEUman requires a unique combination of skills that can be provided by the best researchers and professionals of 10 European, including emerging, countries, (Italy, Germany, Lithuania, Greece, Hungary, UK, Turkey, Poland, Belgium, Slovenia). The project will further strengthen an R&I&D ecosystem that can foster world-class European manufacturers supported by a knowledge triangle of academia, research and industry, working in synergic way towards a cross-KET solution for a battery manufacturing in Europe.

2.2 Measures to maximise impact - Dissemination, exploitation and communication

2.2.1 Exploitation of the project results

The rEUman exploitation plan will be led by **G-MEDIA**, including (i) Communication and engagement with the relevant stakeholders and target publics concerning actions and initiatives developed in rEUman project; (ii) Successful development and implementation of dissemination plan of the project results; (iii) Definition and implementation of rEUman exploitation strategy, and its two enhancements (IPR and financing amendments) during the course of the project; (iv) Assuring a successful exploitation of validated pilot cases by defining congruent business models for each business case, matching them with viable pathways for the market uptake; (v) Action initiation to support standardization and legislation to ensure applicability of remanufacturing technologies; (vi) Supporting the market uptake of business cases and other KERs by systematic industry scouting and financing support. More in-detail, “*Public Awareness, Communication and Dissemination Plan*” will methodically enable to reach wider communities for dissemination of project results; *“Value Maps”*, generated by simultaneous evaluation of core Exploitable Results (ER) of rEUman, will demonstrate the potentials and advancements of ERs; *“Market Uptake and Financing Action Plan”* will address financial opportunities and industry absorption: one scouting event and two workshops will be hosted by G-MEDIA in the last year of rEUman to connect investors, fund-owners or absorption actors with project beneficiaries; lastly, the open access book “*Towards human-centric and digitally-enhanced remanufacturing: the rEUman way”* presenting the key achievements will be published. In addition to that, during the training and skill development part of the workplan (WP8, led by **ES**), the rEUman will coordinate the partners and identify the skill gaps and key market requirements. A comprehensive training program which aims both short-term needs and long-term exploitation beyond the project will be organized. Besides the technical upskilling, rEUman training program will integrate informal learning activities: (i) a joint international Summer School for engineering master students, to be organized by POLIMI in cooperation with the Idea League network and the APRA Europe academic members; (ii) RemanMasterClasses, to be organized by BORG, targeting executives and professionals from different value chains and companies size; (iii) the ReEUmanuthon, to be organized by ES and POLIMI with the Italian Cluster for Intelligent Factories - CFI, a hybrid hackathon dedicated to remanufacturing (applying a 5-steps design thinking process validated by two EIT communities); (iv) the RemanChallenge, to be organized by BORG, to develop cooperation skills internal to a value chain by competition among multiple value chains through challenges to be tackled. Furthermore, APRA Academy cultivating the future automotive remanufacturing workforce towards the adoption of the rEUman innovations will be held by APRA and POLIMI, and a gamification platform, encouraging the participants to imagine future market situations and their respective

roles and potentially, other project results, emerging from rEUman will be developed by G-MEDIA.
rEUman aims at fostering competitiveness and growth and increasing benefits to the partners involved and to EU economy and citizens. The innovation activities will produce highly competitive results based on new digitally-enhanced, remanufacturing-based business cases and enabling hardware and software technologies. Depending on the project result type, the consortium has developed an innovative method for identifying KERs in a comprehensive and systemic way, following a matrix structure, highlighting different exploitation routes customized to the specific pilot strategies. Moreover, since the rEUman solutions embraces innovations that affect the whole value-chain in the target sectors, the rEUman consortium has analyzed all the exploitable solutions generated at value-chain level and identified two stakeholder groups for exploitation:

- Technology and service providers – **TP** which are interested in selling the digital and physical solutions (or the use of the solutions) developed in rEUman to largest possible target end-user groups, contributing to a sustainable transition to Circular Economy in the remanufacturing and aftermarket industry.
- Remanufacturers – **RR** - (Lead-users), remanufacturing companies (established or potential) interested in using the new solutions embedded within the rEUman for (i) selling remanufactured components to end-users; (ii) selling services to end-users; (iii) increasing the understanding of remanufacturing market potential, when applied.

Table 2.4. Preliminary identification of KERs and exploitation routes.

Exploitable products	Main Exploiter(s)	Route to exploitation		Time to market	Target Industry
		During rEUman	After rEUman		
New remanufacturing business cases and reman products, enhanced by the rEUman					
Remanufacturing business cases in the e-mobility sector	**TP:** HEPENIX, ZEISS, SZTAKI, POLIMI, KIT, SYXIS, CR&C, CORE. **RR:** KB, BORG,	rEUman will test the effectiveness of the developed solutions and will demonstrate the benefits at TRL5 in 2 circular pilots.	The rEUman demo-cases will be translated into new industrial practices. Extensions to other markets and valuable post-use products will be considered in output of the rEUman exploitation strategy.	4 years after the project ends. Form: internal product development, spin-off from RTOs.	Automotive
Remanufacturing business cases in the home appliance sector	**TP:** HEPENIX, ZEISS, POLIMI, KIT, SYXIS, CR&C, CORE. **RR:** ARCELIK, OLIMPIA	rEUman will demonstrate this remanufacturing strategy for heat pumps and refrigerators. Results will be highlighting directions of extensions to other home appliances streams.	The demonstrations of rEUman will be transferred to the home appliances industry at large scale. The manufacturers will further test the obtained streams also in terms of safety and regulation.	3 years after the project ends. Form: internal product development.	Home appliances
Remanufacturing business cases in the optoelectronics sector	**TP:** HEPENIX, ZEISS, SZTAKI, CORE, POLIMI, SYXIS **RR:** CONVERGENT	rEUman will implement the remanufacturing line for multi-emitter modules.	The optoelectronics demonstration will be enlarged to photonics and semi-conductor industries.	4 years after the project ends. Form: internal product development.	Optoelectronics
Human-centric remanufacturing technologies	**TP:** HEPENIX, ZEISS, SZTAKI, POLIMI, CR&C, CORE**.**	rEUman will develop and test 6 human-centric enabling technologies for high regeneration rates in reman process-chains.	After validation at TRL7, these green technologies will be ready for uptake. Financial instruments, I3, EIT or EIC opportunities will be evaluated.	4 years after the project ends. Form: Internal product develop. Spin-off	All reman mature industries.
New software technical enablers. MULO (Make, Use, Licensing, Outsourcing)					
Value-chain digital tools and services at design and operational levels (VCd, VCo)	**M:** SIMPLAN, POLIMI, BRI, CORE, FLEXIS. **U:** All partners. **L:** POLIMI, KIT, SZTAKI, BRI **O:** ES, APRA	During the project, each single digital tool is deployed and tested in the demo-cases, to demonstrate the effectiveness and the accessibility and value on the remanufacturing business.	After the project, each tool can be exploited by the owner individually or through the joint exploitation described as part of the rEUman. Owners will look for funding opportunities to achieve a market-ready product to be offered to stakeholders in the remanufacturing industry.	3 years after the project ends. Form: Licensing.	• Customers in different sectors. • rEUman industrial partners, players in their value chains.
rEUman DPP-compliant data management platform.	**M:** SYXIS **U:** All partners. **L:** POLIMI, KIT, SZTAKI, BRI **O:** ES, APRA.	The DPP data model targeting the remanufacturing industry will be developed and tested in compliance with the ongoing results of the Cirpass CSA. It will be validated in the 3 pilots.	Thanks to the dissemination and exploitation activities and the participation to the Cirpass open workshops, this technology will be fine-tuned to comply with the ESPR guidelines. Through APRA more validation will take place.	3 years after the project ends. Form: open-access for acceptance and fine tuning (only the DPP data model).	• All ESPR relevant stakeholders across multiple sectors.
Factory level digital tools and services at design and operational levels (Fd, Fo)	**M:** POLIMI, CORE, FLEXIS. **U:** All partners. **L:** KIT, SZTAKI, BRI **O:** ES, APRA	During the project, tools are deployed and tested in the demo-cases, to demonstrate the effectiveness to support the new concept of Cyber-Pysical reman system.	After the project, each tool can be exploited by the owner individually. Exploitation of the overall rEUman solution as a kit for CPS-based reman will be considered.	3 years after the project ends. Form: Licensing or service sale.	Reman mature sectors: • Aeronautics; • Consumer electronics; • Forniture.

2.2.1.1 Preliminary Business Plans for Exploitable Products and Enabling Technologies

Individual Partners Business Plan – BORG: Through the successfulness of this project BORG aims at bringing to the automotive aftermarket two products which aren't served today and are crucial in the electrified powertrains. BORG product portfolio extension is customer driven, therefore the first step will be to promote toward its customer base the possibility to introduce the electric motors (exploited benefit 1) and inverters (exploited benefit 2). Once customers are showing concrete interest, the entire process development will be performed and from there a continuous activity of product range extension will be done, to serve customers with the widest range possible.

Table 2.6: individual partner business plan: BORG.

Potential economic benefits for BORG						
Benefits	**Reman Navigator**	**+1 years**	**+2 years**	**+3 years**	**+4 years**	**+5 years**
*Sales: Exploited benefit 1 [n° units]: motors		100	1657	4187	5297	8075
*Sales: Exploited benefit 2 [n° units]: inverters		110	1823	4606	5827	8883
Gross Sales Revenue [M€/year]		0.1 M€	1.7 M€	4.3 M€	5.5 M€	8.4 M€
Expenses [M€/year]	0.4M€	0.6 M€	1.5 M€	3.2 M€	3.9 M€	6.0 M€
EU grant [M€/year]	0.4M€					
NET Benefits per year [M€]	0	-0.5 M€	0.2 M€	1.1 M€	1.6 M€	2.4 M€

Individual Partners Business Plan – OLIMPIA: Through the rEUman project Olimpia aims at introducing remanufacturing best practices into home appliances creating the first demo case in heat pump products, a fast growing market contributing to european decarbonization. Olimpia aims at promoting remanufactured products as an additional service to the customer base and to new customers. In addition an activity of extension will be done, in order to serve customers with a wider product range. Finally lessons-learnt from rEUman experience will be implemented in new product development best practices in order to improve circularity in future products.

Table 1.7. Individual partner business plan: OLIMPIA.

Potential economic benefits for OLIMPIA						
Benefits	**rEUman**	**+1 years**	**+2 years**	**+3 years**	**+4 years**	**+5 years**
*Sales: [n° units]		2000	3000	4000	5000	6000
Gross Sales Revenue [M€/year]		0,5	0,75	1	1,25	1,5
Expenses [M€/year]	0.3	0,3	0,45	0,6	0,75	0,9
EU grant [M€/year]	0.3	0	0	0	0	0
NET Benefits per year [M€]	0	0,2	0,3	0,4	0,5	0,6

Individual Partners Business Plan – CONVERGENT: Within the rEUman project, Convergent will develop specific techniques to remanufacture multi-emitters that for the moment represent a cost as waste. The end-life products would be completely remanufactured and will be an important revenue in the incoming years. In parallel, the development of an innovative method for life prediction of the product to guarantee long term functionality will optimise repair costs with targeted and predictable interventions. After the design and implementation of remanufacturing techniques, the validation will be an important guarantee of its functionality, in the same way of the new products. Both will be offered to the market with specific information and programmed intervention plans for possible refurbishments that will close the circle of the circular economy designed within the project.

Table 2.8. Individual partner business plan: CONVERGENT

Potential economic benefits for CONVERGENT						
Benefits	**rEUman**	**+1 years**	**+2 years**	**+3 years**	**+4 years**	**+5 years**
*Sales: Exploited benefit 1 [n° units]		200	300	500	600	1000
Gross Sales Revenue [M€/year]		0.44	0.66	1.1	1.32	2.2
Expenses [M€/year]		0.2	0.3	0.5	0.6	1
EU grant [M€/year]	0.45					
NET Benefits per year [M€]		0.24	0.36	0.6	0.72	1.2

2.2.2.2 Industrial Impacts: Innovation for Market Success

rEUman will produce multiple impacts in the European industry. The participation of industrial partners will ensure that the project will directly impact on the automotive and home appliances industries. The following table summarizes the relevant exploitation strategies of a sub-set of project partners (Table).

Table 2.9. Main strategic interest of industrial partners towards exploitation of the project results.

BORG	BORG will in a first place proactively promote to its customer base the interest in expanding the current business to remanufactured electric motors and inverters. The finalization of the development will arrive as soon as one or more customers will provide positive feedback. Through the successfulness of this project BORG aims at bringing to the automotive aftermarket two products which aren't served today and are crucial in the electrified powertrains.
KB	Knorr-Bremse will - after a certain time necessary for standardization - implement successful demonstrated tools and services into the existing process or respect their results during the set-up of a new remanufactured product. The goal of Knorr-Bremse is to further improve and advance the remanufacturing process for the benefit of its customers.

