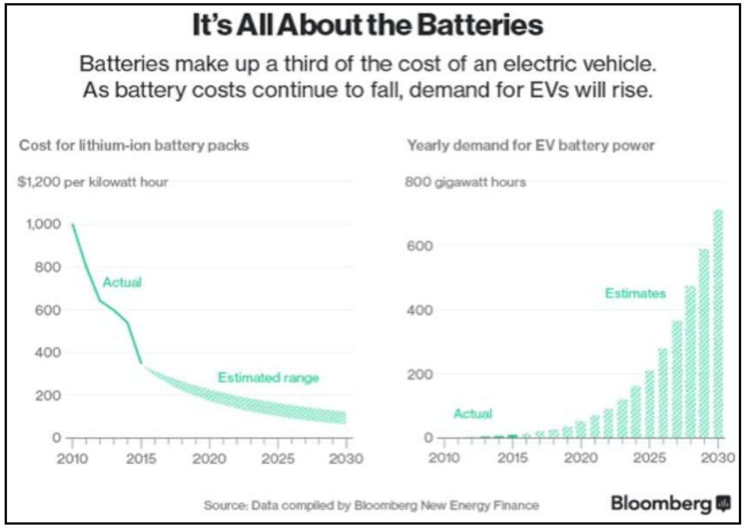
POLITECNICO
MILANO 1863

Inter-Departmental laboratory CIRC-eV

Circular Factory for the Electrified Vehicles of the Future

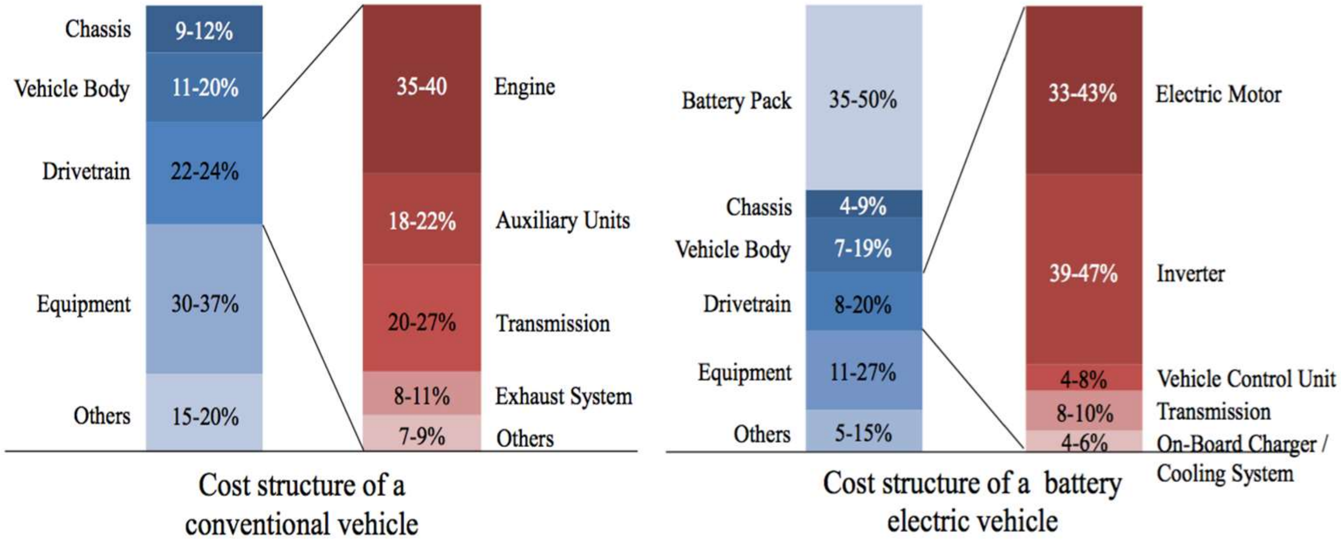
Macro-challenge: e-mobility Li-Ion batteries remanufacturing

Cost. The real take-off for EVs will happen from the second half of the 2020s when electric cars become cheaper to own than ICE models. Manufacturing improvements, also for battery energy density, are set to cause a further fall of more than 70% by 2030.



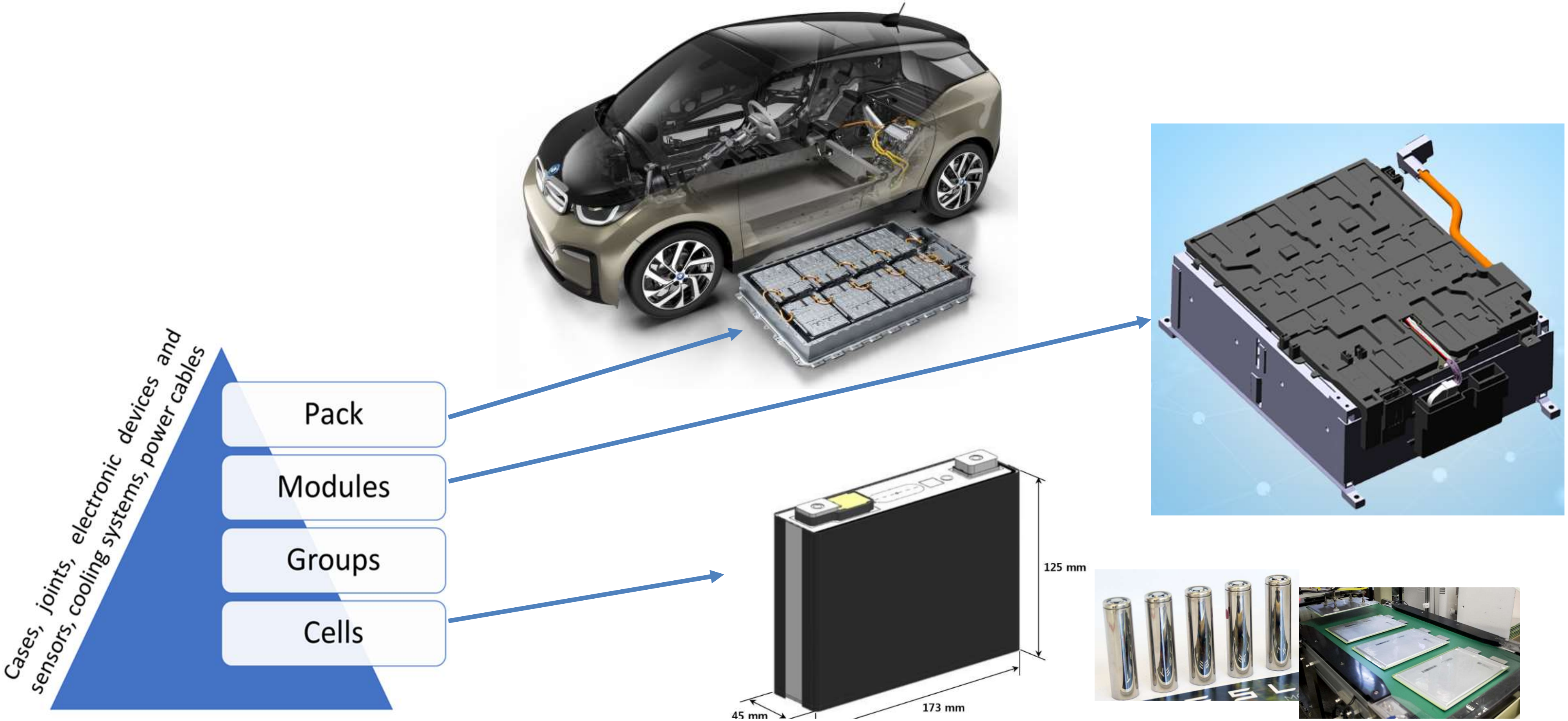
Cost structure of conventional ICEVs and EVs. Main differences:

- Battery Pack
- Drivetrain



Macro-challenge and opportunity: modular architecture

Automotive **Li-Ion battery packs have a modular architecture** where the final power and capacity are reached by the parallel and series connection of Li-Ion cells.



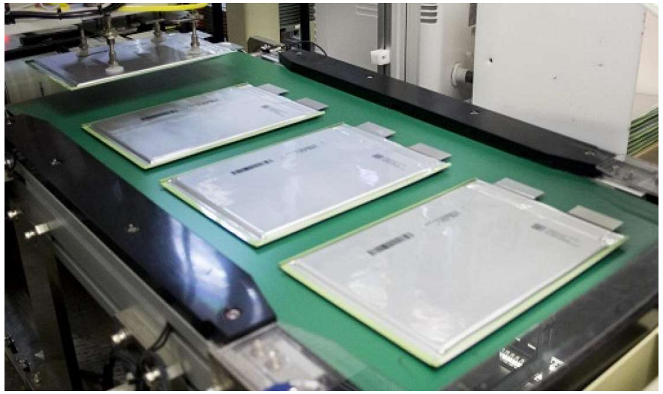
Macro-challenge: Variability in design

Substantial **differences in the design** of battery modules of different car manufacturers and availability of different types of joints within the same battery make the disassembly phase complex and challenging.

