Istituto di Tecnologie Industriali e Automazione
Consiglio Nazionale delle Ricerche

CENTRAL EUROPEAN COOPERATION FOR INDUSTRY 4.0 workshop

from research …. to market

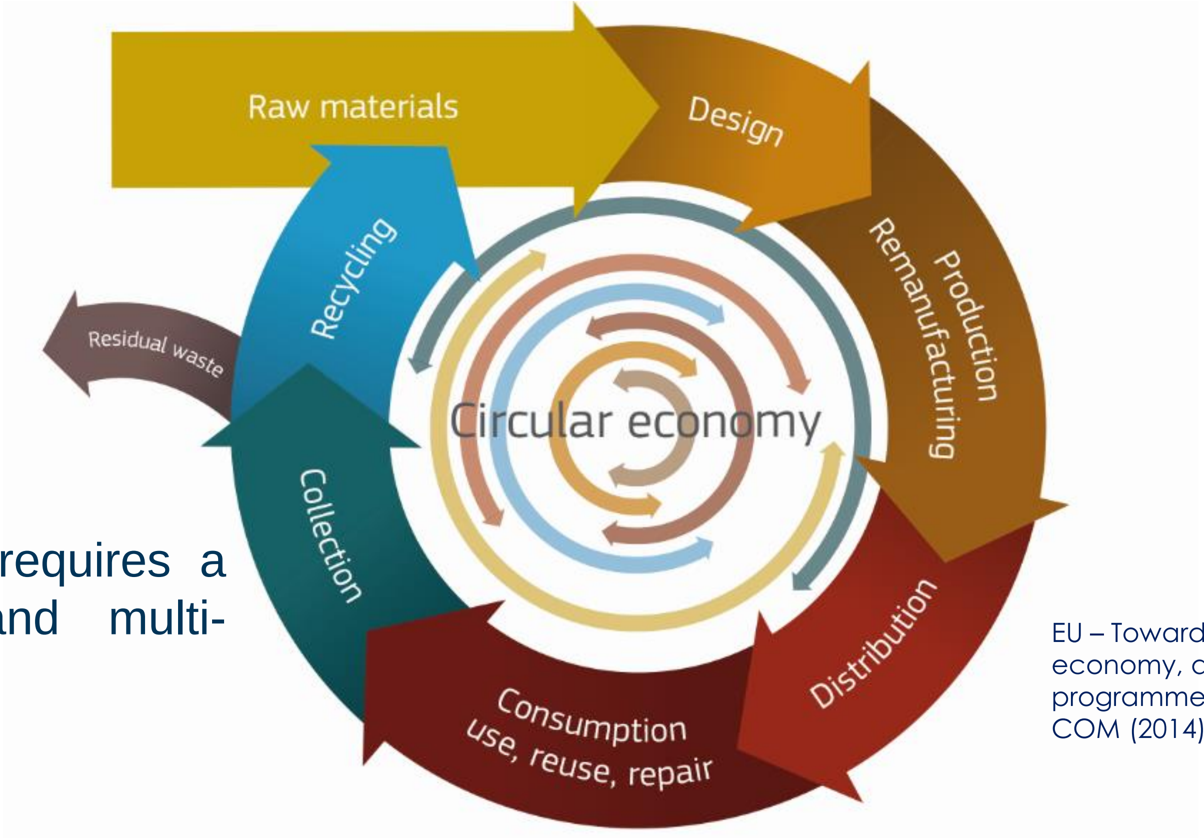
Demanufacturing and Remanufacturing Systems for Circular Economy

Prof. Tullio Tolio

20-21st September 2017, Budapest, Hungary

De – and Remanufacturing and Circular Economy

Demanufacturing and Remanufacturing (De-and Remanufacturing) includes the set of technologies and systems, tools and knowledge-based methods to systematically recover, reuse, and upgrade <u>functions</u> and materials from industrial waste and post-consumer products, to support a sustainable implementation of <u>manufacturer-centric</u> Circular Economy businesses.