ARC	Arcelik will deploy developed technologies to improve existing refrigerator re-evaluation processes. This solution has the potential to widen all product range's re-evaluation. Arcelik has 28 different re-evaluation and 2 recycling centers.
OS	Olimpia Splendid will in the first place implement tools and services to improve existing processes. Then, Olimpia Splendid will proactively promote this new service of remanufactured products to its customer base and to new customers. In addition, Olimpia will exploit the experience gained in the project to other product families.
FLEX	FLEX will - after a certain time for standardization and productization - sell the tools implemented in rEUman to customers (as SaaS). In addition, individual modules developed in the project will be incorporated into other software products of the company, generate additional customer benefits and thus generate additional sales. Through the results of the project, FLEX expects to expand its customer base and gain access to previously unserved business areas of those in its current client base.
SimPlan	SimPlans will enable its value stream simulation tool to support value stream modelling and simulations for re-manufacturing and circular economy processes and generate license and service revenues for this exploitable item. SimPlan will also provide dedicated simulation and modelling tools for circular supply (value) chains and dedicated digital twinning support on the level of re-manufacturing hubs or workstations. In this context, SimPlan also intends to generate license and service revenues.
SYX	SYX will jointly exploit the rEUman, with all partners interested in it t, being in charge of the core components of the solution. Syxis will also proceed with individual exploitation of the concepts generated through the project about data management for circular economy.
HEPENIX	HEPENIX uses the potential in rEUman to further support the development of tools for the needs of the circular economy. The rEUman solution will join existing solutions for assembly, testing and repair of high-value and safety- relevant components for the automotive and other industries. The exploitation in multiple forms - directly, as platform in the form of variants/derivatives and the software and digital twin solution augment each other to provide a complete portfolio for customers. rEUman will also be used in the educational activities of HEPENIX. The possibility of the international cooperation project will be used as a networking possibility.
POLIMI	POLIMI will exploit the project results in several ways. The developed Digital Services at remanufacturing process level will be tested and integrated within the CIRC-eV pilot laboratory, focused on circular economy solutions for the e-mobility. This will help attracting more business cases, further testing and validating the impacts. Moreover, POLIMI will take care of launching one spin-off company for commercial exploitation of the CPS for zero-defect remanufacturing. Further, POLIMI will exploit the learning contents and training modules for internal use in its circular economy track courses.
KIT	KIT will exploit the project results of rEUman aiming at reaching a wider audience through new service development and demonstration activities. The latter will be presented on a regional and national level (e.g. regional Think Tank on "Industrial Resource Strategies" with joined partners of industrial and academic partners) as well as international conferences. Furthermore, the learning factory laboratory on Global Production as well as the Demo-Factory of the AgiProbot project on automated disassembly will be used as demonstration platforms of the project results.
SZTAKI	SZTAKI wants to strengthen its existing competence in special human-robot collaboration tasks and to build relationships with the developed technologies towards Hungarian industrial companies as well. In the latter activity, SZTAKI intends to rely on EPIC Innolab Ltd., a joint venture of SZTAKI and Fraunhofer-Gesellschaft.
BRI	University of Bristol will exploit the Business Strategy Oriented services for consulting and future projects with local remanufacturers at UK level.
APRA	APRA Europe represents about ⅔ of the European automotive remanufacturing industry's employees. APRA will make project results available to all its members as well as to its broad community of stakeholders thus enabling the application and use of the outcomes of rEUman in manifold practical business cases in the industry.

2.2.2 Dissemination and Communication of rEUman results

The Communication and Dissemination part of the C&D&E plan (WP7) will tackle both B2B and B2C relations along the remanufacturing value-chain to reinforce the engagement of participating actors and support the ambitious training program for reskilling and upskilling (WP8). APRA will be in charge of developing and continuously updating the Dissemination & Communication activities**.** Dissemination roles are listed in Table 2.18 for a subset of partners due to space limitation. The strategy and tools that will be used to implement rEUman communication and dissemination (C&D) strategy will be gathered in the D7.1 Public Awareness, Communication and Dissemination Plan. This will outline the variety of channels and formats which will be considered to ensure a broad coverage of all audiences targeted by the project. To maximize the impact of the C&D activities the use of partners' networks and their participation in National and International platforms will be promoted.

Table 2.10. Specific partners activities for the Dissemination and Communication plan of the rEUman results

PARTNER	DISSEMINATION & COMMUNICATION ACTIVITIES
POLIMI	Scientific publications and participation to national and international conferences. Editor of the high-visibility, open-access book (based on the work done in WP1). Synergy with other Green Deal projects. Co-organize of the World Reman Summit 2024 and the APRA Academy.
APRA	Dissemination and Awareness-Raising Task leader; responsible for the coordination of dissemination and awareness-raising activities, including the design of Public Awareness and Dissemination Plan, the brand strategy and communication processes. Organizer of the APRA Academy.
SYX	SYX will involve the entire network of contacts, and will also ask all the federated partners (including the founding partners Holonix, CyberBrain) to share the project activities and results with their networks. Channels and activities will be: social media communication on direct channels, content of the blog on the SYX website, thematic webinars, podcasts to describe results.
SZTAKI	Dissemination towards robotic community. Trade fairs. Presentation and exhibition at Project Open Days. Scientific publications and participation to national and international conferences.
BORG	Organizer of the RemanMasterClasses, the RemanChallenge, and co-organizer of the ReEUmanuthon bringing challenges.
ES	Coordination of the Dissemination and Communication activites with the Training activities. Organization of the ReEUmanuthon.

With respect to Communication, the main channels that will be activated in the project are listed in Table 2.11.

Table 2.19: Stakeholder groups targeted by rEUman communication activities.

Target groups	**Aims (**Benefits that AutoBat project will offer to them)	**Main channels and methods**

Remanufacturing industry	**Awareness, Involvement, Exploitation**: Demonstration of human-centric, digitally-enhanced remanufacturing approach of rEUman.	Industry Associations, Exhibitions, Conferences.
Technology providers	**Awareness, Involvement, Exploitation**: Demonstrations of the 6 human-centric physical technologies of rEUman.	Industry Associations, Exhibitions, open-infrastructure (VI).
European manufacturing industry	**Awareness, Involvement, Exploitation**: Strong industrial involvement towards the new opportunities for remanufacturing. Inspiration and best practices for the development of new Circular Economy business cases.	Direct proactive communications. Industrial training. Demonstration workshops. Exhibitions. Clusters. Vanguard Initiative.. Project web site. Social media.
European Technology Platforms	**Awareness, Multiplication**: Maximum diffusion of the project results within the Vanguard Initiative regional network, through the EFFRA portal organizing the KERs according to the Innovation Radar.	Direct communication, input to strategy papers and research roadmaps at regional and EU levels.
Standardisation, certification bodies	**Awareness, Involvement, Exploitation**: New guidelines for sustainable remanufacturing through APRA. Standardization possibility scouting for the developed green technologies.	Direct Proactive communication. Participation to CENELEC working groups.
Professional Associations	**Awareness, Understanding:** Involve associates and stakeholders to rEUman training modules and open exploitation sessions.	Direct Proactive communication. Industrial training webinars and hands-on sessions (in synergy with EIT)
Teachers and Students	**Awareness, Understanding:** Up-to-date information on remanufacturing technical features. Attractive jobs in sustainable circular economy businesses.	Material to be used in education and vocational training.
Research community	**Involvement, Exploitation:** New reman business cases to be extended to other prodcuts and sectors.	Scientific publications. Dissemination workshops, book.
Regional agencies	**Awareness, Involvement**: Showcase of the implementation of Regional Smart Specialization RIS3 Strategies, Lombardy Region CE Roadmap 2020.	Direct communication, Demonstrators' Open-Door event.
Policy makers	**Awareness**: Recommendations for legislation guidelines supporting the business model of rEUman. Evidence of benefits of Circular Economy at large scale. Best practice evidence.	Direct Communication; Clusters, White papers from associations, European Commission's events on Circular Economy.
NGO, Citizens	**Awareness**: Closing of material streams to the benefit of the environment. Bringing battery recycling problems and solutions to the attention of citizens, boosting environmentally conscious behaviors.	Project web site. Social media, Action under the European Week for Waste Reduction Demonstrators', Open Door, Press release, living labs.

Table 2.11. Specific activities and methods for dissemination & communication in rEUman.

Specific Channel	Scope and procedure for design, set-up and maintain the channel
The project image and identity	Image and visual identity will be documented in the stylebook. The image will include the logo, project specific design elements and templates for MS Office tools. Promotional material utilizing the visual identity will be generated (Prezi, SlideShare) and two Youtube videos will be produced to communicate the project's vision, objectives and results.
The project website	Will be produced by a professional marketing company to support the implementation of the project and it will be main interface for communication to the public. The website will host communication tools and a blog to facilitate interaction between partners and interested parties. The private section will facilitate the communication within the consortium.
Social media	Will be utilized by the consortium to communicate the project in professional social networks (e.g. LinkedIn). Official LinkedIn groups will be used to raise awareness of professional network groups.
The website blog	Will highlight outcomes, distil updates, presents the growth of the network and relevant news concerning exploitation opportunities and offering by the rEUman companies.
The project factsheet	Will be prepared at start of the project and twice updated. The first version will focus on the project's objectives and the vision. The second version will highlight achieved results while the third and last version will demonstrate key results and pilots.
Scientific publications	Will be increasingly submitted throughout the project to disseminate the results to the scientific community and experts in the industry. In the beginning of the project various conference participation will allow presentation of posters. Thereafter, the accumulating results will be published in peer-review scientific journals. A open-access book will be published.
Trade articles in professional magazines	Will be prepared to disseminate the results to experts and investment decision makers. Attendance on trade fairs and exhibitions are foreseen to present the project's results and to foster customer relationships and prepare for the commercial exploitation.
Press releases	The consortium will issue regular press releases at key milestones of the project by employing the main media communications (special websites, TV, newsletters, journals radio, etc.).

Regarding publications, the project will publish scientific and technical results in high impact open-access journals and relevant technology focused congresses.

Table 2.12. Journals and Magazines, Conferences, Industrial Fairs and Exhibitions

JOURNALS	**MAGAZINES**
CIRP Annals - Manufacturing Technology, NDT & E International, Journal of Remanufacturing, Resource, Conservation and Recycling, Journal of Cleaner Production, Waste Management, Journal of Renewable Materials.	APRA Newsletter, Lightweght Design newsletter, Manufacturing Global, Renewable Matter, Recycling Magazine, CompositesWorld, Composites Manufacturing Magazine, RemanWorld, JEC Magazine.
CONFERENCES	
CIRP Design Conference, CIRP General Assembly, CIRP Conference on Life-Cycle Engineering (LCE), European Conference on Composite Materials (ECCM), International Conference on Remanufacturing (ICOR), Circular Economy European Summit (IEEE ICIT), IARC, SAE AeroTech Congress & Exhibition, Enterprise Integration, Interoperability and Networking, International Composites Congress (ICC), European Biomass Conference	
INDUSTRIAL FAIRS AND EXHIBITIONS	
REMATEC; EGG CONTROL; ECOMONDO; Plastics Recycling Show Europe; European Trade Fair & Forum for Composites, WindEnergy Hamburg, Husum Wind, JEC World Paris, Singapore Air show, International Paris Air Show Le Bourget, Luftfahrtmesse Farnborough, Dubai Air Show, Aircraft Interiors Expo, Mouldtec, EXIST, World Remanufacturing Summit, Automechanika Frankfurt, APRA European Symposium, World Circular Economy Forum – WCEF, CO-VERSATILE Manufacturing Resilience Week for SMEs	

Table 2.13. List of EU wide platforms for exploitation and dissemination

Platform	Details	**MEMBERS**
MANUFUTURE	Technology platform bringing together actors interested in the manufacturing industry.	POLIMI, SZTAKI
EFFRA	PPP: European Factory of the Future Research Association.	POLIMI
Open Group	A world-wide standardization group. Its core objective is to define and maintain standards such as "the Single Unix Specifications", "TOGAF", "UDEF", and "O-LM" focusing on IoT, lifecycle management	SYXIS

euRobotics	euRobotics is an international non-profit association for all stakeholders in European robotics with the aim to strengthen Europe's competitiveness and to ensure industrial leadership of manufacturers, providers and end-users of robotics technology-based systems and services.	SZTAKI
Ai4Manufacturing	The connecting community hub to help innovate manufacturing with AI, learn and interact with a community of peers and experts (ai4manufacturing.com)	SYXIS

2.2.2.1 KPIs for the C&D&E activities

In order to support the ambitions of rEUman, equally ambitious target KPIs have been defined for rEUman.The achievement of these KPIs will be constantly monitored and reported in WP7.