TYPE OF CELLS

Cylindrical

Prismatic

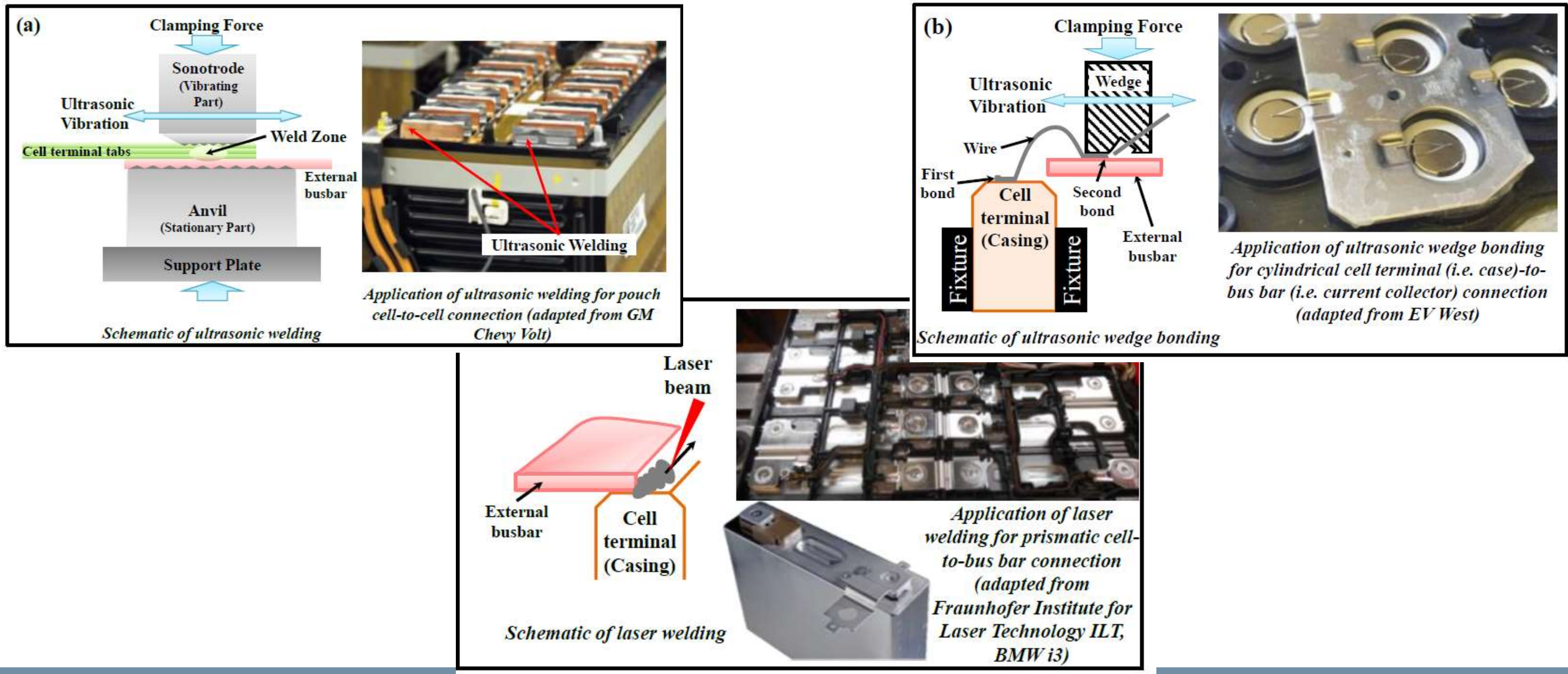


Pouch

Challenges in the disassembly of EV battery modules: different type of joints

Substantial **differences in the design** of battery modules of different car manufacturers and availability of different types of joints within the same make the disassembly phase complex and challenging. Moreover, different disassembly strategies affect the reassembly feasibility and easiness.

TYPE OF WELDING



Schematic of ultrasonic welding

Application of ultrasonic welding for pouch cell-to-cell connection (adapted from GM Chevy Volt)

Schematic of ultrasonic wedge bonding

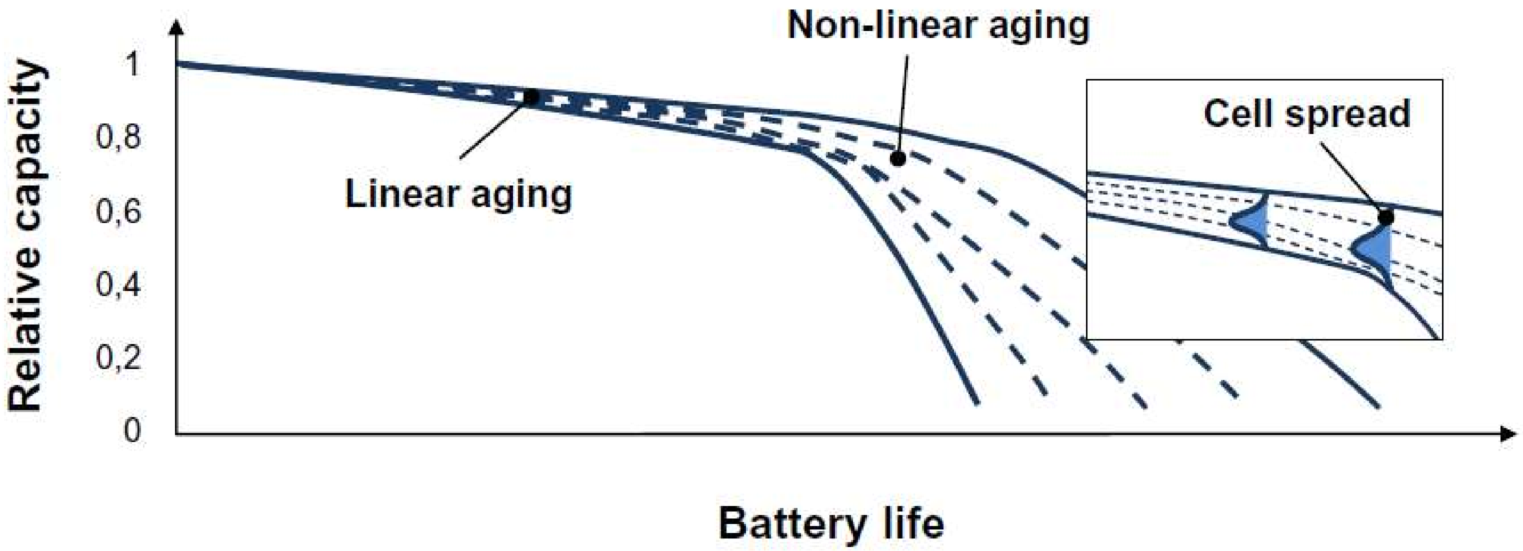
Application of ultrasonic wedge bonding for cylindrical cell terminal (i.e. case)-to-bus bar (i.e. current collector) connection (adapted from EV West)

Schematic of laser welding

Application of laser welding for prismatic cell-to-bus bar connection (adapted from Fraunhofer Institute for Laser Technology ILT, BMW i3)

Macro-challenge: degradation

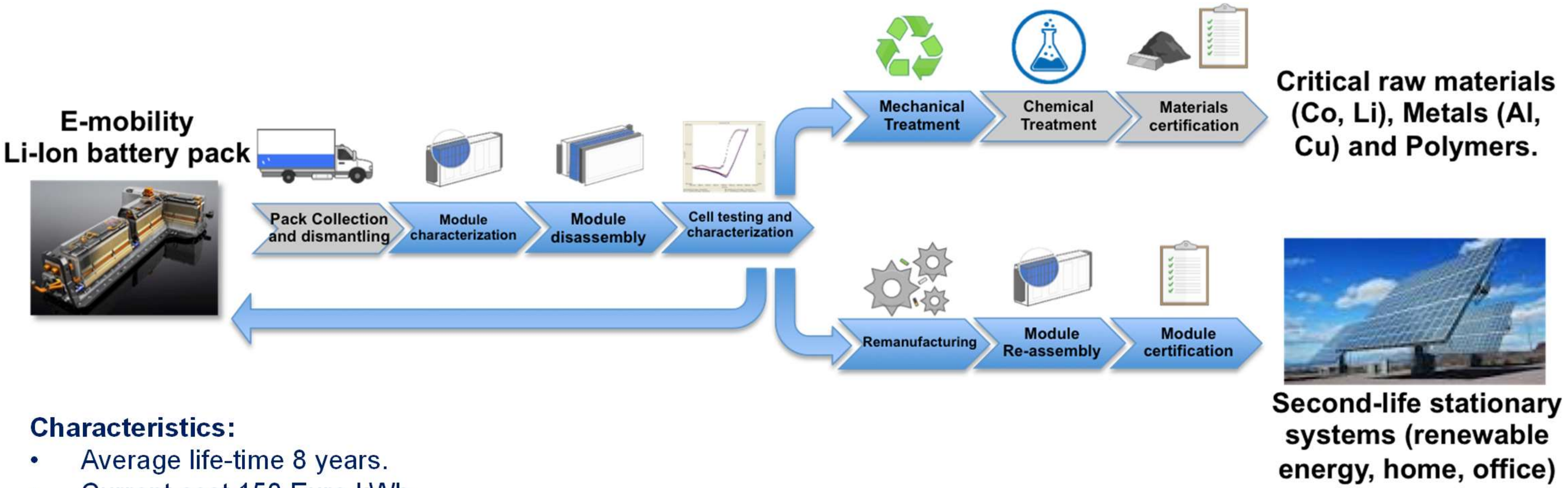
Unavoidable chemical and physical degradation of the cells forces battery packs to a performance fade over time (Palacin and de Guibert, 2016). **EVs battery packs have an average lifespan of 8 to 10 years** (DeRousseau et al., 2017), during which their **actual capacity goes below the 80% of the initial one**, established performance threshold for pack substitution.