Circular Economy requires a multi-disciplinary and multi-level approach

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

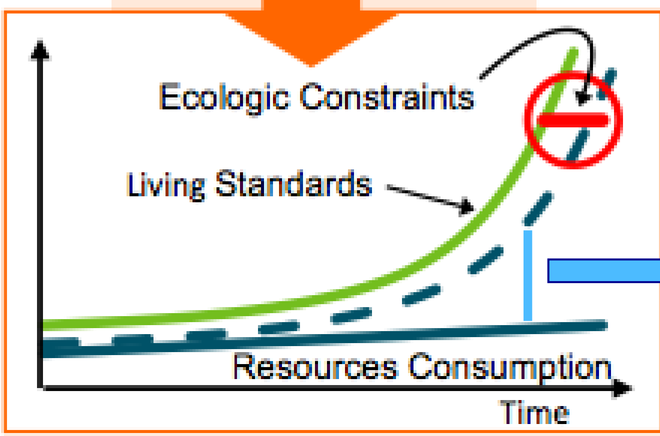
De-and Remanufacturing macro-challenge

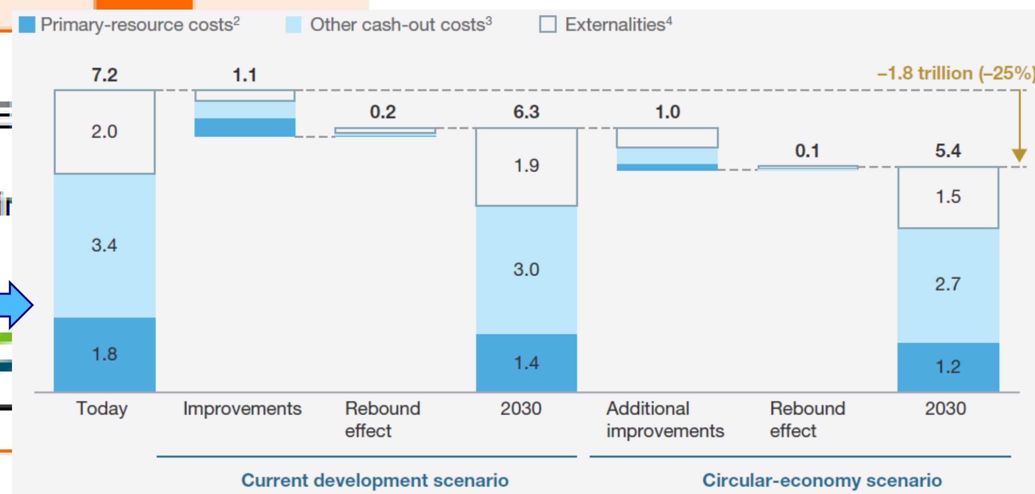
Higher living standards are sustainable only when the per capita resources consumption decreases