Table 2.14. Key Performance Indicators for C: Communication, D: Dissemination and E: Exploitation activities.

ID	Indicator	Number of:	Y1	Y2	Y3	Y4
KPI1	C+D through the internet	rEUman unique website visits	1500	2500	5000	8000
KPI2		Other websites linking to the rEUman website	25	40	60	200
KPI3		Website updates	10	20	30	30
KPI4		Contributions to discussions in social media (Youtube, Linkedin, Twitter)	20	35	45	65
KPI5		Uploaded presentation to SlideShare/Prezi	4	6	12	12
KPI6		Number of press release	5	10	15	30
KPI7	C+D through general media	Media coverage (print, radio, TV)	5	8	10	25
KPI8	C+D through presentations	Scientific/technical presentations	6	10	20	40
KPI9	D through scientific publ.	Submitted publications in Journal and Conferences	2	6	10	10
KPI10	D activities promoting the results' exploitation	Events attended to present the demonstrators	3	10	12	15
KPI11		Industry participants in the exploitation workshop	N/A	N/A	60	150
KPI12		Requests from industry	15	30	100	200
KPI14		N° of training webinar modules for industry and academic			8	20

2.2.2 Management of research data, knowledge and Intellectual Property Rights (IPR)

Each rEUman partner will be responsible for protection of their IP rights and the applications for patents on fabrication methods, devices concepts, and codes generated during the project (Key Exploitable Results, IP and ownership list would be created and regularly updated). G-Media, as IPR strategy expert and neutral partner (not owning or seeking to own IPR), will mitigate all possible IPR disagreements between partners that might occur, following the rules defined in the CA. G-Media will organise an IP training workshop to help partners to gain knowledge regarding IP measures and management. The IPR and technology monitoring report will be created at M18 and updated twice at M36, M48 (D7.2) to plan IPR development and avoid possible patent infringements. G-Media could also prepare customised patentability reports that will assist partners during the IP protection process and help them in possible patent filings preparation and claims formulation. Data Management Plan will be created.

2.3 Summary

SPECIFIC NEEDS

Remanufacturing is the most valuable circular economy option, creating knowledge-intensive jobs, combined with environmental benefits in terms of CO2 emissions (-90%) and material consumption (-80%) compared to new manufacturing operations.

Modern products are evolving into high-complexity smart products. This transformation is posing additional burden on remanufacturing business cases (e.g. e-vehicles).

The remanufacturing industry is lacking behind in adopting digital technologies. This limits remanufacturing in a wider set of EU sectors.

The regeneration rate in remanufacturing is usually between 50%-70%.

A novel human-centric and digitally-enhanced multi-level remanufacturing solution is needed for a wide implementation of remanufacturing within the European industry.

TARGET GROUPS

Remanufacturing industry as a whole. European SME, both end-users and technology providers. Core collectors, workshops, service.

Manufacturing equipment providers and system integrators, smart automation integrators, robotic companies, machine tool builders, inspection technology providers.

IT service delivery companies, digital tool developers, MES, PLC, PLM, and ERP software providers, process control solution providers.

Cross-sectorial business facilitators (Clusters). European citizens of different age and cultural background. Public and legislation bodies at Regional and Municipality levels.

Replication and multiplication: exploiting the Vanguard Initiative De-and Remanufacturing network including 8 regional hubs for Circular Economy network,150 EU stakeholders, more than 100 de-risking project expected 5 years after BATTwin, potential turnover of about 500MEuro generated for European SMEs using the hubs for exploring their transformation path towards circular economy.

EXPECTED RESULTS

Demonstration and validation of the effectiveness of a human-centric and digitally-enhanced multi-level remanufacturing solution, with tight coupling between the value-chain level digital tools and the factory level digital and physical solutions.

Digital Product Passport – compliant data management platform for traceability and certification, through semantics and data modeling.

Validation of 6 human-centric remanufacturing technologies for pre(in) process inspection, smart human disassembly, human empowerment, collaborative disassembly, electronics and mechatronics regeneration, and function oriented re-assembly and certification.

Validation of 3 factory levels operational digital tools, for quality class-based disassembly planning and cyber-physical control.

Validation of 3 factory levels design digital technologies, for hybrid reman factory (re) design and production planning.

Validation of 5 value-chain levels, design and operational digital technologies, for reman business stategy definition, circular value-chain configuration, reverse BoM, core collection schema through incentives and remote core assessment before delivery.

Successful demonstration in 3 pilots in high-tech sectors, with 5 industrial demo-cases and 8 new reman products.

OUTCOMES

3 pilots demonstrating the developed rEUman soluton in real industrial environment, at Borg, Knorr Bremse, Arcelik, Olimpia Splendid a Convergent (ex Prima Electro).

Massive increase of regeneration rate (+30%, target 95%) and of collection of remanufacturable cores (+20%).

Massive reduction of CRMs contained in high-tech products going to landfill. Resilience and reduction of dependency from raw material imports by keeping resources in EU.

At least 6 patentable high-risk/ high-return enablingcyber-physical technologies (inspection, smart human disassembly, collaborative disassembly with pre-configuring fixtures, cold-spray, servo-based robotics for electronics reman, CPS for function-oriented re-assembly).

Digital Product Passport data-model for traceability and compliance with the ESPR regulation.

D & E & C MEASURES

A list of 6 exploitable results have been populated. These include digital and physical enabling technologies and new products. The strategies for exploitation fo these results is reported and will be further refined through rEUman exploitation workshops.

2 partners dedicated to dissemination and exploitation (G_Media and APRA) targeting different phases of development and stakeholders.

Dissemination and communication towards the manufacturing industry, and users in different sectors, by exploiting the synergy with other highly strategic EU actions, such as the CIrcPass CSA.

Synergies with the data-spaces (IDSA, AAS, Catena-X, GAIA-X) and the Digital Passport initiatives for data modelling.

Scientific publications in the most relevant journals in the field of automotive, energy, remanufacturing, quality control, and circular business models.

Analysis of skill gaps and design of training modules targeted to a wide set of groups exploiting (i) the availability of teaching and research factories (e.g. CIRC-eV, EcoCirc), (ii) digital twins for gamification; (iii) executing ReEUmanuthon, hackathon for future remanufacturing challenges, in cooperation with the EIT Manufacturing; (iv) launching the APRA Academy; (v) running the RemanChallenge and RemanMasterClasses organized by Borg.

Synergic upscale and financing scouting actions with European clusters, Smart Specialisaztion Strategies and the Vanguard Initiative, at regional and national level.

IMPACTS

Economic: Demonstration of human-centric and digitally-enhanced multi-level rEUman solution for high return and regeneration rate for function retain and upgrade in high-tech products.
Size: 0.296 B€ cost savings in the considered by 2030, related to reduced cost of remanufacturing, linked to the avoided acquisition of primary raw materials and lower energy (-80%), combined by more affordable high-tech products for consumers leading to cost savings of 0.146 B€ for European citizens.

Societal: Re-use product functions avoid recycling. In the considered scenario, 13819 Tons of materials will be re-used in remanufactured products (including 1119 Tons of key metals), 4,086 TWh of energy, and 14031,9 kTons/CO2 of emissions can be saved. More knowledge intensive jobs in the targeted industries (+5993 by 2030) due to new remanufacturing operations

Scientific: New breakthrough Digital tools and Green Technologies for a new vision of smart, human-centric remanufacturing.

3. Quality and efficiency of the implementation

3.1. Work and resources

The rEUman workplan is composed of 9 WPs. WP1 sets the requirements for the solution and the individual modules, starting from the formalization of the use-scenarios and target KPIs in the validation pilots. WP2 -WP5 develop the technical innovation portfolio of innovative remanufacturing technologies and digital tools at factory and value-chain levels, as key components of the innovative reman paradigm. WP6 integrates the individually validated results into the pilot demonstration of the rEUman solution. WP7 supports an effective dissemination, communication and exploitation strategy which will ensure rEUman reaching wide adoption among industrial stakeholders. WP8 designs and deliver specific training programs for enhancing future remanufacturing workforce skills and competences. WP9 ensures appropriate project management needed for such a consortium.

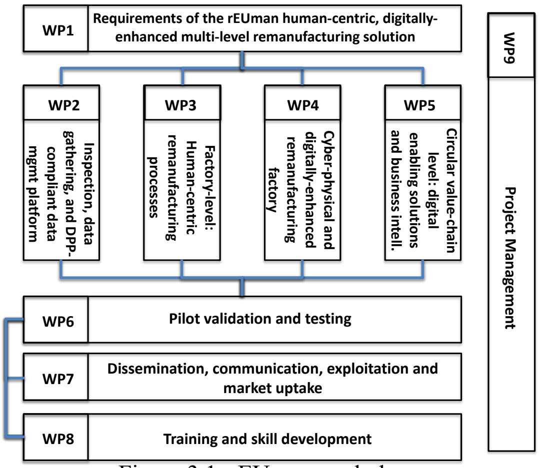


Figure 3.1: rEUman workplan.

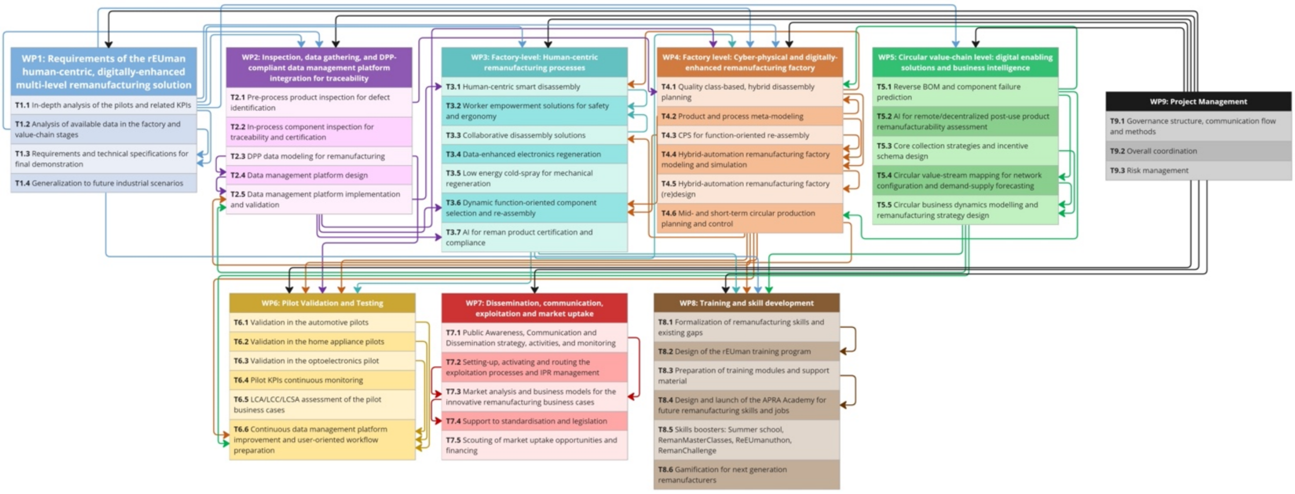


Figure 3.2: rEUman's PERT chart.

Table 3.1: Timing of the different WPs and their components - Gantt chart.