Single cells undergo an **unbalanced electrochemical degradation over time** (Rohr et al., 2017). When the automotive pack is retired, each cell has a unique state-of-health.

Target objective of CIRC-eV

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

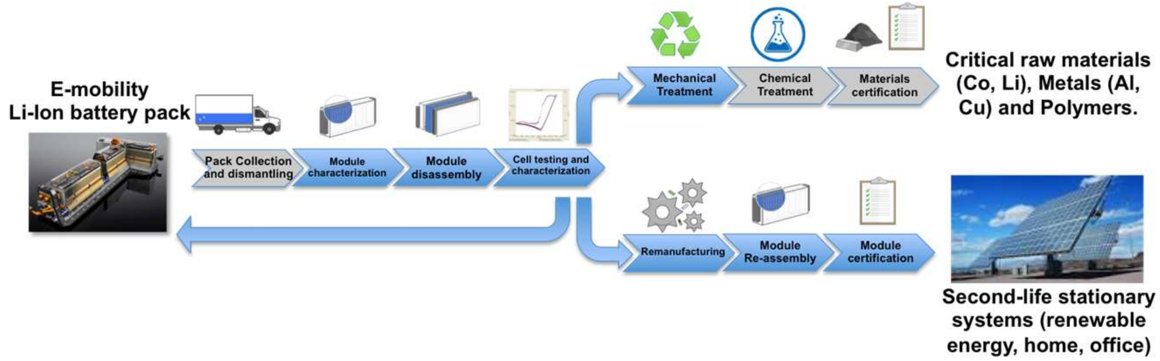


Characteristics:

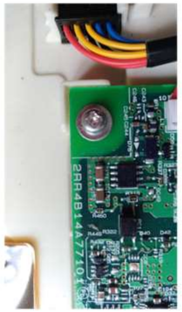
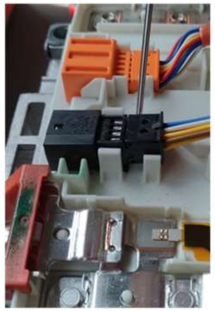
- Average life-time 8 years.
- Current cost 150 Euro kWh.
- Residual capacity >80% (24 kWh on average).
- Warranty for manufacturers usually for 5 years (e.g. Tesla, Nissan).

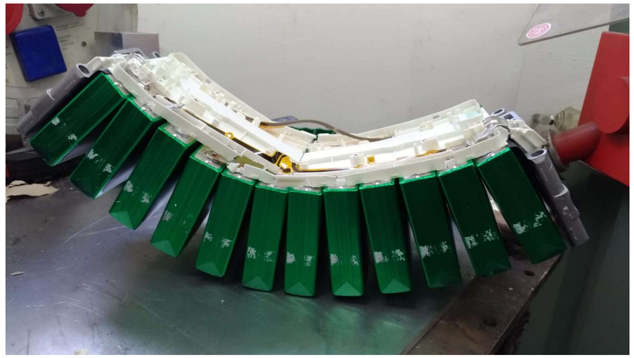
Activities of CIRC-eV: flexible disassembly technologies and systems

Design and development of a safe and cost-effective battery cells disassembly process and system, with the required level of flexibility, enabling to handle a large variety of battery designs.



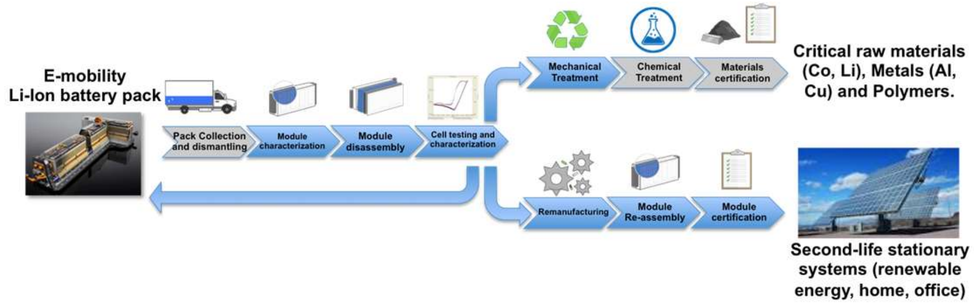
VW eGOLF EXAMPLE: screws, plugs, pins, rivets, etc.

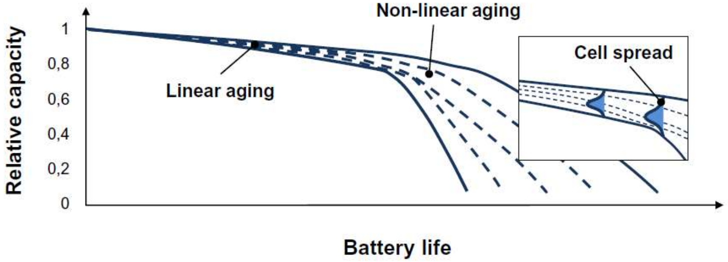




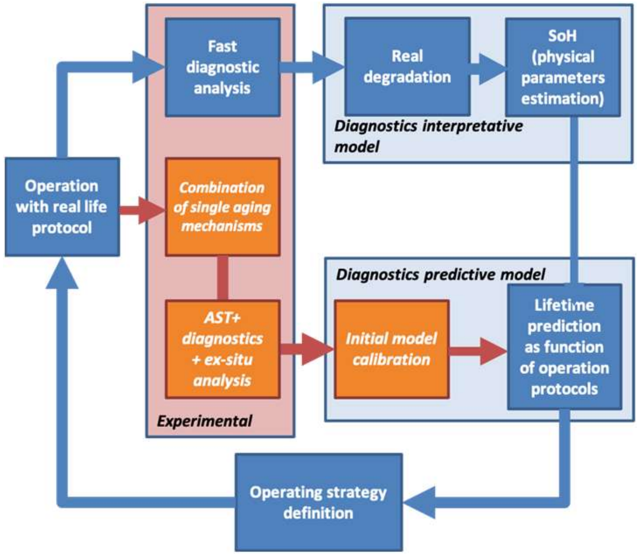



Activities of CIRC-eV: battery testing and chartacterisation

Definition of methods and procedures to estimate the State of Health (SoH) and characterize the degradation modes and the residual useful life of battery cells to enable their application in second-life modules with certified performance.

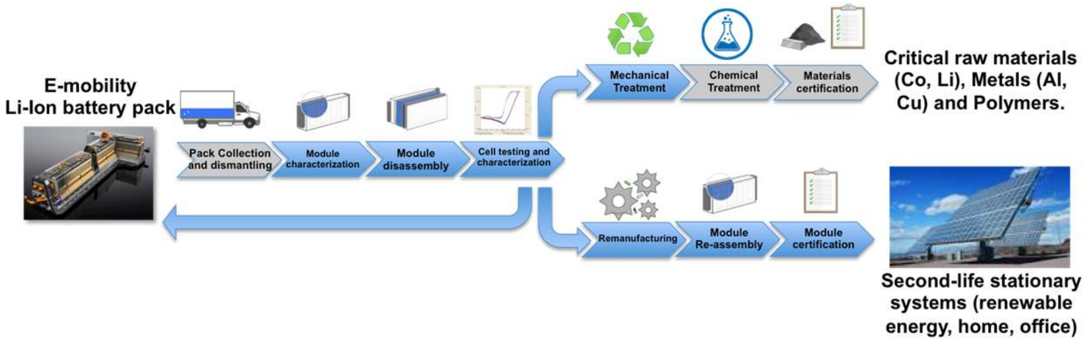


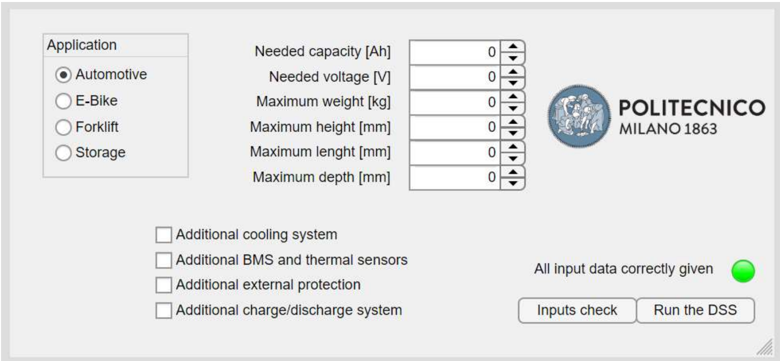




Activities of CIRC-eV: battery reassembly for second-life applications

Development of knowledge-based and data-driven decision support systems to select and configure second-life battery modules and their Battery Management System (BMS) depending on the specific second-use requirements and the post-use conditions of re-usable cells.