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

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

Prof. Seliger

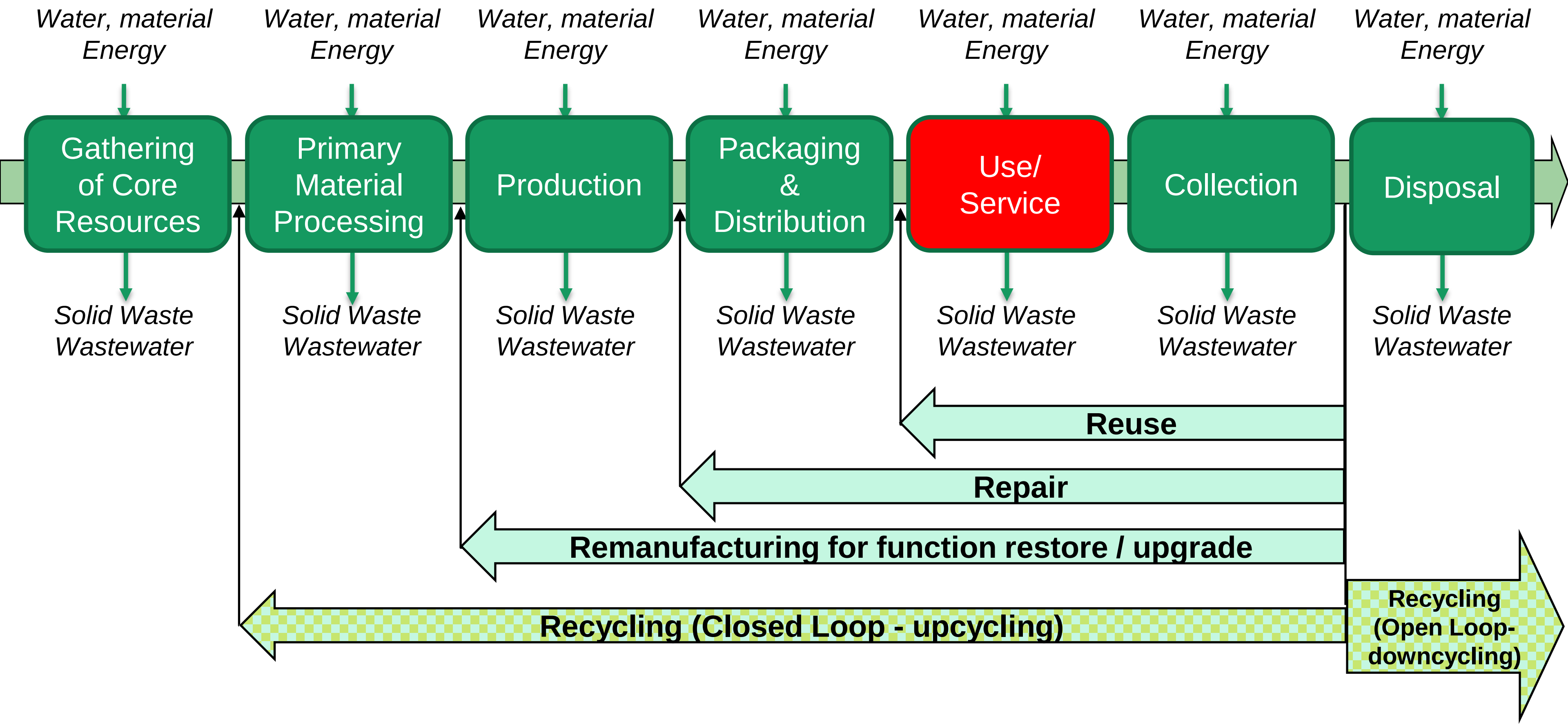




A new industrial model that decouples revenues from material input, and production from resource consumption is needed for achieving a sustainable development path, both in early-industrialized and in emerging countries.

Key definitions in a value-chain perspective

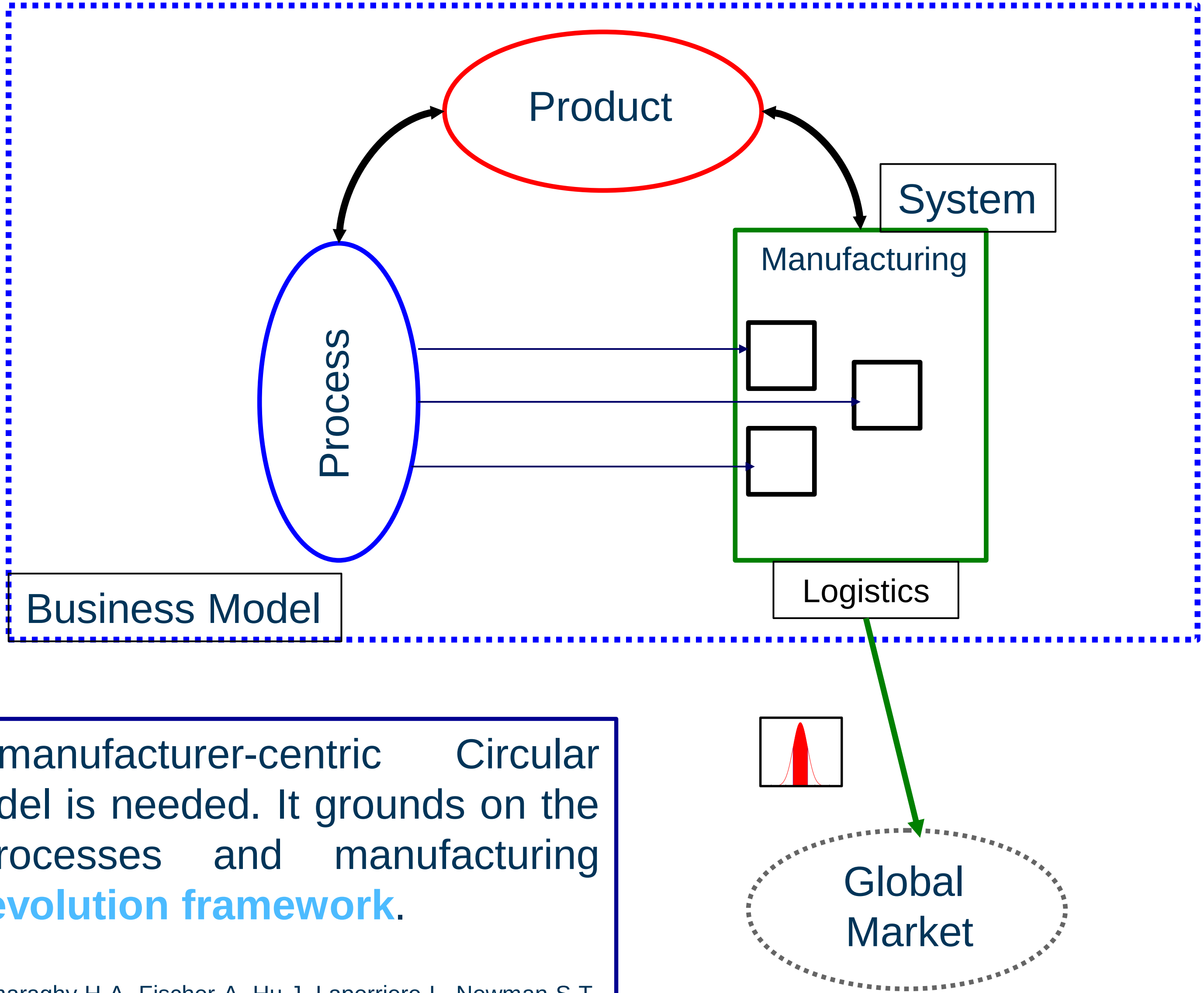
At technical levels, different business options for Circular Economy have been proposed to generate benefits by exploiting different value-creation mechanisms:



[Parker, D., 2007, An Analysis of the Spectrum of Re-use. Aylesbury, Oakdene Hollins Ltd, for Defra.]
[Parkinson, H.J., Thompson, G., 2003, Analysis and taxonomy of remanufacturing industry practice, Proc. Inst. Mech. Eng., 217:243-256.]
[Apra – Automotive Part Remanufacturers Association, 2012, Remanufacturing Terminology, Remanufacturing Term Guideline.]

What are the operational implications for manufacturers while introducing these Circular Economy business options?

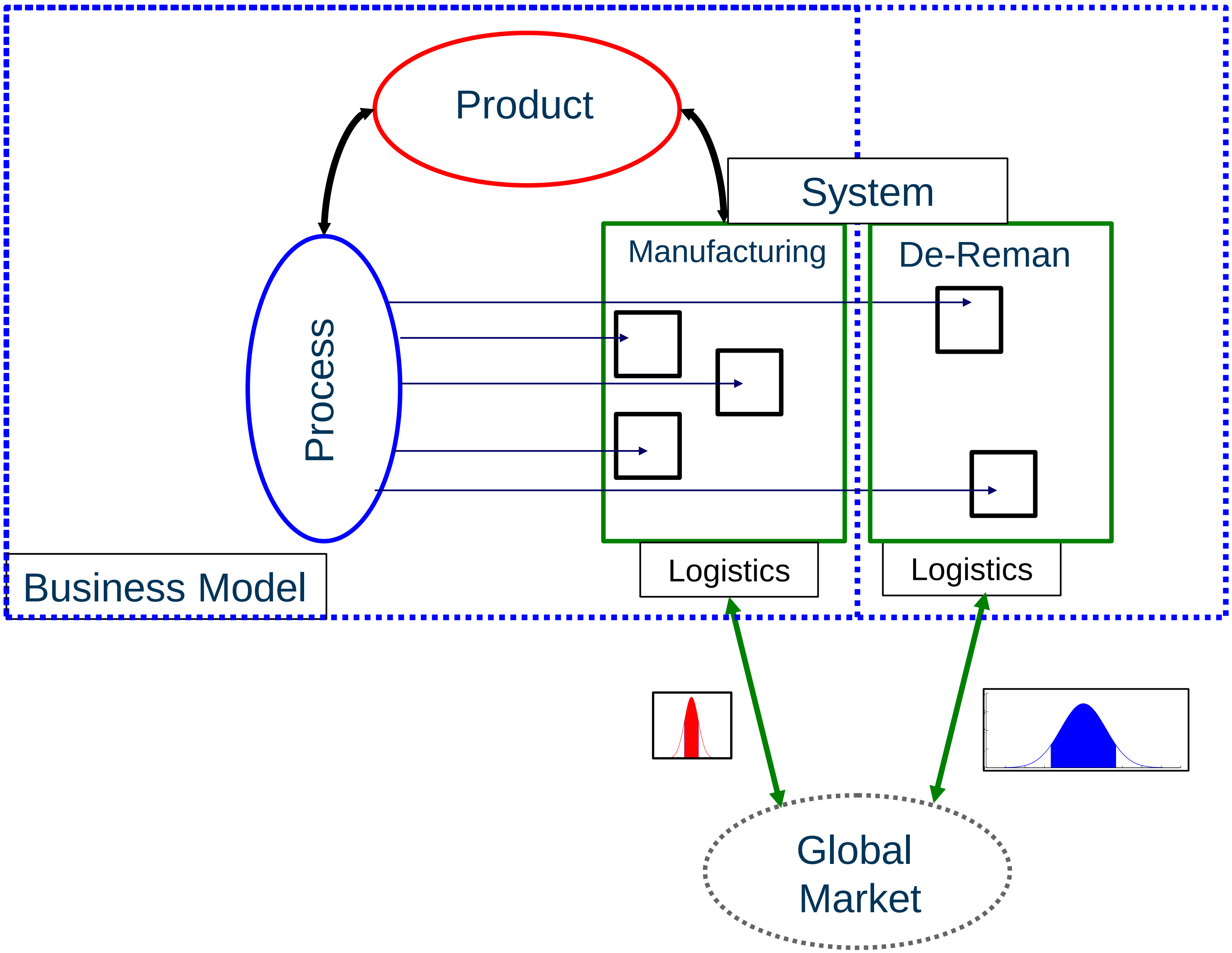
A new manufacturer-centric Circular Economy model