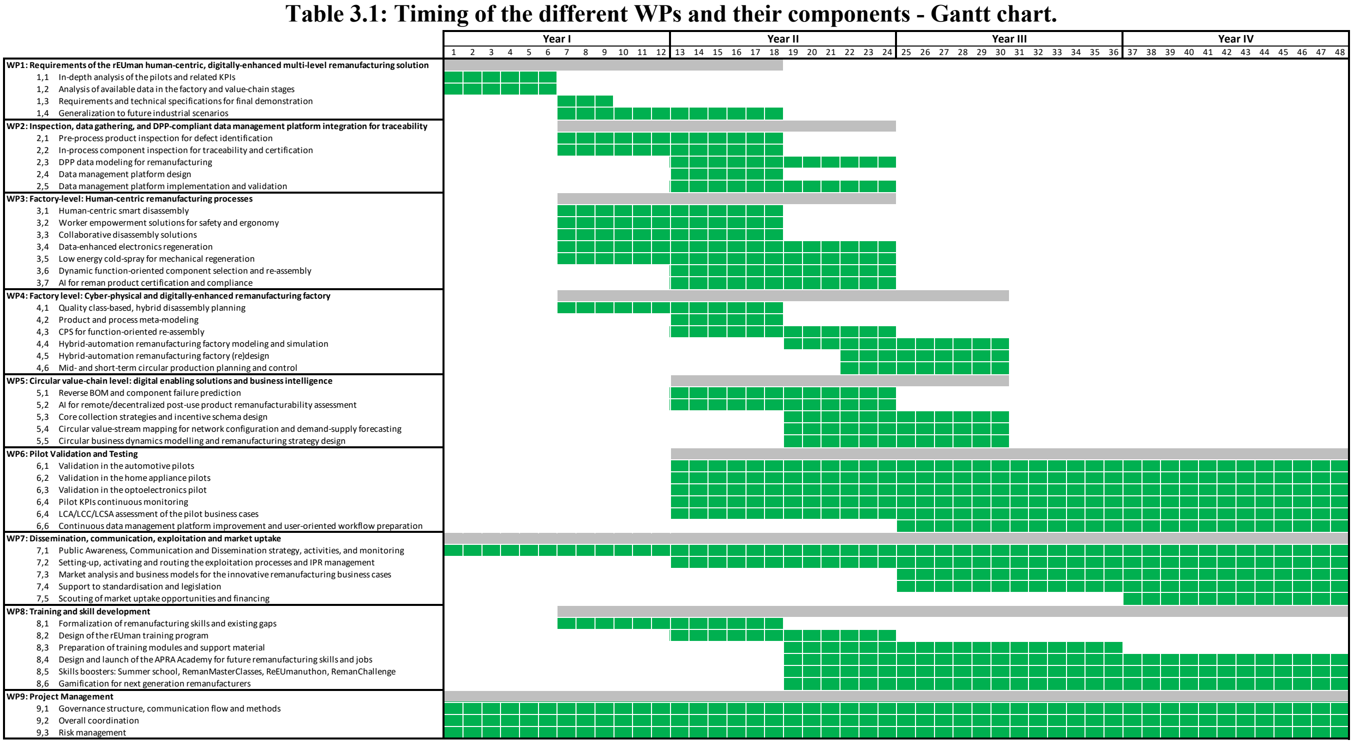


Table 3.1a: List of work packages.

n°	Work Package Title	Leader	PMs	Start	End

1	Requirements of the rEUman human-centric, digitally-enhanced multi-level remanufacturing solution	KIT	69.5	M1	M18
2	Inspection, data gathering, and DPP-compliant data management platform integration for traceability	SYXIS	74	M7	M24
3	Factory-level: Human-centric remanufacturing processes	POLIMI	166.5	M7	M24
4	Factory level: Cyber-physical and digitally-enhanced remanufacturing factory	SZTAKI	159	M7	M30
5	Circular value-chain level: digital enabling solutions and business intelligence	FLEXIS	114	M13	M30
6	Pilot validation and testing	BORG	190	M13	M48
7	Dissemination, communication, exploitation and market uptake	G_Media	86.5	M1	M48
8	Training and skill development	ES	73.5	M7	M48
9	Project management	POLIMI	63	M1	M48
Total			**996**		

Table 3.1b: Work package description.

Work package number	1
Work package title	**Requirements of the rEUman human-centric, digitally-enhanced multi-level remanufacturing solution**

Objectives

The objective of this work package is twofold. Firstly, the detailed specifications of the rEUman technologies, digital tools and the related service applications, at factory and value-chain level will be derived, based on an in-depth analysis of the pilots and their use-cases. Moreover, a detailed set of quantitative and qualitative KPIs for validating the circular economy benefits within the pilots will be detailed. Secondly, potential business cases of interest for future exploitation of the rEUman solution, across multiple EU sectors, will be highlighted. This WP will ensure the seamless interaction of all modular components that will be developed for multi-levels.

Description of work

Task 1.1: In-depth analysis of the pilots and related KPIs

Task leader: BORG | **Task Partners:** All partners

Firstly, a detailed analysis of the rEUman pilots will be performed to identify the baseline situation both at value chain level and at factory level. A check list approach will be adopted to gather detailed information on the existing technological, hardware and digital, and workforce capabilities within each pilot. Moreover, each process stage at factory and value-chain level will be described using the IDEF0 formulation. Secondly, the target situation of the pilots after the implementation of the rEUman solutions will be predicted. The validation matrix correlating the pilots with the enabling technologies will be updated to the specific situation of the pilots at the start of project. Starting from this information, user stories exploiting multiple hardware and digital technologies will be formalized. Moreover, the new business models and technological processes enabled by rEUman technologies will be detailed, also considering the implications on the new business relations made possible across the sectors. KPIs, covering both technical and socio-economic aspects, and their verification means will be identified to evaluate the pilot results (WP6). The specific mechanisms to perform pilot validation will also be defined. Furthermore, the product samples will be selected for validation of the developments in WP2 - WP5.

Task 1.2: Analysis of available data in the factory and value-chain stages

Task leader: Syxis | **Task Partners:** All partners

This task will analyze pilots from the viewpoint of the available data at each process-chain stage at factory level and within each stage of the circular value-chain. It will then provide the backbone structure of the ecosystem data model and will include the essential nature of the ecosystem describing the actual knowledge about how data are generated and how the consortium is going to use them (data sources identification, data collection methods, data processing, data storage definition, management and traceability needs, data receivers and users). Potential gaps between data needs and data availability will be reported in the output document and provided in input to WP2.

Task 1.3: Requirements and technical specifications for final demonstration

Task leader: KIT | **Task Partners:** All partners

Based on T1.1 and T1.2, this task gathers and formalizes the functional and non-functional requirements for the rEUman solution. For each target remanufacturing business case a schematic technical data sheet will be delivered, including product, remanufacturing processes, and value-chain characteristics as well as the underlying business model structure. Starting from this analysis, technical specifications for the rEUman enabling technologies, in view of their final demonstration, will be formalized. The output of the task will be a requirement catalogue and the detailed list of specifications to be exploited for solution assessment and validation in the final demonstration.

Task 1.4: Generalization to future industrial scenarios

Task leader: KIT | **Task Partners:** Polimi

By constantly analysing market trends and opportunities, this task will scout potential emerging remanufacturing scenarios for the rEUman solution in different sectors, in order to generalise the application to new emerging remanufacturing business-cases at European scale. Moreover, a preliminary analysis of the expected impacts in these emerging business cases will be conducted in order to identify future uptake priorities. The output of this task will be the formalisation of the rEUman solution potentials in future circular value-chain scenarios.

Work package number	2
Work package title	**Inspection, data gathering, and DPP-compliant data management platform integration for traceability**
Objectives	
This workpackage develops product inspection and automated data gathering solutions for pre-process inspection of post-use products returning from the market through a core-collection process as well as for in-process components, as soon as they become observable along the disassembly operations, to support human-driven decision making in remanufacturing process-chains. Moreover, it designs and implements the data management platform supporting the rEUman innovation at factory and value-chain level, through a smooth interaction with already existing tools within the pilots (e.g. PLM, ERP, etc.) exploiting the emerging idea of the DPP as a source of product design information, in compliance with the ESPR guidelines and the Cirpass project mapping activities.	
Description of work	
Task 2.1: Pre-process product inspection for defect identification	
Task leader: ZEISS	**Task Partners:** KIT, Sztaki, Polimi
This task is devoted to the development of solutions for the automatic inspection of the conditions of post-use products and the subsequent classification of potential defect causes. The challenges to be overcome are the accessibility and visibility of important product areas in the context of a visual inspection. Concerning assembled post-use products and mechanical sub-components, Zeiss will adopt modern visual inspection sensing technologies to obtain a map of deviations of product critical characteristics, both geometrical and dimensional, with respect to the nominal product. Concerning electronics, a precise on-spot measurement solution based solely on visual information, but without precise a priori information on the PCB testing protocols adopted during manufacturing, will be developed by Sztaki. Concerning the integration of these inspection technologies, robots will be employed and dynamically targeted to the acquisition of relevant data. The gathered data will provide the human precise information to support critical remanufacture-ability decisions.	
Task 2.2: In-process component inspection for traceability and certification	
Task leader: ZEISS	**Task Partners:** KIT, POLIMI
This task is devoted to the development of solutions for the in-line inspection of components for supporting traceability and the subsequent adaptation of the remanufacturing process plan. In remanufacturing process-chains, various decision-making points are distributed as more sub-components become observable during disassembly. Based on the target remanufacturing process-chains in the pilots, specific critical decision-making points that would benefit by rigorous data gathering and inspection will be identified. Zeiss will then explore and suggest the correct in-line quality inspection hardware, with a focus on high throughput visual inspection and spectroscopic solutions. With the support of the academic partners Polimi and KIT, the smooth integration of these technologies will be investigated and the suitable GUIs for the presentation of the acquired data to support in-line decision making by the informed human operators will be designed and implemented.	
Task 2.3: DPP data modeling for remanufacturing	
Task leader: POLIMI	**Task Partners:** APRA, SYXIS
This task elaborates on the initial outcomes and the ongoing developments of the Cirpass project to develop a first data model and support digital tool compliant with the ESPR guidelines, by grounding on the needs of the remanufacturing value-chain stakeholders. The goal is to (i) identify the set of data that are relevant for the remanufacturing factory and value-chains levels; (ii) to prepare the pilot WP6 in demonstrating the benefits that could be generated by the availability of DPP data in remanufacturing. In line with this goal, this task develops the knowledge graph, or data model, for the electronics / mechatronics components that will be remanufactured within the pilots, being the only DPP high-priority component (electronics, textile, batteries) intersecting the rEUman pilots. Based on an in-depth discussion with rEUman remanufacturers and the APRA stakeholders, a specific digital tool will be developed to support the user needs, by elaborating on the DigiPrime 3.1 service.	
Task 2.4: Data management platform design	
Task leader: SYX	**Task Partners:** Polimi
This task designs the data management platform supporting the implementation of all data-enhanced rEUman solutions. The activities will start from the collection of requirements done in WP1 including the analysis of already	

available data, and from the data modelling proposed in T2.3, to design the structure of the data management platform in a way that guarantees FAIR data management. The interoperability among digital tools and the integration with existing data sources will be considered, e.g. in PLM, ERP and MES. Connectors among IT digital tools and the platform, and among pilot data and the platform, will be designed by interested partners. Existing experience from previous projects, e.g. DigiPrime, will be discussed among partners sharing knowledge and competences in a participatory approach that will drive to a commonly shared and agreed solution.	
Task 2.5: Data management platform implementation and validation	
Task leader: SYX	**Task Partners:** ES, digital tool developers
The implementation of the data management platform will be based on the design made in Task 2.4, and needs coming from WP4 and WP5. This will allow defining the minimum viable platform (MVP). The hosting environment will be prepared by ES, then the MVP will be implemented by SYX and the connectors will be implemented by pilots and by IT partners. IT partners will cooperate in its verification and testing, checking suitability with WP4 and WP5 needs.	