	Car model	Car Brand	Type	n° modules	Voltage (V)	Capacity (Ah)	Weight (kg)	Dimensions (mm)			Chemistry	Pack assembly	Remanufacturing technology
								Lenght	Width	Height			
1	A3 Sportback e-tron	Audi	PHEV	8	44	25	15	320	160	110	NMC/LMO	Plug-in cable Mechanical connections	Plug-in cable Mechanical connections
2	Q7 TFSI e	Audi	PHEV	14	45	28	15	320	160	110	NMC	Plug-in cable Mechanical connections	Plug-in cable Mechanical connections
3	A7 Sportback TFSI e quattro	Audi	PHEV	8	48	37	19	350	250	150	NMC	Plug-in cable Mechanical connections	Plug-in cable Mechanical connections
4	A8 TFSI e quattro	Audi	PHEV	8	48	37	19	350	250	150	NMC	Plug-in cable Mechanical connections	Plug-in cable Mechanical connections
6	e-tron	Audi	BEV	36	44	60	19	350	250	150	NMC	Plug-in cable Mechanical connections	Plug-in cable Mechanical connections
9	i3/i3s	BMW	BEV	8 (12 celle)	47	60	25	360	310	145	NMC LiFePO	Plug-in cable Mechanical connections	Plug-in cable Mechanical connections
...	...	...	...	...	...	...	...	...	...	...	...	...	...
99	Model 3	Tesla	BEV	2 (1058 cells) 2 (1150 cells)	85 92	220	86.6 98.9	1715 1854	292	90	2170 NCA	Mechanical connections	Mechanical connections
100	Model S	Tesla	BEV	16	22.8	230	25.0	680	320	80	18650 NCM 18650 NCA	Mechanical connections	Mechanical connections
101	Model X	Tesla	BEV	16	22.8	230	25.0	680	320	80	18650 NCM 18650 NCA	Mechanical connections	Mechanical connections

$$\min \sum_{i=1}^{I} \sum_{j=1}^{J} x_{i,j} C_{i,j} \quad (1)$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} x_{i,j} = 1 \quad (2)$$

$$C_{i,j} = c_{rem-i} + c_{mod-i,j} \quad (3)$$

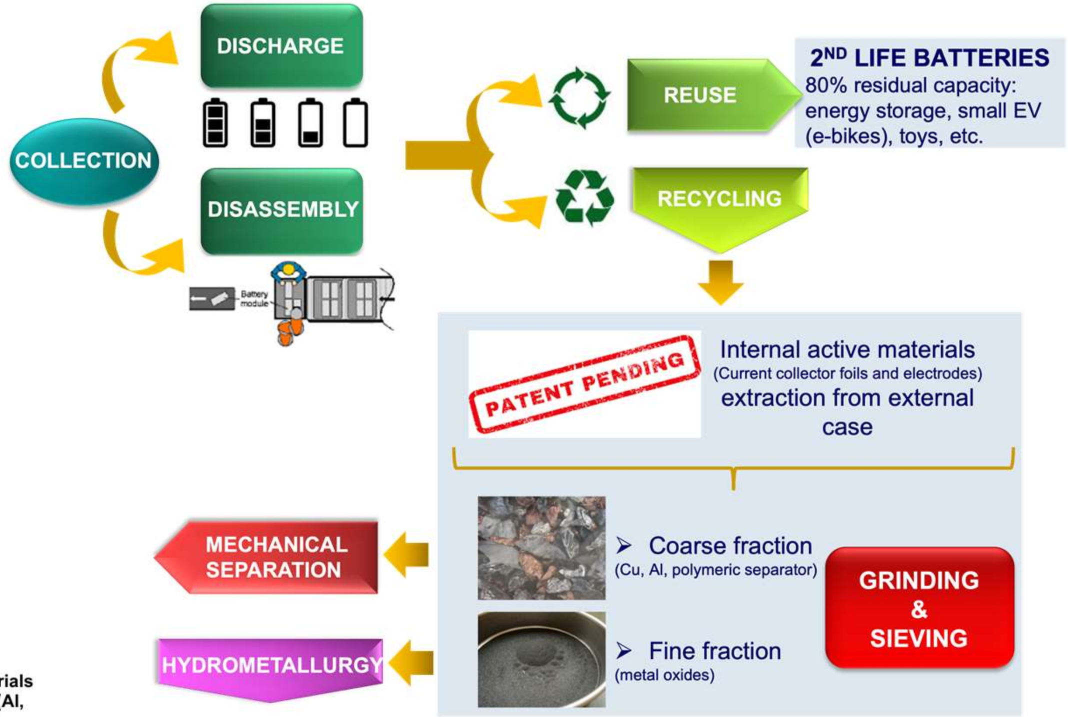
$$c_{rem-i} = c_{frem-i} + n_{i,j} \cdot c_{srem-i} \quad (4)$$

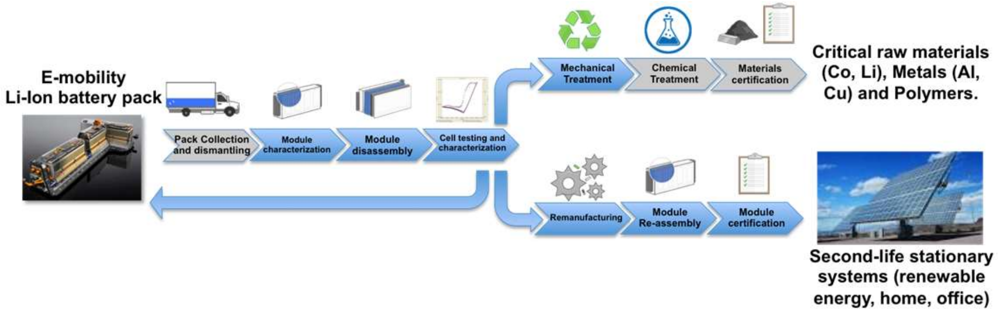
$$c_{mod-i,j} = min \sum_{y_{i,j,s}=1}^{Y_{i,j}} y_{i,j,s} str_s \quad (5)$$

...

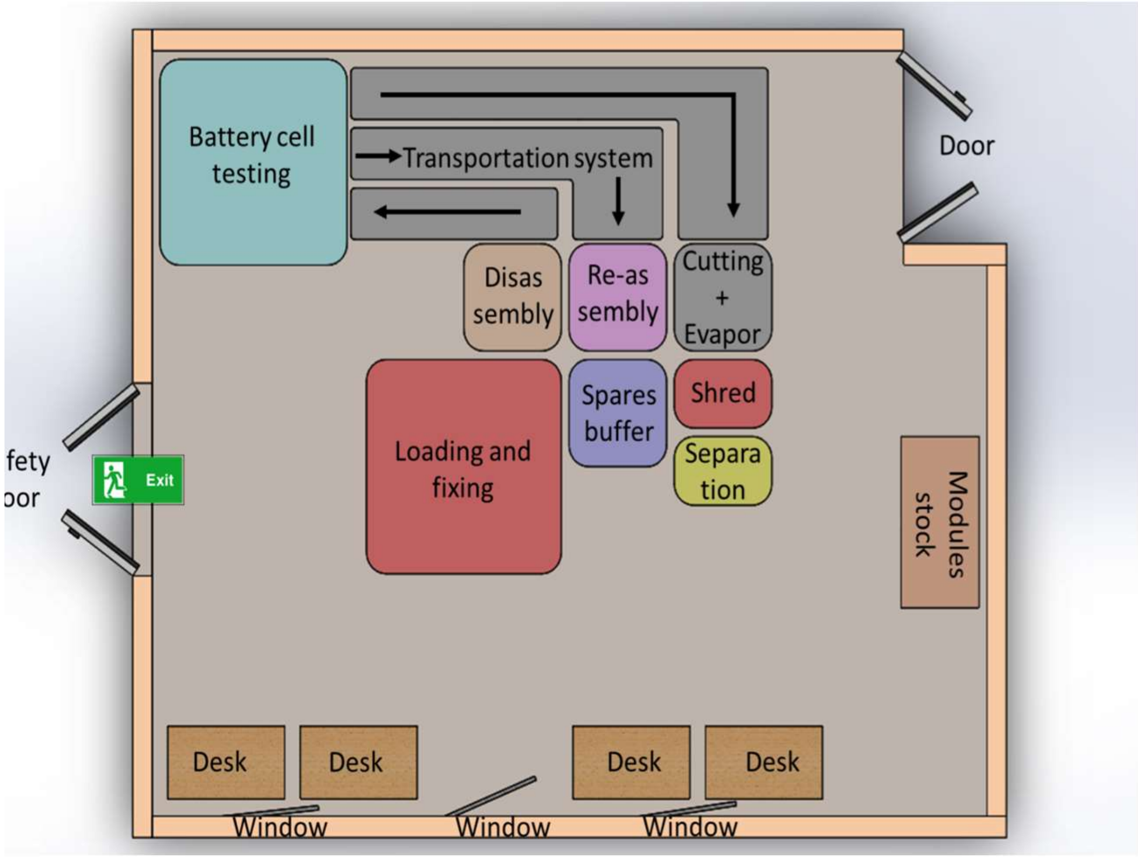
Activities of CIRC-eV: mechanical pre-treatment