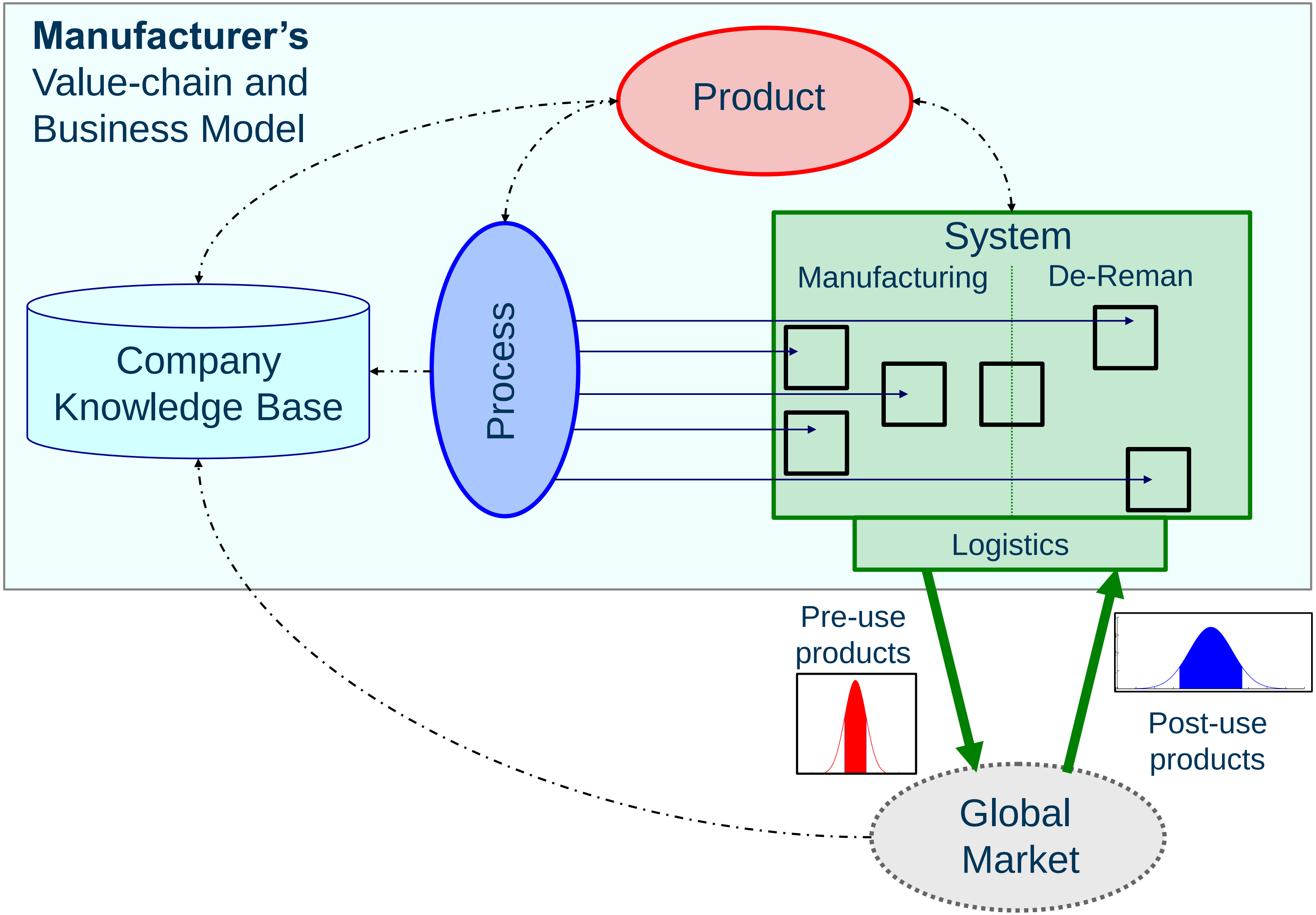
A new manufacturer-centric Circular Economy model is needed. It grounds on the products, processes and manufacturing systems **Co-evolution framework**.