Work package number	3
Work package title	**Factory-level: Human-centric remanufacturing processes**
Objectives	
The objective is to develop a set of methodologies, technologies and approaches encompassing human-centric remanufacturing processes at factory level. This will entail the support and empowering of the human operator and the interactions with automatic/robotic systems. Regeneration technologies will be investigated for electronics and mechanical products. Furthermore, methodologies will be developed to support the quality-oriented selection of components for reassembly and the certification of remanufactured products. The developed integrated set of technologies, tools and approaches will be validated at pilot scale within the individual tasks to support the final validation of remanufacturing processes within the industrial pilots in WP6.	
Description of work	
Task 3.1: Human-centric smart disassembly	
Task leader: Polimi	**Task Partners:** Sztaki, Borg, OS Splendid…
This task will focus on integrated approaches to support the operators in the execution of complex manual disassembly processes characterised by a wide variety of products and wear states. The proposed approaches will be based on a digital twin of the disassembly processes and working area taking into consideration: the characteristics and state of the products (WP2) and the related assembly/disassembly processes (T4.1), the working area (tools, fixtures, bays, etc.), and the structure of manual operations (gestures, sequences, etc.). The integrated approaches aim to monitor, support and ensure safe conditions for manual operations in remanufacturing environments; while taking advantage of data acquired on-site using low-cost cameras and other sensors. Support to the operators will be provided in the form of customised disassembly sequences and operator instructions, adapted on the specific operator, , as well as identification of possible errors (missing or uncompleted operations, wrong sequences, etc.), and warnings for potentially hazardous situations, thus increasing safety.	
Task 3.2: Worker empowerment solutions for safety and ergonomy	
Task leader: Polimi	**Task Partners:** Arcelik, OS Splendid, …
In coordination with T3.1 and T3.3, this task deals with assisting the worker with activities that cannot be fully automatised, including supporting the operators in the execution of complex manual disassembly processes and high-load, safety critical, product handling tasks. Work phases are: i) characterisation of the target activity, ii) modelling of the target activity on a simulated human to derive critical tasks and most affected human joints, iii) simulation of the effect of assistance to the most affected joints in the critical tasks given by collaborative devices (wearable or cobots), iv) implementation and test of the selected solution(s) in a controlled environment. Support will be provided to the worker in terms of fatigue relief and improved ergonomy for a safer workplace.	
Task 3.3: Collaborative disassembly solutions	
Task leader: Hepenix	**Task Partners:** Sztaki, Polimi
This task will address the use of collaborative human-robot processes for the disassembly of complex products. This solution is intended to leverage both the intrinsic flexibility and versatility of human operators, with the performance and capability of robotic/automatic operations. Based on the characteristics of the products and their associated disassembly process, and the digital twin model of the robot and the environment (WP4), collision-free robot trajectories for disassembly operations will be dynamically generated; considering the evolving status of the working environment and the action of the human operators. Visual servo-based robot control may also be necessary for individual disassembly operations.	
Task 3.4: Data-enhanced electronics regeneration	

Task leader: CR&C	**Task Partners:** Borg, KB
This task, based on the enhanced data, refer to a process of testing / repairing / refurbishing the electronics boards. The work phases are: i) go-nogo Test and Procedure, ii) troubleshooting procedure and Faulty analysis Fault Fixing, iii) predictive maintenance and refurbish, iv) final Test Bench design and production. This process involves analysing the functional specifications of the product and identifying if the electronics boards can be repaired and or refurbished instead of scrapping. The "used" electronics boards are selected based on their ability to perform their original purpose or physical attributes. If needed and possible, the electronics boards based on the enhanced data can be updated to increase their performance. Finally, these electronics boards are re-assembled into a remanufactured product that meets the required or upgraded functional specifications.	
Task 3.5: Low energy cold-spray for mechanical regeneration	
Task leader: Polimi	**Task Partners:** Borg, KB.
The task is aimed to design the cold spray process to obtain mechanical structural parts regeneration with the original or better mechanical performance proving the sustainability of the process by an affordable energy consumption and process efficiency. The activities will performed as follows: (i) collection of the cases and data from the partners, (ii) design and development of the cold spray process parameters at the Polimi EcoCirc facility, (iii) application of cold spray to preliminary samples reproducing the industrial cases for powder/substrate combination, (iv) microstructural and mechanical characterization of the cold sprayed samples, (v) analysis of the results in terms of performance, energy demand, efficiency and possible correction of the process parameters.	
Task 3.6: Dynamic function-oriented component selection and re-assembly	
Task leader: Polimi	**Task Partners:** Convergent, Hepenix
This task will develop a hardware unit for function-oriented selection and re-assembling of used components based on their functional status (WP2), rather than physical attributes or the original purpose. Functional specifications of the product will be analysed and the critical component functions will be identified. Then, based on their ability to perform those critical functions, predicted by meta-models in T4.2, the used components will be dynamically selected and re-assembled into a remanufactured product that meets the required functional specifications, supported by the intelligence of the CPS developed in T4.3.	
Task 3.7: AI for reman product certification and compliance	
Task leader: Core	**Task Partners:** Polimi
This task addresses the certification of remanufactured products based on their initial wear conditions and the results of the remanufacturing process carried out. Thus, based on the data collected and structured (WP2), the required inspections and verification tests are defined, to be executed after the remanufacturing process to assess the compliance of the product with quality standards and to certify it as remanufactured. AI will support approaches related to data analysis, the categorization of products, and the identification of correlations between the state of used products, and the results of tests and inspection procedures, with the aim at selecting the best set supporting and guaranteeing the certification and the compliance of remanufactured products.	

Work package number	4
Work package title	**Factory level: Cyber-physical and digitally-enhanced remanufacturing factory**
Objectives	
In this workpackage, the digital models and tools for achieving a cyber-physical, digitally-enhanced remanufacturing factory will be designed, developed, implemented and harmonized, based on the requirements collected in WP1 and with the objective to gather the highest benefits from the human-centric technologies developed in WP3. The digital solutions will rely on the data made available within the data management platform (WP2). The results of this workpackage will be validated in the pilots (WP6) and further developed and exploited as educational materials (WP8) for remanufacturing skill development.	
Description of work	
Task 4.1: Quality class-based, hybrid disassembly planning	
Task leader: Polimi	**Task Partners:** Sztaki, Flexis, KIT
This task develops an effective disassembly planning system to maximize the disassembly economic return by adapting the specific process plan to the quality of the incoming post-use products, observed through the inspection solutions of T2.1. The main components of the disassembly planning digital tool will be (i) a module to generate post-use part quality classes depending on the gathered data concerning the key quality characteristics measurements; (ii) a dynamic optimization kernel, able to find the optimal disassembly level and allocation of the disassembly tasks, selecting among manual, hybrid, and automatic modes, for each quality classes, exploiting the information provided by the Reverse BoM (T5.1); (iii) a GUI for optimal disassembly plan visualization to the human operator capable of implementing the best strategy on-line based on the gathered part measurements.	

<table>
<tr><td colspan="2">Task 4.2: Product and process meta-modeling</td></tr>
<tr><td>Task leader: Sztaki</td><td>Task Partners: Flexis, Polimi, Hepenix</td></tr>
<tr><td colspan="2">The task will develop combined physics-based and data-driven meta-models for supporting adaptation and control of robotics disassembly, regeneration and function-oriented re-assembly operations. Independently of the application scenarios, each meta-model will be designed to elaborate on key product-related variable measurements, combined with physics knowledge, to reconstruct simplified digital twin of the part under processing. This product meta-model will be integrated into a process digital-twin to optimize and adapt the processing strategy to the conditions of the specific part. During the use-phase, the developed parametric meta-model will take in input the specific part measurement and deliver optimized control actions to be implemented at shop floor level through CPSs.</td></tr>
<tr><td colspan="2">Task 4.3: CPS for function-oriented re-assembly</td></tr>
<tr><td>Task leader: KIT</td><td>Task Partners: Sztaki, Flexis</td></tr>
<tr><td colspan="2">This task will develop and implement cyber-physical systems for dynamically selecting the most proper set of components, both regenerated by remanufacturing and newly manufactured, to be re-assembled into remanufactured products by optimizing the capability to respect its functional requirements, identical or upgraded with respect to the equivalent new product. This strategy, called function-oriented assembly, requires (i) component clustering based on quality characteristics measurements, (ii) the meta-model of T4.2 for the definition of re-assembly functions, linking the individual component key quality characteristics with the assembled product functionality, (iii) an optimal selection strategy, to ensure balanced utilisation of the available components and practically acceptable trade-offs between regeneration rates and production logistics performance. These modules are integrated into the CPS and the proper input connections with the data management platform and output connections with a GUI for on-line interaction with the human, responsible to accept the optimal selection and activate the re-assembly process within the technology of T3.6, are developed.</td></tr>
<tr><td colspan="2">Task 4.4: Hybrid-automation remanufacturing factory modeling and simulation</td></tr>
<tr><td>Task leader: Sztaki</td><td>Task Partners: KIT, Hepenix</td></tr>
<tr><td colspan="2">Based on the disassembly plans (T4.1), the product/process models (T4.2) and the re-assembly functions (T4.3) a simulation model will be constructed and implemented to support rEUman factory (re)design. Manual, automated and collaborative disassembly and remanufacturing stations will be included in the simulation environment. Moreover, connections to the new product manufacturing resources will also be considered as possible elements in the entire remanufacturing process-chain. The tool will provide the capability to model the remanufacturing system at conceptual and material flow level, considering also use-phase-related stochastic input as delays in core supply. Once validated, the simulation will predict the integrated quality (regeneration rates) and production logistics performance of small-lot remanufacturing, including throughput, lead-time, service level and defect rates.</td></tr>
<tr><td colspan="2">Task 4.5: Hybrid-automation remanufacturing factory (re)design</td></tr>
<tr><td>Task leader: ES</td><td>Task Partners: Sztaki, KIT</td></tr>
<tr><td colspan="2">This task develops tools for the optimization of remanufacturing system re/configurations during factory re/design phases grounded on the T4.4 results. The simulation-driven digital twin and the optimization tools will provide the capability to verify and optimize the configurations against multiple user criteria. The factory’s digital model of T4.4 will be iteratively manipulated by optimization algorithms and will be evaluated by a workflow for generation of new configurations and parameter adaptation of the original model in a way that ensures the improvement of target values of the multi-criteria defined by the user. The outputs of this tool provide the list of optimal re/design actions of the remanufacturing factory that satisfy user defined target KPIs. The tool also integrates a user interface for the specification of target KPIs and the visualization of the optimal configurations.</td></tr>
<tr><td colspan="2">Task 4.6: Mid- and short-term circular production planning and control</td></tr>
<tr><td>Task leader: Flexis</td><td>Task Partners: Sztaki, KIT</td></tr>
<tr><td colspan="2">In this task short-medium term production planning / scheduling algorithms will be developed and implemented for remanufacturing factories. Due to the variability of incoming core conditions and supply, the reman planning has to be very reactive, dynamic and fast in execution. Depending on the medium-term remanufacturing demand and the availability of remanufacturing resources, the tool will manage the production plan in the short-term horizon, in order to meet specific demand in a small-lot, hybrid, remanufacturing contexts. The digital tool will be tested on a fictitious plan of orders in the five rEUman pilots before being delivered for validation in WP6.</td></tr>
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Work package number	5
Work package title	**Circular value-chain level: digital enabling solutions and business intelligence**
Objectives	

This work package aims to develop digital solutions for supporting remanufacturing at the circular value-chain level. Tasks 5.1-5.3 intend to examine the critical inputs for the development of circular supply chain for remanufacturing, and the following Tasks 5.4 - 5.7 intend to develop tools to facilitate a) analysis of efficiency and effectiveness of circular flows (operational characteristics) and b) analysis of economic viability of remanufacturing system and circular value-chain.	
Description of work	
Task 5.1: Reverse BOM and component failure prediction	
Task leader: Flexis	**Task Partners**: UBristol
In this task, a universal tool that enables the graphical modelling of the Bill of Material (BoM) of components and parts in post-use cores and their integration within remanufactured products will be developed. This makes it possible to associate the components contained in the post-use cores with the components in remanufactured products, even considering other product models that are not identical in design. Furthermore, the system enables the integration of dynamic information on inventory levels of different components, their return volumes and conditions, and expected regeneration rates. When available, in-use data considering specific component failure mechanisms and frequency will be gathered to enrich the estimation of predicted component return rates. This tool will provide inputs to the disassembly planning tool (T4.1), the production planning tool (T4.6) and the demand-supply forecasting tool (T5.4).	
Task 5.2: AI for remote/decentralized post-use product remanufacturability assessment	
Task leader: Core	**Task Partners**: Flexis, UBristol, Polimi
This task will focus on the definition and implementation of an AI system that assesses the condition of the returned products via visual means (i.e., utilizing images of the parts) directly at the point of collection, e.g. workshops or service centers. Based on the condition of the parts, the AI system will provide a recommended action, considering parts remanufacturability in terms of technical and economic aspects, thus avoiding logistics cost and environmental impacts while shipping cores to the remanufacturer that are not suitable for remanufacturing. The AI model will integrate a mechanism to adjust the influence of the feasibility aspects to the model's final recommendation. A preliminary exploration of various classical Machine Learning models that are human interpretable, such as Decision Trees for image segmentation, and more advanced AI models such as Deep CNNs will take place. State of the art AI models for image recognition/image segmentation such as Unet, PSPNet will be utilized to identify/detect relevant defects. The whole system will provide explainable means, to trigger human insights about the system's recommended decisions.	
Task 5.3: Core collection strategies and incentive schema design	
Task leader: Polimi	**Task Partners**: KIT, UBristol, Flexis
This task aims to improve current post-use product returns management through: (i) Post-use Product Source Selection, i.e. the examination and definition of the structure of the collection system and the types of involved stakeholders including independent workshops, own brand service centers, retailers and consumers through "opportunistic returns" at specific critical life-times of the in-service product; (ii) Acquisition Strategy, i.e. the analysis and definition of incentives, reward mechanisms and contractual agreements to incentivize the collection of high-quality cores already from the product sale phase; (iii) Collection Strategy, i.e. the definition of collection modes, policies, and needed infrastructure for each type of involved stakeholder. The analysis will be conducted starting from interviews with core collection stakeholders to understand the relevant pre-conditions and parameters of the designed reward mechanisms. Then, through simplified business dynamics models, the impact of alternative acquisition and collection strategies on the core return rates will be assessed. The obtained results will generate a map of potential core collection strategies and parameters depending on the maturity level, the remanufacturing context (independent or OEM), and the market position in the specific remanufacturing business case. Finally, the rEUman pilots will be analyzed to develop the most appropriate product returns management.	
Task 5.4: Circular value-stream mapping for network configuration and demand-supply forecasting	
Task leader: Simplan	**Task Partners**: Flexis, KIT, Polimi, UBristol
This task aims to develop a Circular Value Stream Mapping (CVSM) tool for remanufacturing systems and the related circular value-chain. The flow efficiency and losses will be evaluated as relevant KPIs (such as economic, logistical and production indicators) from plant to network level, thus supporting the analysis of bottlenecks in the circular factory and value-chain, both in terms of material and information flows. The circular value stream mapping tool will be used to develop (i) network configuration, identifying the best allocation of value-chain phases to different stakeholders by a mathematical programming approach, and (ii) demand-supply forecasting algorithms, by considering stochastic product life-cycle estimates and consumer willingness-to-buy scenarios.	
Task 5.5: Circular business dynamics modelling and remanufacturing strategy design	

Task leader: BRI	**Task Partners**: Polimi, APRA
This task will develop and implement multi-method modelling approach(es) for evaluating the economic viability of remanufacturing strategies and business models. The approach will integrate a business dynamics model, for stock and flow analysis, as well as agent-based models, for mimicking the decision-making process of the involved stakeholders, including consumers, value-chain industrial stakeholders. The model will integrated network configurations and demand-supply forecasting models, from T5.4, and core collection strategies, from T5.3. The developed model will support selection of appropriate remanufacturing strategies and business models for the pilots, considering evolving business context (e.g. market figures and technology developments), supply-demand dynamics, technological risks, network uncertainties, etc. The model will also allow to determine actions to reduce technical risk associated with the implementation of remanufacturing, such as cannibalization of new product sales.	