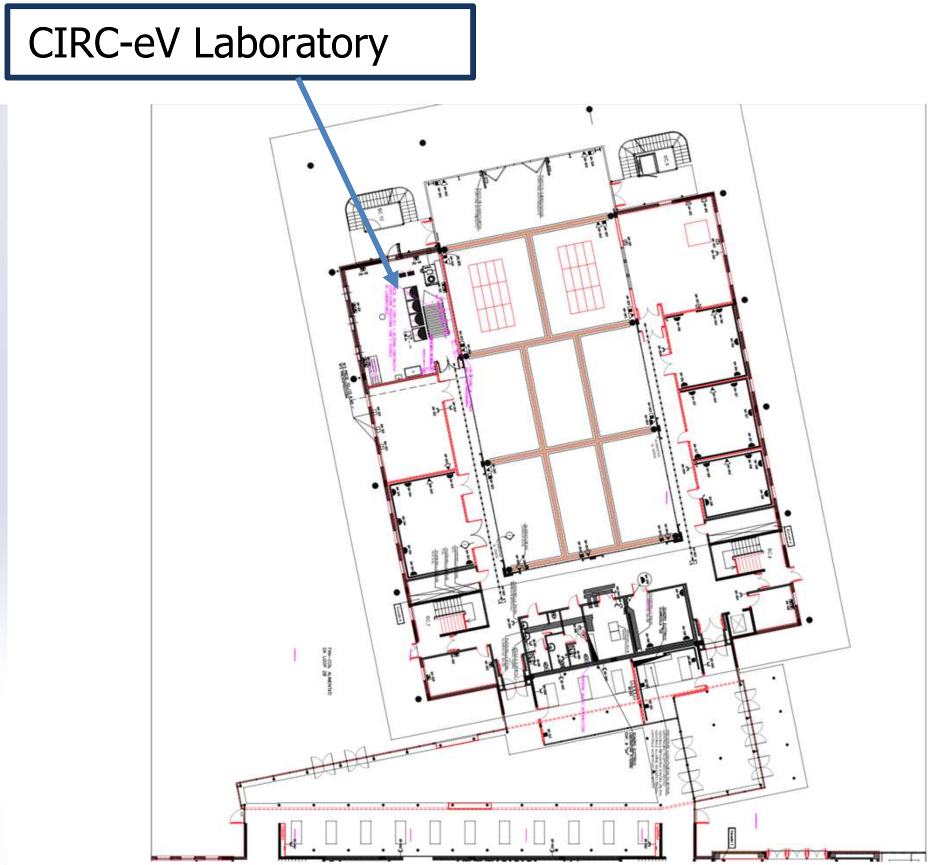
Design and development of a selective mechanical pre-treatment to gather and separate the black mass, with the objective to support the recycling of key materials through downstream chemical treatments.





CIRC-eV plant Architecture





Research challenges addressed by CIRC-eV

Technical challenges:

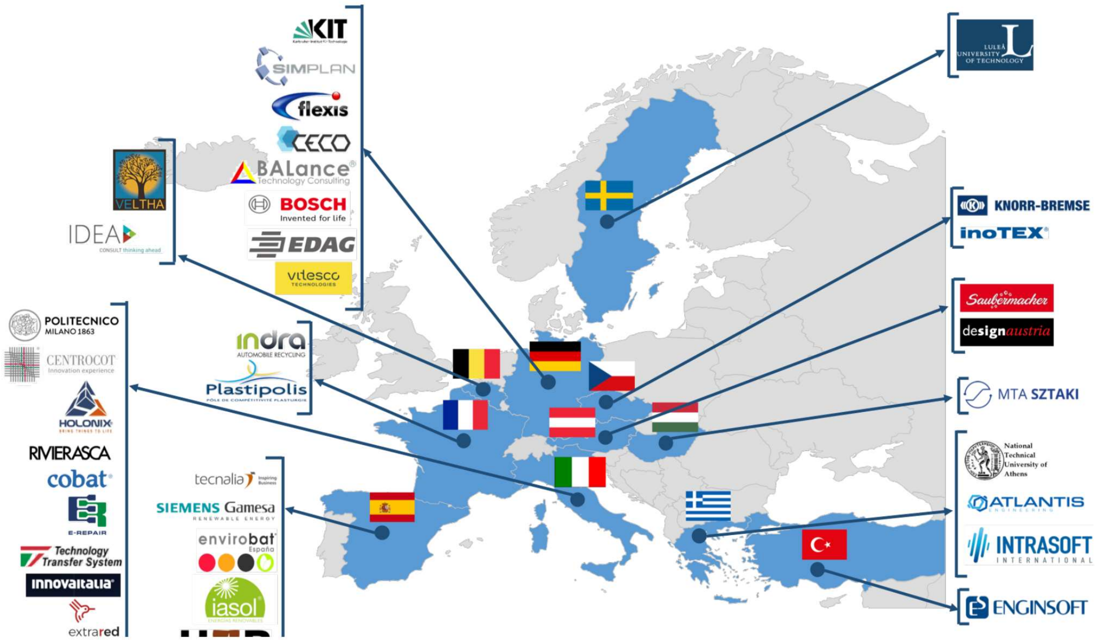
- High variability of input product design
- High variability in the conditions of post-use batteries
- Lack of testing criteria and standard certification procedures:
  - SOH and residual life-time;
  - Acceptability for re-use;
  - Performance regenerated modules.
- Safety and egonomy requirements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

Requirements:

- Flexible and adaptable technologies
- Availability of information from producers and in the use phase
- Standard testing procedures
- Decision Support System for performance-driven re-assembly
- Human-centric and safe-by-design systems
- Automation, traceability and repeatibility

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

The DigiPrime project



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

CALL

H2020-DT-ICT-07- 2018-2019

Digital Manufacturing Platforms for Connected Smart Factories

BUDGET

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

DURATION

January 2020 – Dec 2024

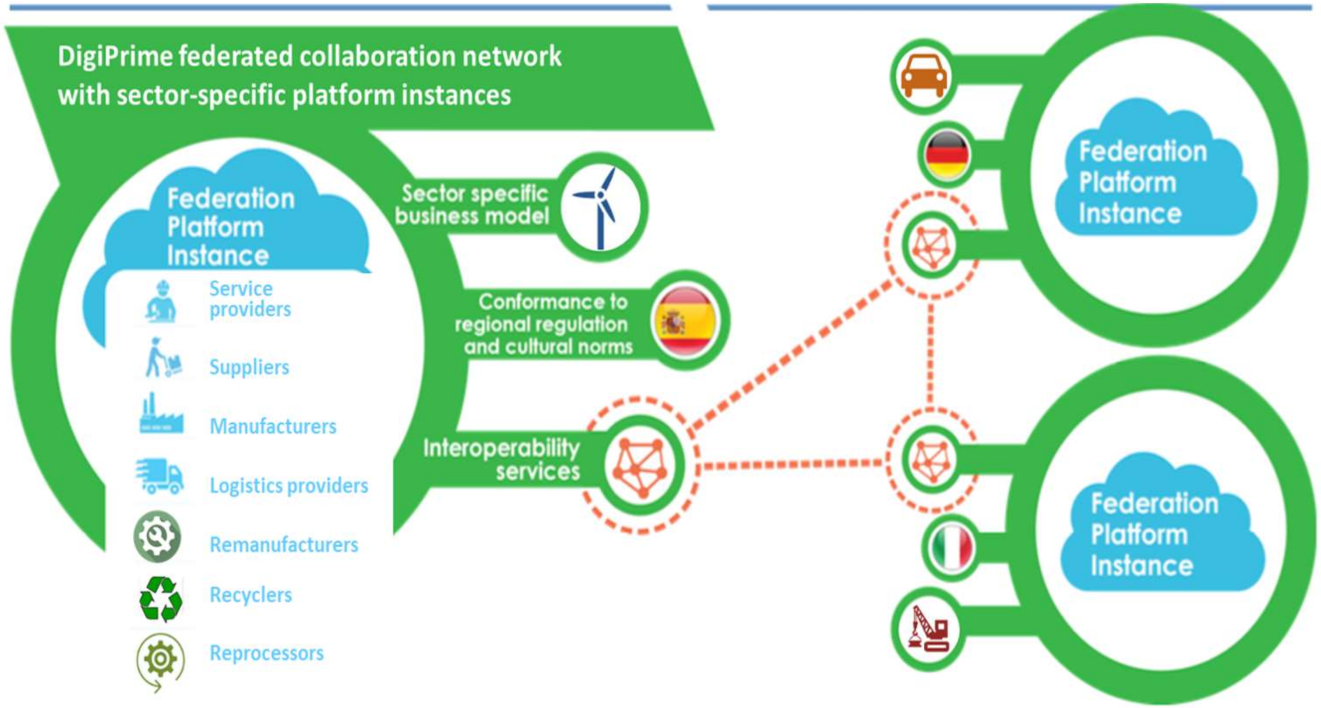
OBJECTIVE

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

Platform Architecture: concept of federation

The overall architecture level of the DigiPrime platform includes:

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

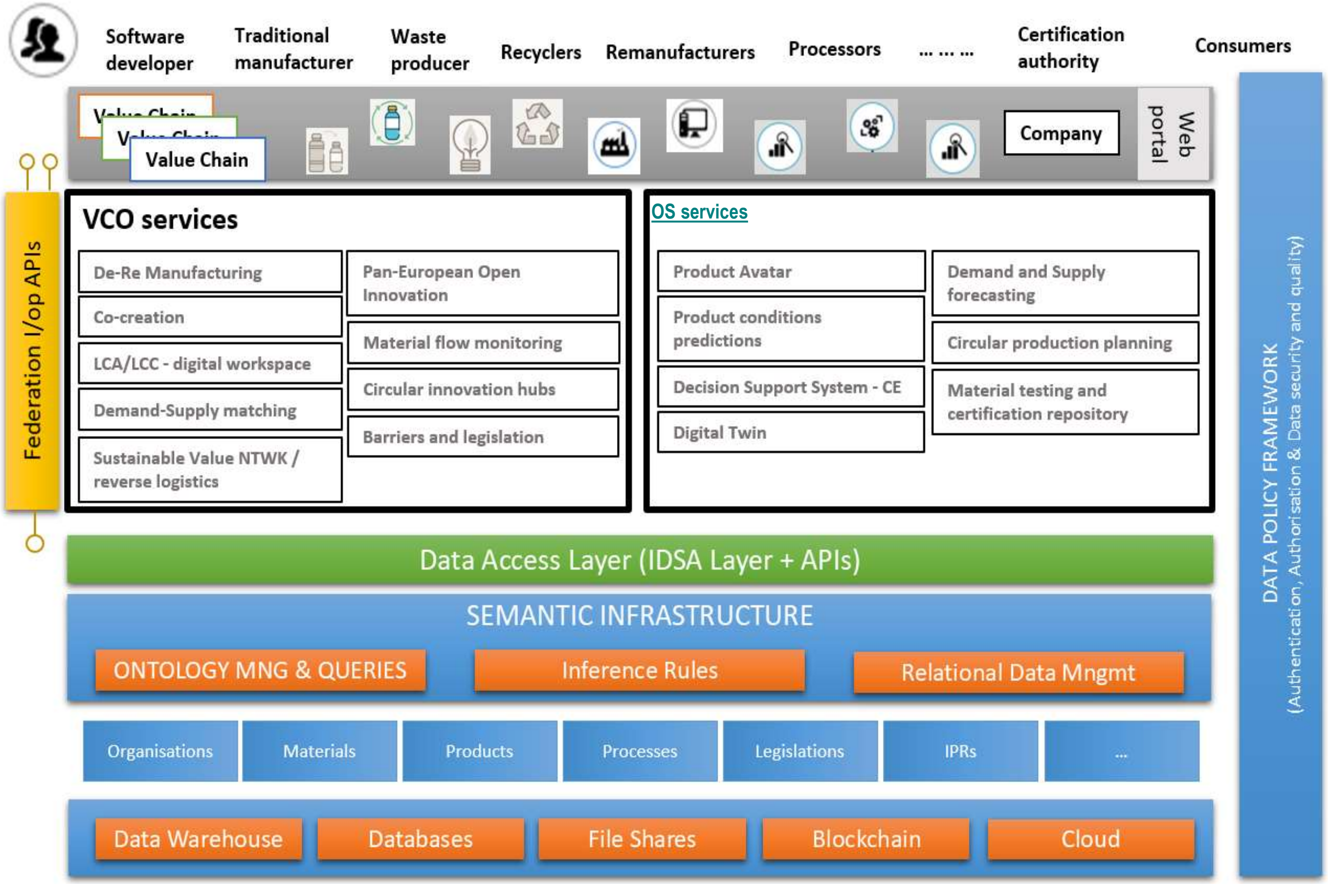


The Blockchain technology will ensure that data cannot be altered, and will keep track of any transaction taking place in the platform.

The DigiPrime platform Services

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

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



The DigiPrime Pilots

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

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

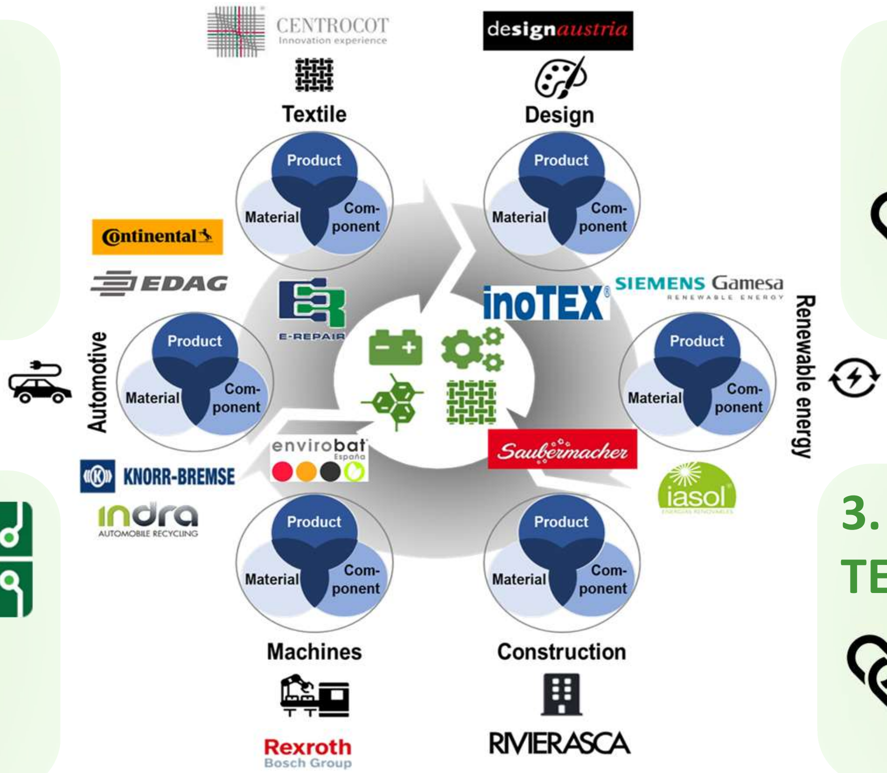
- The interoperability with the company pre-existing ICT infrastructure;
- The continuous interaction with the platform modules and services;
- The generated data to populate the platform for future business cases;
- The industrial feedback for platform maintenance and improvement.

1. BATTERIES

E-MOBILITY
RENEWABLE ENERGY SECTOR
RECYCLING&RAW MATERIALS

2. MECHATRONICS & ELECTRONICS

E-MOBILITY
SMART MACHINING SYSTEM



4. TEXTILE

AUTOMOTIVE
TEXTILE SECTOR

3. COMPOSITES & TECHNO-POLYMERS

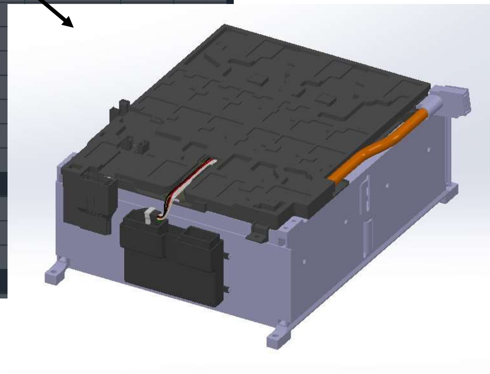
E-MOBILITY
RENEWABLE ENERGY SECTOR
CONSTRUCTION
DESIGN SECTOR

VCO – De-and Remanufacturing Data Management and Sharing

A service application for boosting a collaborative approach between stakeholders in the cross-sectorial value-chain based on the transfer of relevant product information

String based and technical files datasets to effectively test the early developments