Tolio T, Ceglarek D, Elmaraghy H-A, Fischer A, Hu J, Laperriere L, Newman S-T, Vancza J (2010) SPECIES-co-evolution of Products, Processes and Production Systems. Annals of the CIRP 59(2):672–693.

De-and Remanufacturing Vision and Objectives



Vision: Manufacturer-centric Circular Economy



Industrial Motivation

Producer-centric real cases have been formalized from the automotive, railway, electronics, aerospace, heavy machinery and industrial machine industries:

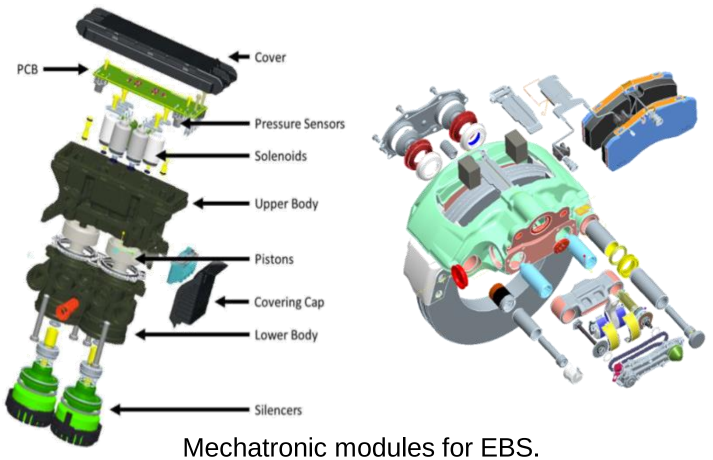
- Reuse of copy machines at **Ricoh**.
- Remanufacturing for function upgrade of construction and mining equipment at **Komatsu**.
- Remanufacturing for function restore of mechatronic breaking system components in the rail industry at **Knorr Bremse**.
- Remanufacturing for function restore of mechatronic components in the automotive industry at **Robert Bosch**.
- Closed-loop recycling of car components and materials at **Renault**.
- Closed-loop and open-loop recycling of aircrafts at **Airbus**.
- Closed-loop recycling in the electronics industry at **Mitsubishi**.

KNORR-BREMSE RENAULT RICOH apra europe KOMATSU AIRBUS BOSCH MITSUBISHI

Remanufacturing for function restore

"*Premium quality remanufactured products are set to play an even more important part in Knorr-Bremse's business... And so we are bundling our remanufacturing expertise and increasing our production capacities*". Wolfgang Krinner, Member of the Executive Board.

The current remanufacturing process is carried out in a plant of 9.000 m^2 for 300 individual product types.



Mechatronic modules for EBS.

1 - Remanufacturing decisions are taken by the operator (Standard Operations Sheets – SOS)

2 - The disassembly is performed manually.