Work package number	6
Work package title	**Pilot Validation and Testing**
Objectives	
The value chain and factory level solutions will be integrated and validated within the rEUman pilots through specified use-cases. The pilots operate in three different industries: automotive, home appliances and optoelectronics. The achievement of the target KPIs and TRL of the developed technology will also be addressed, highlighting the remaining gap towards an industrial implementation and upscale of the solutions, beyond TRL 7.	
Description of work	
Task 6.1: Validation in the automotive pilots	
Task leader: BORG	**Task Partners**: KB, Flexis, Core, Zeiss, Polimi, Sztaki, Hepenix, CR&C, KIT, Simplan
The purpose of this task is to validate the applicability, the benefits and scalability of the rEUman solutions in the automotive sector, within the set-up of a large independent remanufacturer (Borg) and of a large OES (Knorr Bremse). A positive outcome would validate a mix of value chain and factory level solutions which secure a high competitiveness of remanufacturing within a mature sector in profound transition to e-mobility. The pilot will take place along the set-up of activities for new components (e-motor, inverter and e-turbos at Borg) and more traditional components (mechatronics and electronics at KB). BORG is currently selling 9 product groups and 16.000 different references, therefore it secures a validation done into a complex environment with multiple variants. The objective of the pilot is to have for each electrified platform type (MHEV, HEV, PHEV and BEV) at least one remanufactured e-motor, inverter and e-turbos. At the same time, the process should benefit from the rEUman solutions with a throughput increase from 5% to 15%, the process scrap reduced by 10%, as well as the re-engineering cost reduction of 15%. KB has an existing remanufacturing set-up for its commercial vehicle components in the EMEA region and has implemented the design for remanufacturing within the development process (PDC) leading to better remanufacturability of its products in the future.	
Task 6.3: Validation in the home appliance pilots	
Task leader: OS	**Task Partners**: Arc, Polimi, Hepenix, CR&C
This task will validate different tools developed in rEUman for remanufacturing of home appliances, with particular focus on heat pumps and refrigerators as highly strategic products for energy efficiency in Europe. This sector is not yet tackled by remanufacturing business cases, in spite of the relevance of its products being long-lasting, and of high-value. Two pilots will be validated in this sector, i.e. remanufacturing of refrigerators at Arcelik and remanufacturing of heat pumps for function restore/upgrade at Olimpia Splendid. At Arcelik, AI based component remaining life detection and image processing, collaborative robotics, wearable technologies and other software components of the rEUman solution will be validated. At Olimpia, the implementation of a AI based post-use product state modelling and remaining life definition, and the value-network configurator will be tested to increase efficiency and effectiveness of the remanufacturing process. Success criteria include decreasing disassembly and inspection time by 20%, increasing productivity by 50% and reducing operation cost by 20%. The pilot should also test a new circular business model for heat pump, evaluating real market readiness and value distribution across the value chain, with a pilot of 1000 units sold as a service.	
Task 6.3: Validation in the optoelectronics pilot	
Task leader: Convergent	**Task Partners**: Flex, Hepenix, Polimi
This task focuses on the validation of the applicability of the tools developed within the project for an optoelectronic manufacturing line of high-power laser diode. The line designed for the remanufacturing of multiemitter lasers will be implemented considering the recovery of 50-80% of the components of the two multiemitter solutions currently in production in Convergent. A prototype demonstration of a selected relevant disassembly tasks will highlight the concept of a final semiautomatic system, in which optimal mix between automation and manual stations will be identified. Reworked products will be classified according to power and	

reliability, and AI-based algorithms that combine imaging processing, measurement and working condition information will provide life prediction on the products, reworked and new, in order to ensure precise quality standards of 100% products in the new line.	
Task 6.4: Pilot KPIs continuous monitoring	
Task leader: Polimi	**Task Partners**: Sztaki
The continuous monitoring of the pilot status in view of the final validation of the target KPIs identified in WP1 is performed in this task. Two intermediate assessments of the pilots will be performed with the objective to identify the existing gaps towards the achievement of the target KPIs and the identification of improvement actions that will support the final validation (M24, M36). The identified deviations will be reported to the individual demonstration tasks to concretely implement redirection of the validation work. The final analysis of the pilots and the quantitative evaluation of the achieved target KPIs is performed in the last period and delivered at M48.	
Task 6.5: LCA/LCC/LCSA assessment of the pilot business cases	
Task leader: Polimi	**Task Partners**: APRA
In this task, the economic, environmental and social impacts of the developed rEUman solutions will be assessed through quantification of the related measures within the pilot innovative remanufacturing business cases by adopting a formal LCA (life cycle assessment), LCC (life cycle cost) and LCSA (life cycle sustainability assessment) approach. These measures will support refining the large-scale impact figures provided in Section 2.	
Task 6.6: Continuous data management platform improvement and user-oriented workflow preparation	
Task leader: Syxis	**Task Partners**: Flexis, ES
Errors and bugs, in managed data, reported during the validation experiments will be checked and solved. The needed maintenance and technical updates will be continuously carried on. Feedbacks for feature improvements will be discussed and analysed from a functional, technical, and business point of view, in order to identify additional developments which will be done by directly involving partners and will result in the creation of a new version of the platform. Moreover, ES will set-up specific user-oriented workflows integrating the individual digital tools developed at WP4 and WP5 on the basis of the initial user-stories formalized in T1.1 and further refined by the pilot users during validation activities in T6.1, T6.2, and T6.3.	

Work package number	**7**
Work package title	**Dissemination, communication, exploitation and market uptake**
Objectives	
This WP will aim to: (i) Inform, communicate and engage with the relevant stakeholders and target public concerning actions and initiatives developed in rEUman project; (ii) Successfully develop and implement the dissemination plan of the project results to the target relevant stakeholders; (iii) Define and implement a rEUman exploitation strategy, and its two enhancements (IPR and financing amendments) during the course of the project; (iv) Assure successful exploitation of validated pilot cases by defining congruent business models for each business case, matching them with viable pathways for the market uptake; (v) Initiate actions to support standardisation and legislation to ensure applicability of remanufacturing technologies; (vi) Support the market uptake of business cases and other KERs by systematic industry scouting and financing support.	
Description of work	
Task 7.1: Public Awareness, Communication and Dissemination strategy, activities, and monitoring	
Task leader: APRA	**Task Partners:** All
Design and implement the *Public Awareness, Communication and Dissemination Plan*, revising the initial identification of the stakeholders to target already started in the proposal preparation phase, and the modalities to reach and engage them to ensure a wide communication and dissemination of the project results and active involvement of the stakeholders. Brand strategy will be defined and included in the plan, as well as KPIs to assess the efficiency of proposed measures. The plan will be delivered at M6 and updated yearly to monitor the implementation steps and the achievement of the target KPIs. The visual identity of the project and the project website supporting the implementation of this plan are delivered at M4, with continuous active content editing and curation. At the last year of the project, the open access book "Towards human-centric and digitally-enhanced remanufacturing: the rEUman way" will be edited and published for wide dissemination.	
Task 7.2: Setting-up, activating and routing the exploitation processes and IPR management	
Task leader: G_MEDIA	**Task Partners**: All
Identifies the project Exploitable Results (ERs) and critically evaluates the ongoing developments of the project to understand their potentials and promising applications. For each ER, benefits, advantages compared to competitor/substitute technologies, or problem reliever (technical, environmental, economic) are identified to define the 'Value Maps'. The exploitation potential of each ER is continuously assessed against outcomes of	

market analysis and Innovation Watch. This task will also define IPR shares for each (jointly owned) ER and identifies measures for their protection and route for their capitalization.	
Task 7.3: Market analysis and business models for the innovative remanufacturing business cases	
Task leader: G_MEDIA	**Task Partners:** APRA, Polimi
This task will define and apply a strategy to valorise KERs defined in T7.2. A market analysis will be developed to include performance indicators (e.g., time required, running costs, valuation of outputs recovered) and specific target costumers/channels and goals (e.g., target prices, volumes, foreseen turnover) which are collected from WP1 and WP6 activities for each Pilot/KER. The resulting schema is exploited to strengthen the dissemination activities made through T7.1, addressing possible external adopters and to prove the rEUman market attractiveness to the consortium and to external actors. At last, the new value-chain structure, also considering the reverse logistics network architecture, will be formalized to ensure the proper value-adding infrastructure.	
Task 7.4: Support to standardisation and legislation	
Task leader: APRA	**Task Partners:** All
This task aims to provide legislative support and the initiation of standardisation activities to enable market application and uptake of enabling technologies. APRA will research and analyse relevant European and international regulatory and standardisation frameworks (e.g. ISO 26262, DIN SPEC 91472) and policies to identify areas that impact the implementation of remanufacturing technologies addressed by rEUman project. The main output will be comprehensive step-by-step screening guidelines that demonstrators will undergo in order to ensure their alignment with necessary standards and regulations. Next, based on the business models (Task 7.3) and KER's Business plans' objectives, standardisation needs will be identified. If gaps are found, appropriate strategies to handle them will be defined, including the identification of potential stakeholders. Standardization goals will be organised in the IP Methodology, Standardisation and Management Action Plan that: (i) drives the standards' implementation into demonstrators; (ii) identifies what EU and international consortia and committee (e. g. ISO, IEC) and other key alliances (e.g. Platform Industry 4.0 or Connected Factories) need to be addressed; (iii) draws a plan of actions to actively contribute to the standardisation discussion in the field of manufacturing, IT and interoperability characterisation. This action will provide each KER with a *Completion Toolsets* containing recommendations to contribute to standardisation processes, in synergy with CEN-CENELEC.	
Task 7.5: Scouting of market uptake opportunities and financing	
Task leader: G_MEDIA	**Task Partners:** All
Potential industry absorption and financing opportunities will be identified and aligned with the exploitation activities within a Market Uptake and Financing Action Plan. As a task leader G_MEDIA will facilitate this process by scouting a mix of industry financing opportunities and supporting the integration of the enabling remanufacturing technologies (KERs) with a clear objective of ensuring their wide market uptake. One specialised scouting event will be organised at the last year of the project to support scouting activities among target actors: industries, technology brokers, intermediaries and service providers; with a target to attract at least 7 participants at each. Specific support materials will be prepared to support scouting and financing opportunities, to facilitate dissemination and promote project results. Two workshops will be organized during the last year to assure a wide participation of different investors (brand providers, business angels, innovation brokers, large enterprises/brand owners, TT funds and other VC funds, banks; total at least 10 each).	