Car model	Car Brand	Type	Number of modules	Module Voltage (V)	Module Capacity (Ah)	Cell chemistry	Module Weight (kg)	Module Length (mm	ule Width	ule Height
A3 Sportback e-t…	Audi	PHEV	8	44	25	NMC/LMO	15	320	160	110
Q7 TFSI e	Audi	PHEV	14	45	28	NMC	15	320	160	110
A7 Sportback TFS…	Audi	PHEV	8	48	37	NMC	19	350	250	150
A8 TFSI e quattro	Audi	PHEV	8	48	37	NMC	19	350	250	150
e-tron	Audi	BEV	36	44	60	NMC	19	350	250	150
i3/i3s	BMW	BEV	8 (12 celle)	47	60	NMC LiFePO	25	360	310	145
Series 2e	BMW	PHEV	6	47	26	nan	nan	nan	nan	nan
330e	BMW	PHEV	6	47	26	nan	nan			
i8 Coupè/Roadster	BMW	PHEV	6 (16 celle)	60	34	NMC	16			
Series 5e	BMW	PHEV	8 (12 celle)	47	34	NMC LiFePO	25			
Series 7e	BMW	PHEV	8 (12 celle)	47	34	NMC LiFePO	25			
Volt	Chevrolet	PHEV	4 (32 cells) 3 (24 cells)	60 44	52	nan	nan			
Bolt	Chevrolet	BEV	8 (30 cells)	37	150	NMC	45			
Bolt 2	Chevrolet	BEV	2 (24 cells)	30	150	NMC	36			
C-Zero	Citroen	BEV	10 (8 cells) 2 (4 cells)	30 15	50	nan	24 12			
E-Berling Multis…	Citroen	BEV	nan	nan	nan	nan	nan			
E-Meari	Citroen	BEV	nan	nan	nan	nan	nan			
Pacifica	Chrysler	PHEV	nan	nan	nan	nan	nan			
500e	Fiat	BEV	7 (6 cells) 11 (5 cells)	23 20	63	nan	15,2 12,6			



localhost:3000

InfoCircular - DigiPrime

InfoCircular - DigiPrime - Results

Find the data matching your preferences or search

Car Brand	Car Model	Information	Type	Validated	Link
Tesla	Model X	Cell Chemistry	String Based	Yes	rEUse Link
Tesla	Model X	Module CAD	Technical	No	rEUse Link
Tesla	Model S	Disassembly Graph	Technical	Yes	rEUse Link
Nissan	Leaf	Cell Chemistry	String Based	Yes	rEUse Link

VCO - Demand and Supply Matching

Problem Statement

*Suppliers of post-use components and materials **cannot publish information** on their products, nor can "re/de-" actors publish their capacities and requirements, which **makes matchmaking difficult***

Solution & Method(s)

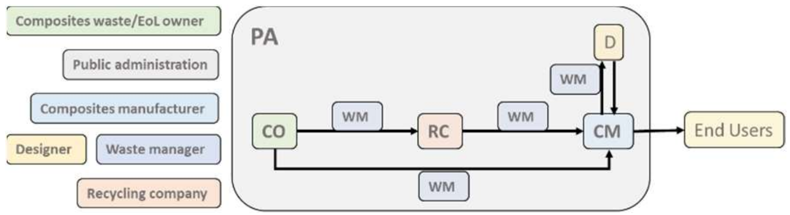
*Demand-supply matching **across multiple sectors**, including (1) **negotiation support**, (2) **traceability of transactions** and (3) **contract definition support***

Circular business-link identification** to digitize DSM with **effective search functionality** and support for **trade and auctioning, and contractual agreements

Circular Economy Vision

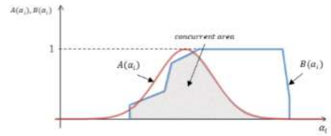
*Facilitate **new business connections** and maintain **dynamic circular economy networks**, thereby **unlocking presently unused circular opportunities***

Circular business-link identification for DSM (POLIMI)

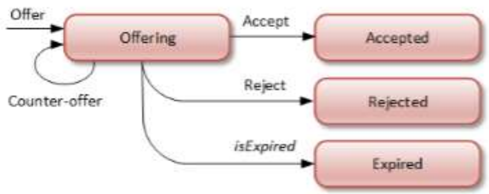


Matchmaking suitability based on elastic factors (KIT)

$$S I_i = \frac{\int_0^{\infty} min(A(\alpha_i), B(\alpha_i))}{\int_0^{\infty} A(\alpha_i)}$$

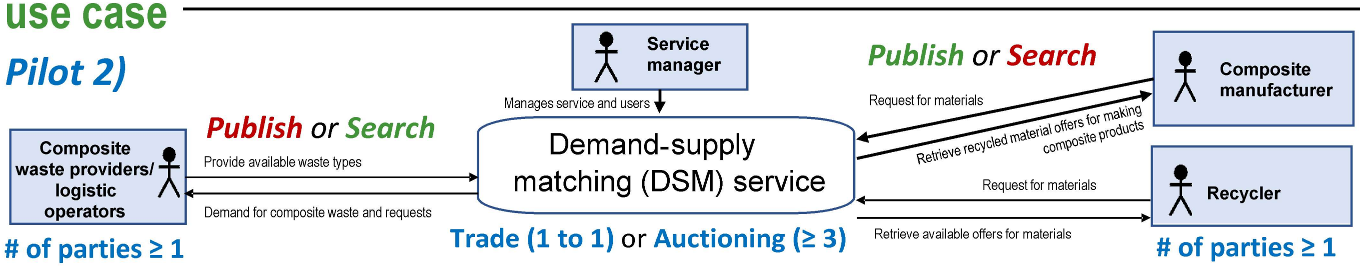


Multi-party negotiation / auctioning and contracts (LTU)



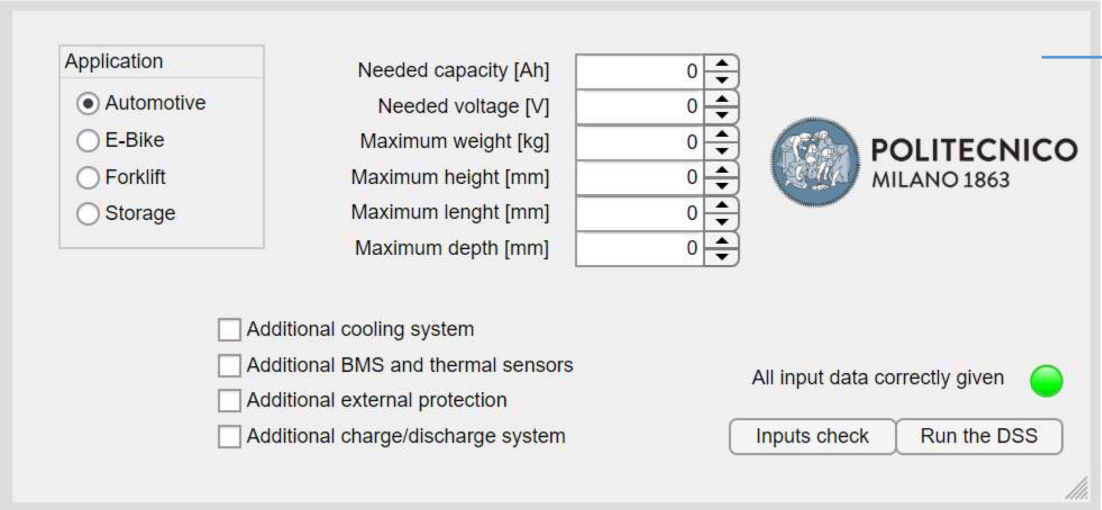
Exemplary use case

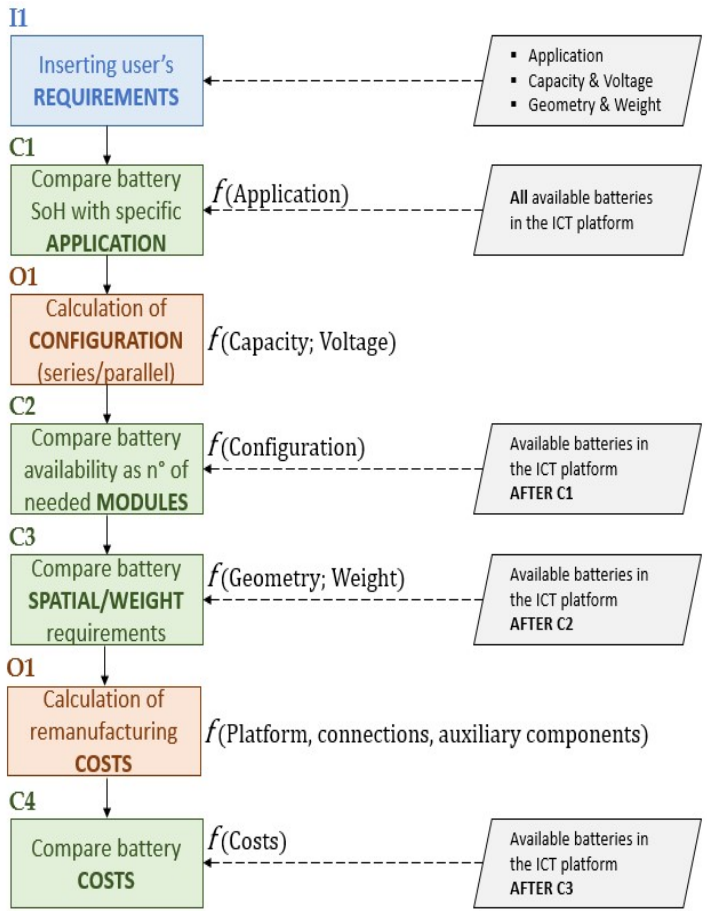
Pilot 3 (and Pilot 2)



VCO – De-and Remanufacturing Decision Support System

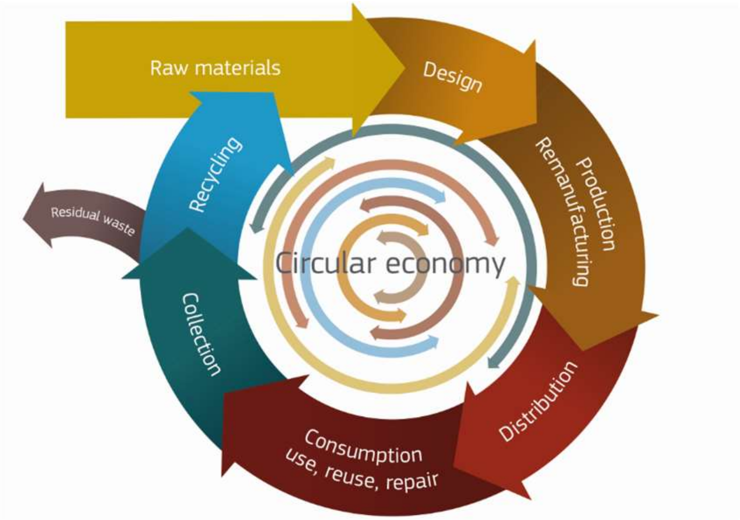
Available solution: application oriented decision support system for the reassembly of modules into second life batteries.