3 - Cleaning and refurbishing are semi-automated.

4 - The PCB is manually repaired.

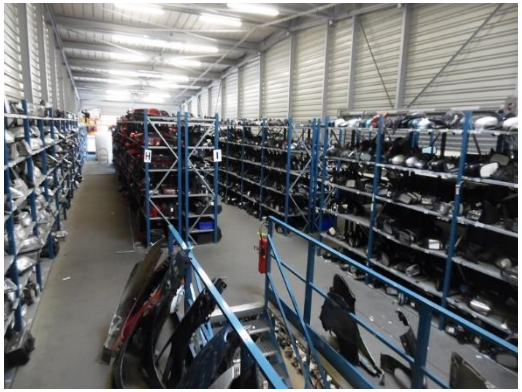
5 - All re-assembly operations are performed in the main line (Germany)

D. C. F. Köhler, F. Merwerth, Mechatronic Remanufacturing at Knorr-Bremse Commercial Vehicles Systems (CVS).
Knorr-Bremse invests heavily in remanufacturing business.

Closed-loop recycling and remanufacturing

"*Detecting potential resources in end-of-life products and safeguarding their technical and economic value is a new, and virtuous, way of sharpening your competitive edge. Who is better able than the producer of the goods and corresponding services to control these resources, ensure their quality and traceability, and make optimum use of them*". The vision of Jean-Philippe Hermine, Head of the Environmental Plan of the Renault group.

Renault's plant in Choisy-le-Roi, near Paris, **remanufactures** automotive engines, transmissions, injection pumps, and other components for resale.