Work package number	8
Work package title	**Training and skill development**
Objectives	
This WP: 1) Identifies the existing skill gaps and key requirements that are highly relevant in remanufacturing; 2) Specifies and designs delivery platforms, training material formats and methodologies for training and skills development; 3) Develops and delivers specific training modules consisting of presentations, videos, self-assessment tools and questionnaires; 4) Sets-up and launches an academy for future exploiters the core skills and competences needed for the uptake of the solutions developed in the project. 5) Organizes and promotes events to foster new business cases in different eco-systems; 6) Assesses the effectiveness of knowledge transfer by gamification of the basic training with stealth assessment, in order to collect data in problem-solving environments.	
Description of work	
T8.1: Formalization of remanufacturing skills and existing gaps	
Task leader: POLIMI	**Task Partners:** ES, Sztaki, APRA
The identification of relevant skills for remanufacturing will build upon an integrated set of desk analysis and company-based activities, incorporating the intermediate results from WP1, WP3-WP5. As this task provides the basis for T8.2, the desk research will include a value-chain-driven analysis concerning the professional profiles	

correlated to the technical functions involved in remanufacturing processes. The analysis shall also review the existing skills descriptors/repositories at (i) company level; (ii) national/regional VET and HE systems; (iii) other market qualifications training. The identification of existing gaps and the development of the relevant training actions in T8.2 will be associated to three main type of actions: (i) Staff reskilling; (ii)Upskilling of existing technical functions; (iii). New/highly qualified profiles to be recruited, if any emerge. The desk research will be complemented and validated by interviews in pilots' facilities. To ensure the transferability to other value chains and training systems, the remanufacturing skills related to each professional profile will be described according to EQF, ECVET and relevant national/regional systems.	
T8.2: Design of the rEUman training program	
Task leader: ES	**Task Partners**: BORG, Olympia splendid, Arcelik, Knorr Bremse, Convergent
The aim of the task is to develop a reference model, namely a blueprint for the acquisition of remanufacturing skills for circular value chains in technical training programs with an industry-driven approach. According to the input provided by the T8.1, a detailed training plan for a representative number of value chains (automotive, white goods, opto-electronics) will be developed. The program will be based on a set of flexible training modules to support the acquisition of new skills by the widest possible numbers of participants according to the specific working context. It will include (i) the definition of methodologies and learning systems (eg. identification of LMS, compliant with both SCORM and AICC standards for eLearning content); (ii) a monitoring approach; (iii)KPIs; and (iv) resources definition (eg. trainers, locations, costs). The training program will consider short term needs as well as a long-term exploitation strategy beyond the project duration.	
T8.3: Preparation of training modules and support material	
Task leader: ES	**Task Partners:** APRA, rEUman Solution developers, Pilots
This task will define the training modules to be delivered and validated by pilot partners as well as representative companies in automotive, white goods and home appliances industries. The training modules will target (i) transversal applicabilaty to any sector/value chain implementing/using rEUman solutions/results; and (ii) industry-specific training modules. Training modules shall be designed and adapted to the target audience (i.e. company workers, pilot staff, students, and professionals) and include a diverse range of learning tools, eg. presentations, videos, apps, self-assessment tools and questionnaires. To facilitate training recognition beyond project boundaries, a digital badges system will be defined; train-the-trainer activities will be implemented.	
T8.4: Design and launch of the APRA Academy for future remanufacturing skills and jobs	
Task leader: APRA	**Task Partners:** Polimi
The automotive remanufacturing industry suffers, as many other industries in Europe, from the difficulty in attracting talents to drive the transition towards digitally-enhanced remanufacturing factories and value-chains. Within this task, APRA will design and set-up the new APRA Remanufacturing Academy fostering the training of future automotive remanufacturing workforce towards the adoption of the rEUman innovation. The training modules and support materials prepared in T8.3 will be integrated into an education program for the duration of 3 weeks followed by 1 week of final hands-on activities for group project development carried out within the Eco-Circ lab at Polimi. The first three weeks will entail on-line lectures carried out by the rEUman technologies and tool developers, integrated with specific industrial problem presentations by the APRA associates. The participants will be selected on the basis of candidatures, with priority given to the APRA associates. Two editions of the APRA Remanufacturing Academy will be carried out during the project life-time, at M33 and M45.	
T8.5: Skills boosters: Summer school, RemanMasterClasses, ReEUmanuthon, RemanChallenge.	
Task leader: ES	**Task Partners**: Polimi, KIT, Bristol, Sztaki Borg, APRA
The task aims to integrate the rEUman training program with nonformal/informal learning activities, thus adopting multi-sided approaches to the development of remanufacturing skills in different eco-systems by a wider range of target groups. The activities include: (i) a joint international Summer School for engineering master students, to be organized by Polimi in cooperation with the Idea League network and the APRA Europe academic members; (ii) RemanMasterClasses, to be organized by Borg, targeting students from different value chains and companies size; (iii) the ReEUmanuthon, to be organized by ES and Polimi with the Italian Cluster for Intelligent Factories - CFI, a hybrid hackhaton dedicated to remanufacturing (applying a 5-steps design thinking process validated by two EIT communities); (iv) the RemanChallenge, to be organized by Borg, to develop cooperation skills internal to a value chain by competition among multiple value chains through challenges to be solved. A gender perspective will be transversally applied to the whole task's activities, by involving at least 40% female participants.	
T8.6: Gamification for next generation remanufacturers	
Task leader: G-Media	**Task Partners:** APRA
In this task G-Media will develop a gamification platform to support the knowledge acquisition. The gaming solution will provide meaningful contexts, which will help participants engage into their future roles. In order to	

develop a suitable transformation itinerary, a multi-purpose gaming concept will be developed in the gamification platform to facilitate the adoption of new technologies. Particularly, the gamification will be used to enable participants to imagine future market situations and their respective roles and would be adaptable to grow through the process of the exploitation of technologies and, potentially, other projects emerging from rEUman project. The development of the platform will begin with designing learning paths, contents and objectives. Contents of the training will be delivered through realistic case-studies in order to enable users to engage with real-world challenges. Each step of the training will focus on supporting the engagement of learners with each of the learning objectives using simulation gamification dynamics. Progress within the e-learning platform will be evaluated based upon an evaluation model using criteria congruent with rEUman project objectives.

Work package number	WP9
Work package title	**Project Management**

Objectives

Establish the proper communications channels and set-up the necessary control infrastructure providing adequate project management through the lifespan of this project. Sub-objectives: (i) monitor, track and supervise the progress on the project WPs; (ii) control deviations that may arise during the lifespan of the project; (iii) manage the overall project according to approved plans, (iv) ensure that the required reporting documents are prepared and presented on time and according to the established format; (v) implement procedures for risk management, (vi) prepare and arrange Steering Board meetings, (vii) supervise the management of Consortium Agreement (CA) and IPR, (viii) coordinate the creation of the project external boards.

Description of work

Task 9.1: Governance structure, communication flow and methods.

Task leader: POLIMI | **Task Partners:** All partners

Takes care of creating and updating the Project Handbook containing necessary information to run the project on a day-by-day basis and administrates the project eRoom integrated with the project website (T9.1), used for sharing documents among project partners. It will plan and arrange common project meetings and define and implement quality procedures for handling of project's quality issues, following the "Good research practice".

Task 9.2: Overall coordination.

Task leader: POLIMI | **Task Partners:** All partners

Guarantees financial, legal, administrative and technical management of the project. Actions: (i) address and coordinate activities for the implementation of project workplan; (ii) supervise technical developments and monitor the technical achievements, including IPR management; (iii) guarantee the quality of deliverables and results; (iv) monitor and control expenditures; (vi) organise and coordinate periodic reporting; (vii) facilitate communication within consortium members and towards the Commission; (viii) manage unexpected events and support the cooperative identification of solutions; (ix) prepare and update a data management plan.

Task 9.3: Risk management.

Task leader: KIT | **Task Partners:** All partners

Building upon the risk identification and management table reported in this project proposal, this task is aimed at elaborating and constantly updating a detailed and comprehensive risk management plan. The logic behind this task is to ensure the timely identification and management of potential risks that may arise during project realization. The risk management plan will be updated periodically. The Risk Manager will be leading this process.

Table 3.1c: List of deliverables.

N°	Deliverable name	Short description	Lead	Type	Task	Diss.	Date
D1.1	Analysis of pilots and related KPIs	As-is and to-be situations of the pilots. Target KPIs and mechanisms for validation.	Borg	R	T1.1	SEN	M6
D1.2	Available data in factory and value-chain stages	Map of data stored in different pilot IT systems, at factory and value-chain levels.	Syxis	R	T1.2	SEN	M6
D1.3	Requirements of the rEUman solutions	Requirements and technical specifications of rEUman solutions for pilot demonstration.	KIT	R	T1.3	SEN	M9
D1.4	Generalisation to future industrial scenarios	Analysis of European sectors for future uptake of the rEUman solution.	KIT	R	T1.4	PU	M18
D2.1	Pre-process and in-process data gathering solutions	Design, development, validation of pre- and in-process data gathering solutions.	Zeiss	R + DEM	T2.1 T2.2	SEN	M18
D2.2	DPP data models for remanufacturing	DPP data model and tool for transferring data relevant for electronics remanufacturing	Polimi	R+O	T2.3	PU	M18
D2.3	Data management platform for remanufacturing	rEUman data management and digital tool integration platform design and prototyping	Syxis	R+O	T2.4 T2.5	PU	M24
D3.1	Monitoring, support, and empowerment of human operators	Development, validation of human empowerment, smart and collaborative disassembly solutions for	Polimi	R+ DEM	T3.1 T3.2	SEN	M18

	in disassembly	remanufacturing			T3.3		
D3.2	Data-enhanced regeneration technologies for reman and re-assembly	Development, validation of electronics and mechanical components remanufacturing and function-oriented re-assembly solutions.	CR&C	R+ DEM	T3.4 T3.5 T3.6	SEN	M24
D3.3	AI for reman product certification & compliance	Development, prototyping of the AI-based remanufactured product certification system.	Core	R+O	T3.7	SEN	M24
D4.1	Quality class-based disassembly and function-oriented reassembly	Digital tools for disassembly process adaptation to variable core quality and CPS for function-oriented re-assembly.	Polimi	R+O	T4.1 T4.2 T4.3	SEN	M24
D4.2	Simulation and (re)design of hybrid-automation remanufacturing factory	Development, validation of hybrid reman factory simulation models and integration in multi-objective optimization for (re)design.	Sztaki	R+O	T4.4 T4.5	SEN	M30
D4.3	Circular production planning	Development, validation of mid and short term production planning algorithms.	Flexis	R+O	T4.6	SEN	M30
D5.1	Reverse BoM and AI-based decentralized assessment core conditions.	Development, validation of reverse BoM and AI-based remote core characterization for remanufacturing.	Core	R+O	T5.1 T5.2	SEN	M24
D5.2	Core collection strategies and incentive schema.	Proposal and validation of incentive schema for core-collection improvement in pilots.	Polimi	R	T5.3	PU	M30
D5.3	Business modeling and reman strategy design	Development, validation of CVSM and business dynamics tool for reman strategy.	UBristol	R+O	T5.4 T5.5	PU	M30
D6.1	"Automotive pilot " validation	Description of the pilot validations and KPIs analysis in Borg and Knorr Bremese pilots.	BORG	R+ DEM	T6.1	SEN	M48
D6.2	"Home appliance pilot" validation	Description of the pilot validations and KPIs analysis in Arcelik and Olimpia pilots.	OS	R+ DEM	T6.2	SEN	M48
D6.3	"Opto-electronics pilot" validation	Description of the pilot validations and KPIs analysis in Convergent Photonics pilot	Conv	R+ DEM	T6.3	SEN	M48
D6.4	Progress status of the pilots and KPIs assessment.	Report of the dynamic KPIs assessment along the project life-time and formalization of the countermeasures for improvement.	Polimi	R	T6.4 T6.5	PU	M24 M36M 48
D6.5	Data Management Platform upgrades and final release.	Data management testing report and final release. User-driven workflows for uptake.	Syxis	R+ DEM	T6.6	SEN	M48
D7.1	Public Awareness, Communication and Dissemination Plan	Public Awareness, Communication and Dissemination Plan design, development and monitoring. Web-site and visual identity.	APRA	R+O	T7.1	PU	M: 6,18, 36, 48
D7.2	Exploitation Roadmap Portfolio and IP Audit	Report identifying the project Exploitable Results (ERs) and their exploitation routes towards market uptake. IPR agreements.	G_Media	R	T7.2	SEN	M18M 36M48
D7.3	Market, business, logistics analyses summary report	Market analysis and business models for the innovative pilot business cases.	G_Media	R	T7.3	SEN	M36 M48
D7.4	Standardization and legislation recommendations	Identification of KERs standardization opportunities and legislation boundaries.	APRA	R	T7.4	PU	M36M 48
D7.5	Market Uptake and Financing Action Plan	Report of the market uptake routes for the KERs and analysis of financial instruments.	G_Media	R	T7.5	PU	M48
D8.1	Professional profiles	Identification of reman skills and gaps.	Polimi	R	T8.1	PU	M18
D8.2	rEUman Training program	Detailed training plan for remanufacturing.	ES	R	T8.2	PU	M24
D8.3	Validated training modules and tools	Prepared training materials and modules supporting the training plan of T8.2.	ES	R+O	T8.3	PU	M36
D8.4	Remanufacturing Academy	Reports from two editions of the novel APRA Remanufacturing Academy.	APRA	R+O	T8.4	PU	M36 M48
D8.5	Skills boosters activity report	Report on RemanMasterClasses, ReEUmanuthon, RemanChallenge	ES	R	T8.5	PU	M48
D8.6	rEUman Gamification approach	Design, validation of gamification approach and tools for next-gen remanufacturers.	G-Media	R+O	T8.6	PU	M48
D9.1	Quality Assurance Plan (QAP)	Project handbook and quality assurance plan.	POLIMI	R	T9.1	SEN	M2
D9.2	Data Management Plan (DMP)	Part of the T9.2 activities, elaborates data security, accessibility and reproducibility within the rEUman framework.	POLIMI	R	T9.2	SEN	M: 6,18, 36, 48
D9.3	Risk Management Plan (RMP)	Project risk identification and management methodology and periodic report.	KIT	R	T9.3	SEN	M:18, 36,48

Table 3.1d: List of milestones.