Thematic Domain

De- and Remanufacturing includes the set of technologies, tools and knowledge-based methods to recover, re-use and upgrade functions and materials from industrial waste and post-consumer high-tech products, under a new producer-centric Circular Economy perspective.



EU – Towards a circular economy, a zero waste programme for Europe, COM (2014) 398 final

Regions involved

- **Lombardy**
- Scotland
- Saxony
- Tampere
- Flanders
- Basque Country
- Norte
- Emilia Romagna
- Wallonia
- Eastern Netherlands

Potential Interest

- Friuli Venezia Giulia
- South Netherland
- Slovenia
- Upper Austria
- Navarra
- Auvergne Rhone Alpes

Thematic Domain

G7 Summit Declaration June 2015: The **G7 Alliance on Resource Efficiency** promotes Circular Economy, Remanufacturing and Recycling as strategic actions.

At European level, the Commission has launched in December 2015 the strategic initiative **"Closing the loop - An EU action plan for the Circular Economy"**.

H2020 R&I projects under the Focus Area "**Industry 2020 in the Circular Economy**", calls CIRC, Spire and FOF, at TRL 6-7.

G7 GERMANY
2015 | Schloss Elmau

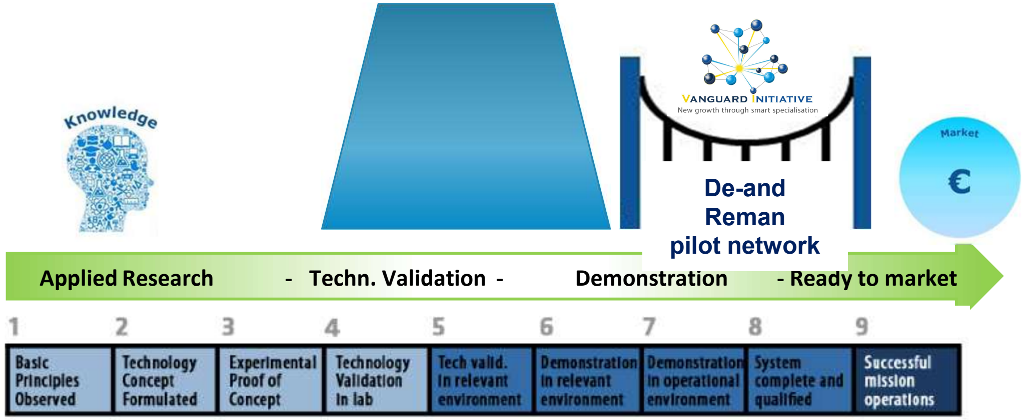
CIRCULAR ECONOMY
Closing the loop
AN AMBITIOUS EU CIRCULAR ECONOMY PACKAGE

Factories of the Future
Public Private Partnership

Sustainable Process Industry through Resource and Energy Efficiency

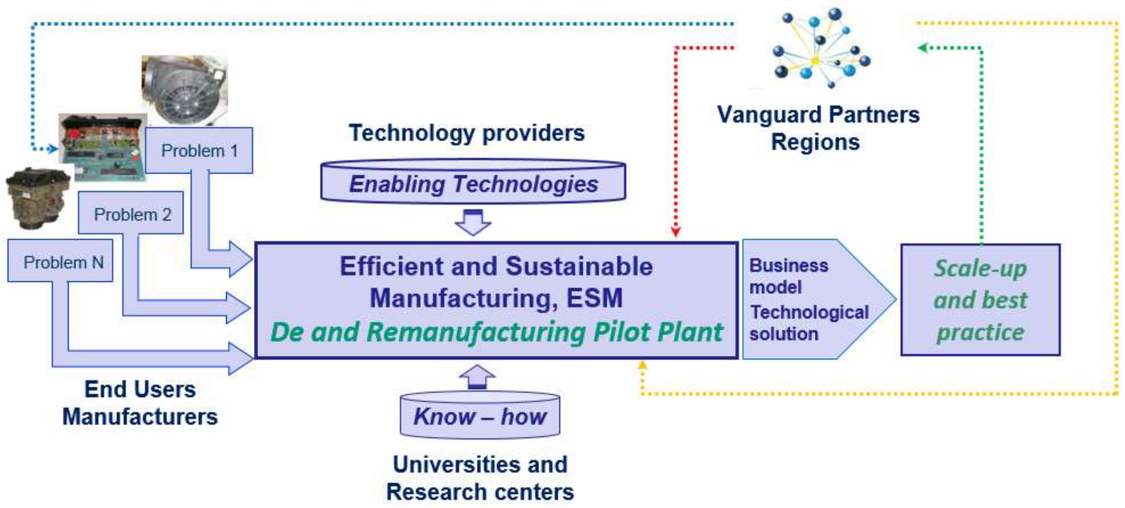
Lack of infrastructures that can demonstrate to industry integrated circular economy solutions and business models, de-risking the private investment.

These Innovation Hubs should act as "**technology gateways**" that any business sector can use.



Objectives

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



Selected within Pilot actions for "**Interregional innovation projects**" by the DG Regio.
TAF supported partnership.

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

Envisaged inter-regional nodes configuration

- 🔴 Totally new pilot site (or connection)
- 🟡 Upgraded existing pilot site (or connection)

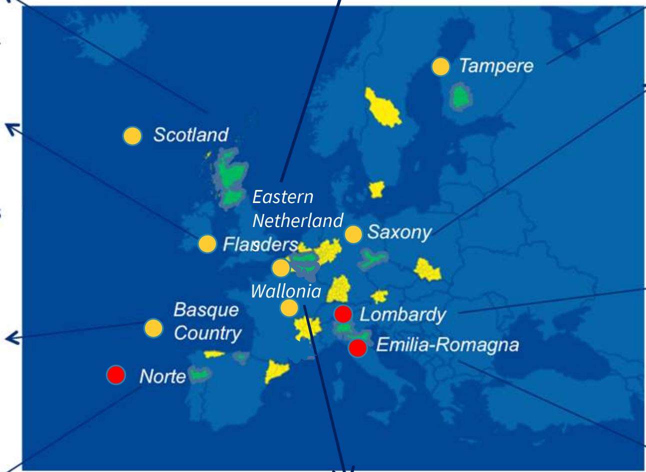
Recovery and reprocessing to enable plastics re-use in electronics.

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

Laser-based remanufacturing of the large machinery.

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

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



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

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

Moulds and dies De-and Remanufacturing and repair

Metallurgical processing to recover metals and valuable components

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

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

Use-case configuration

A detailed analysis of identified ***sectorial Use Cases***, with industrial partners associated, has been performed, where more regions are involved. For each Use Case, a business case has been detailed including a ***business plan*** for the industrial take-up of the solutions.

Regional/Cross-Regional Use Case	Involved Regions
1.Composite Recovery from Wind Energy System	Basque Countries, Saxony, Lombardy, Tampere, Scotland
2.Heavy machinery components remanufacturing	Tampere, Basque Countries, Lombardy, Saxony, Emilia Romagna
3.Automotive parts remanufacturing	Scotland, Lombardy, Saxony, Norte
4.High-value TLC systems and Electronics Recovery	Lombardy, Tampere
5.Metal components reprocessing	Saxony, Tampere, Lombardy, Wallonia
6.Remanufacturing of e-motors	Saxony, Lombardy
7.Plastics recycling and re-use in electronics	Flanders, Lombardy, Wallonia, Eastern Netherlands
8.Automotive Li-Ion batteries disassembly, remanufacturing and re-assembly for second use	Lombardy, Saxony, Basque Countries
9.Photovoltaic panels de-manufacturing	Flanders, Lombardy
10. Machining equipment retrofit and upgrade	Emilia Romagna, Lombardy
11. Manufacturing of metal-sponge catalysts from aluminum waste material for chemical catalysts.	Emilia-Romagna, Lombardy
12.Recovery of both metallic and non-metallic parts of slags, incinerator bottom ash, leaded glass - closing the material loop.	Wallonia, Lombardy, Basque Countries

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Grazie per l’attenzione

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