MS No.	Milestone name	WP	Due Date	Means of verification
MS1	Pilot requirements and target KPIs.	1	M6	D1.1
MS2	Specifications and use-scenarios for the rEUman solutions.	1	M9	D1.3
MS3	Pre-process and in-process data gathering solutions.	2	M18	D2.1
MS4	Data management platform for remanufacturing, MVP.	2	M24	D2.3
MS5	Human-centric factory level disassembly technologies	3	M18	D3.1

MS6	Human-centric factory level remanufacturing technologies	3	M24	D3.2, D3.3
MS7	CPS for function-oriented re-assembly	4	M24	D4.1
MS8	Circular factory (re)design and planning tools	4	M30	D4.2, D4.3
MS9	AI-based remote core characterization	5	M24	D5.1
MS10	Core collection strategies by incentives and rewards	5	M30	D5.2
MS11	Intermediate report of pilot validation and KPIs monitoring	6	M36	D6.4
MS12	Final report of pilot validation and KPIs monitoring	6	M48	D6.1, D6.2, D6.3
MS13	rEUman platform final release	6	M48	D6.5
MS14	Exploitation Roadmap Portfolio – final version	7	M48	D7.2
MS15	Standardization and legislation recommendations	7	M36	D7.4
MS16	Validated training modules and tools	8	M36	D8.3
MS17	Skill booster activities, APRA academy, and gamification	8	M48	D8.4, D8.5, D8.6

The project will implement a risk management process (T9.3). Risks (Table 3.1e) are analysed according to their likelihood (L) and the level of their seriousness/impact (S) and graded from A to E, with decreasing harm.

Table 3.1e: Critical risks for implementation and risk-mitigation measures: preliminary analysis

Risk	WP	Grade		Actions to prevent/manage (risk mitigation measures)
Organizational - project management				
Socio-cultural risks. Collaboration among multidisciplinary partners can be critical if process modules are inter-dependent and interfaces are not well defined.	9	S=Med L=Med	C	Project monitoring and control is intended as a continuous process, facilitating the interface between WPs; specifications changes will be made visible to all the technical WPs by demo leaders.
Technological				
Requirements and KPIs. Incomplete identification of KPIs before the development of solutions and pilots may lead to misalignment with respect to market needs.	1	S=Med L=High	B	After the definition of requirements in WP1, a critical analysis will be carried out by partners in charge of solutions development and, if needed, requirements will be better characterised before the solution development.
Poor DPP data exchange ad integrability. The digital tools development may result in delivered outputs which can be poorly integrated in the data management platform.	2	S=High L=Med	B	Cross WPs periodic sync calls and online development tracking tools will ensure that all the IT partners will share and cross-validates their technical choices as data formats and input/output protocols and APIs.
Poor throughput of in-process inspection technologies. The vision-based solutions for reman product are too slow.	2	S=High L=Low	C	The developed vision-based systems for in-process inspection will be tested at lab scale on the provided industrial samples within the Zeiss laboratory at KIT.
Poor performance of CPS for re-assembly. The control presents sources of error caused by poor data quality.	3,4	S=Mid L=Med	D	Multi-sensorial data acquisition equipment, redundancy and multiplication of the products inspection will mitigate the risk of poor input data quality.
Poor acceptability of human-centric reman solutions. The developed human-centric technologies are poorly accepted by reman workforce, used to work without support tools.	3	S=High L=Med	B	The future users of human-centric solutions for disassembly will be involved since the initial design phase and feedback collection will let usability problems emerge.
Poor robustness of the AI methods. The decentralized core classification tool fails in supporting decision making on remanufacturability of cores, thus reducing regeneration rates.	5	S=Med L=Med	C	During the validation phase, potential situations of wrong classification of cores will be recorded and used to understand the AI failures and identifying actions to increase their robustness in critical conditions.
Implementation and validation of project results				
Limited pilot implementation possibilities: timing. Slowdown of earlier WPs force WP6 activities starvation because of no input results available.	6	S=Med. L=Low	D	The effective project management and coordination between WPs ensured by WP9 structure mitigates the risk of intermediate results late achievement.
Results exploitation				
Insufficient participation of end-users in definition of specifications. Poorly defined specifications will lower the possibility to obtain results which meet market standards.	1	S=High L=Low.	C	The importance of T1.3 will be raised at consortium level. Products specifications will be constantly monitored and updated, also after the end of WP1, to ensure that each project intermediate activity is made in function of clear specifications.

For the rEUman project the consortium requests co-funding of 7.000.000 €. The highest volume fraction of the mobilized resources will be due to personnel costs (86%). The remaining fraction is dedicated to travels, equipment and goods and services. A negligible budget is for subcontracting costs, highlighting the consortium completeness in terms of technical capabilities. In terms of budget distribution, there is a predominance of budget dedicated to SME's and the IND's (63%), followed by RTDs (35%) and associations (2%). WP6 (demo) has budget predominance.

Table 3.1f: Summary of staff effort – MMs per participant.

Short name of participant **Work package**	POLIMI	KIT	SZTAKI	BRI	FLEX	SIM	BORG	CPI	HEPENIX	KB	ARC	OLIMPIA	SYXIS	ES	APRA	CONV	CORE	G-Media	CR&C	ZEISS	MMs
WP1	5	10	7	2	6	1	1	1	6	4	4	3	7	2	0.5	3	3	0	0	4	69.5
WP2	5	12	7	0	0	0	0	1	4	1	0	3	20	2	0	3	4	0	0	12	74
WP3	43.5	0	16	0	0	0	3	3	34	2	2	2	0	2	0	12	22	0	16	0	157.5
WP4	17.5	24	32	0	11	8	2	1	25	4	6	1	0	18	0	5.5	4	0	0	0	159
WP5	9	0	3	15.5	22	19	1	3	3	2	6	4	0	2	0.5	2	22	0	0	0	114
WP6	20	4	10	3	8	10	21	10	16	0	20	14	10	3	0	12	9	0	9	6	185
WP7	5	4	5	4	3	2	0	1	3	8	3	2	4	2	5	0.5	4	30	1	0	86.5
WP8	5	0	4	4	2	0	2	3	2	1	0	3	3	28	2.5	3	0	10	1	0	73.5
WP9	32	6	2.5	2	2	0	1	1	4	2	1	2	1	1	0.5	1	1	1	1	1	63
Total	**142**	**60**	**86.5**	**30.5**	**54**	**40**	**31**	**24**	**97**	**24**	**42**	**34**	**45**	**60**	**9**	**42**	**69**	**41**	**28**	**23**	**982**

Table 3.1g: 'Subcontracting costs' items.

Partner 18. G.Media	**Cost (€)**	**Justification**	**Total: €20.000**
Subcontracting	20.000	Part of programming work for gamification	

Table 3.1h: 'Purchase costs' items (travel and subsistence, equipment and other goods, works and services).

Partner Arcelik	Cost (€)	Justification	Total: €53.000
Travel	15.000	7 Consortium and Review Meeting Attendance, 2 People/Each Travel, 1.000 € Each Travel (Transport, Accommodation, Subsistence): 14.000 € 1 Conference Attendance, 1 Person/Each Travel, 1.000 € Each Travel (Transport, Accommodation, Subsistence): 15.000 €	
Equipment	32.000	1 x Industrial High Resolution Camera (2.000 € each): 4 years deprecation time, these equipment will be used for 2 years = 1 x 2.000 x (2 / 4) = 1.000 €. 1 x Collaborative Robot (40.000 €): 5 years deprecation time, these equipment will be used for 2,5 years = 1 x 40.000 x (2,5 / 5) = 20.000 €. Long Performance Unit Hardware for Functional Test Including Temperature and Power Measurement Modules (20.000 €): 4 years. deprecation time, these equipment will be used for 2 years = 1 x 20.000 x (2 / 4) = 10.000 €. 1 x PC for Long Performance Unit (2.000 €): 4 years deprecation time, these equipment will be used for 2 years = 1 x 2.000 x (2 / 4) = 1.000 €	
OG&S	6.000	Electronic Consumables (Cable, Thermocouple etc): 3.000 €. Conveyor Protoyping Materials: 3.000 €	
Partner Convergent	**Cost (€)**	**Justification**	**Total: €71.200**
Travel	12.000	12000 Euro travel cost (7 project meetings for 2 persons + 5 dissemination events).	
Equipment	19.200	1 x Industrial thermal Imaging Camera (18000€), used for 2.5yaers within the project (x 2.5/6) = 0.4 x 18000€ = 7200€. 1 x industrial lenses for Imaging Camera (20000€) = used for 2.5years within the project = 0.4 x 20000€ = 8000. 1 x abration laser system for disassembly collaborative robot (20000€) = used for 1year within the project (0.2) = 0.2 x20000€ = 4000€	
OG&S	40.000	Packages and modules for destructive tests. Assembly material consumable (optics, carrier submounts, fiber connectors)	
Partner CR&C	**Cost (€)**	**Justification**	**Total: €117.000**
Travel	17.000	22500 Euro travel cost (7 project meetings for 2 persons + dissemination events).	
OG&S	100.000	Test Bench for Measurement and repair	

3.2 Capacity of participants and consortium as a whole

The rEUman consortium's members have been selected to combine suitable S&T knowledge, industrial background, as well as capability to commercially exploit the outputs of this project, thus unlocking the human-centric, data-enhanced remanufacturing solution at factory and value-chain levels. The rEUman consortium groups 20 European organizations, 6 large companies, 9 SMEs, 4 research centres and universities and 1 leading association in the remanufacturing business, representing more than 150 companies in Europe. The consortium has the expertise (Table 3.2a) needed to develop, implement and validate the rEUman solutions in 3 target European sectors.

Table 3.2a Competence matrix of the rEUman consortium.

Competences	WP	POLIMI	KIT	SZTAKI	BRI	FLEX	SIM	BORG	CPI	ARC	APRA	CONV	HEPENIX	OLIMPIA	KB	SYXIS	ES	CR&C	CORE	ZEISS	G-Media
IT platform requirement formalization	1		■										■			■	■			■	
Data gathering and processing	2									■						■			■	■	
In-process and post-process inspection	2	■	■	■															■	■	
Digital Product Passport	2	■														■					
Disassembly process planning	3	■	■	■		■		■	■						■						
Artificial Intelligence technologies	3		■	■						■			■				■		■		
Human-centric disassembly	3	■		■				■		■			■								
Worker empowerment solution	3	■																			
Electronics remanufacturing	3														■			■		■	
Cold spray	3	■																			
Function-oriented assembly	3	■	■										■				■	■			
Development of cyber physical systems	4	■	■	■		■							■				■				
Simulation and factory modelling	4	■		■		■	■			■			■								
Production Planning and control	4	■	■	■		■	■						■								
Core management	5		■		■		■														
Reverse BoM	5		■		■	■	■												■		
Post-use product characterization	5	■		■	■	■														■	
Reverse network design	5				■	■	■														
Value-Stream Mapping	5		■	■	■	■	■														
Business Dynamics and reman strategy	5	■			■						■										
Digital services integration	6															■	■				
Dissemination	7	■	■		■	■					■						■		■		■
Exploitation and business uptake	7	■	■		■	■		■	■	■	■	■		■	■				■		■
Skill and competence mapping	8	■	■														■				
Learning module organization	8	■	■	■							■						■				■

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