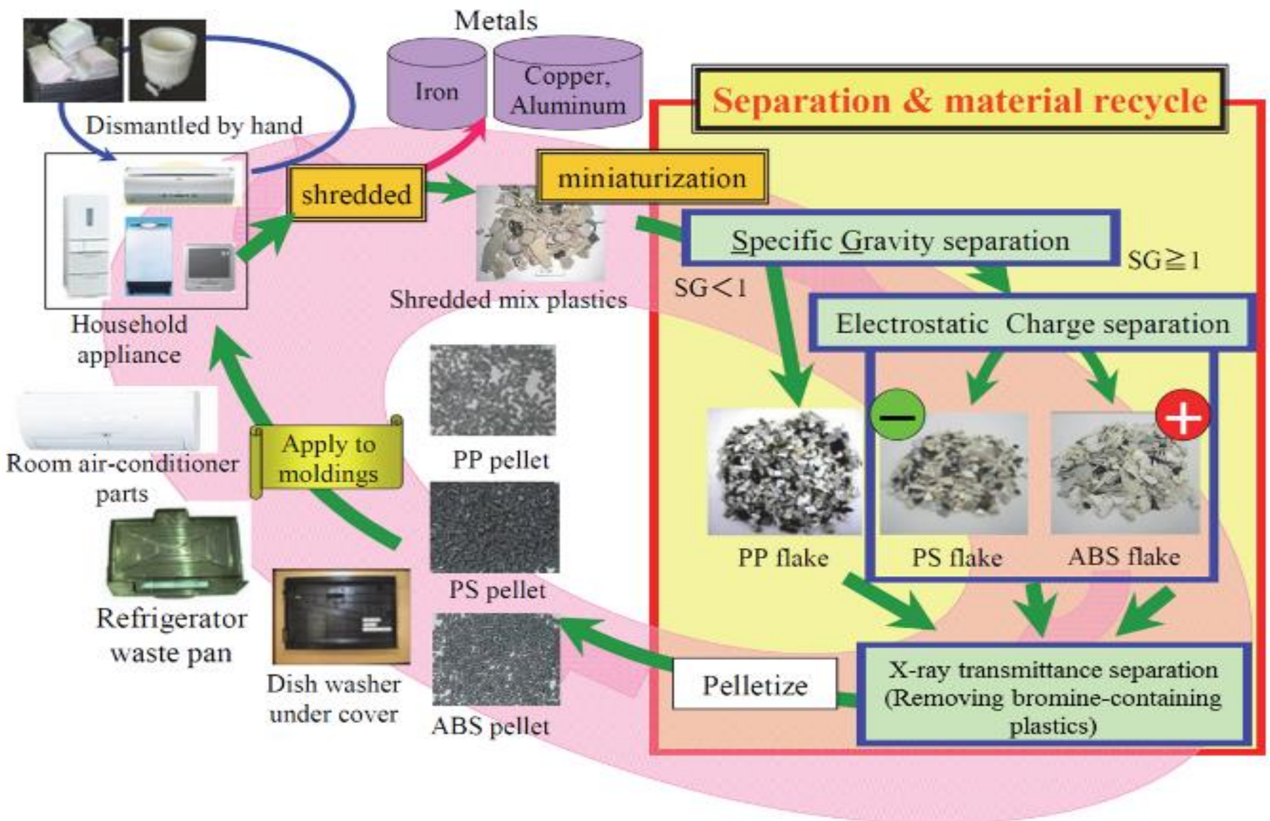


Renaults contributes to the collection and processing of the 25% of the total End-of-Life vehicles (ELVs) in France through **Indra, operating a network of 400 dismantlers** processing more than 95,000 vehicles in 2015.

Renault, A Committed Player In The Circular Economy, 2014

Closed-loop Recycling for material re-use

Following the enactment of the home appliance recycling law in Japan in 1998, Mitsubishi Electric Corporation introduced in 2010 a large-scale high-purity plastic recycling system, enabling closed-loop recycling of shredded plastic mixtures.



With this system, the company secured a stable supply of high quality plastics, also reducing the cost for producing new home appliances.

Industrial Cases: lessons learnt

The reported industrial cases support these considerations:

- Circular Economy is already a profitable business opportunity for manufacturers in different sectors.
- The application of Circular Economy businesses is not in contrast but, in fact, is highly synergic with new product manufacturing operations.
- Uncertainties in product returns and market demand are the major causes of complexity in de-and remanufacturing systems, with respect to manufacturing systems
- Product information plays an important role in the decision making process about de-and remanufacturing operations, and this feature provides competitive advantage to the manufacturer in the implementation of circular businesses.
- The role of advanced de-and remanufacturing technologies and systems is fundamental to achieve the required quality and efficiency of the regeneration process.
- The profitability of the business is strongly influenced by manufacturers' product design decisions.
- A value-chain and business model reconfiguration may be needed while shifting to new Circular Economy businesses.

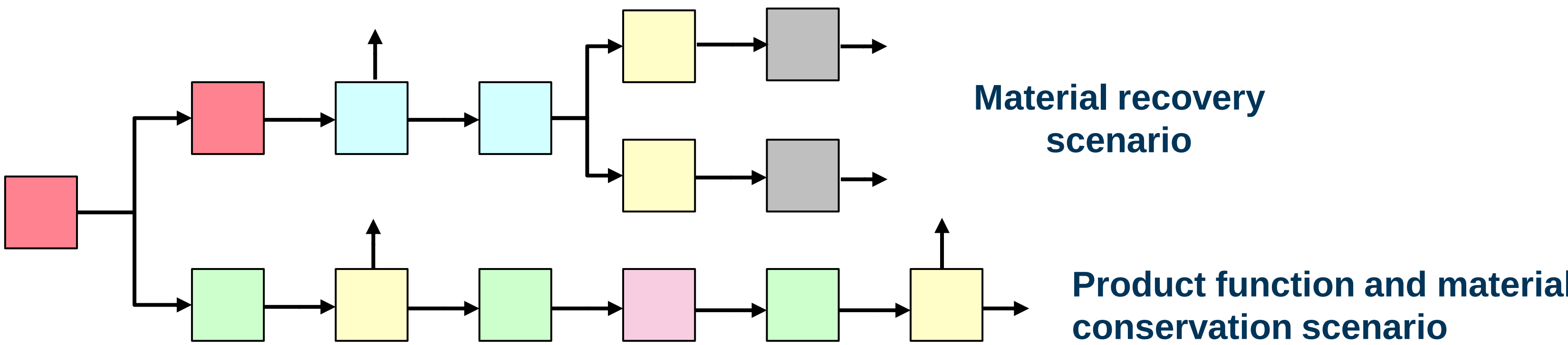
Challenges and requirements for De-and Remanufacturing systems

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

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

Processes and Emerging Technologies

A simple **taxonomy of de-and remanufacturing processes** is proposed. The goal of this taxonomy is the positioning of each process in a typical de-and remanufacturing process-chain, highlighting its function and its scope.

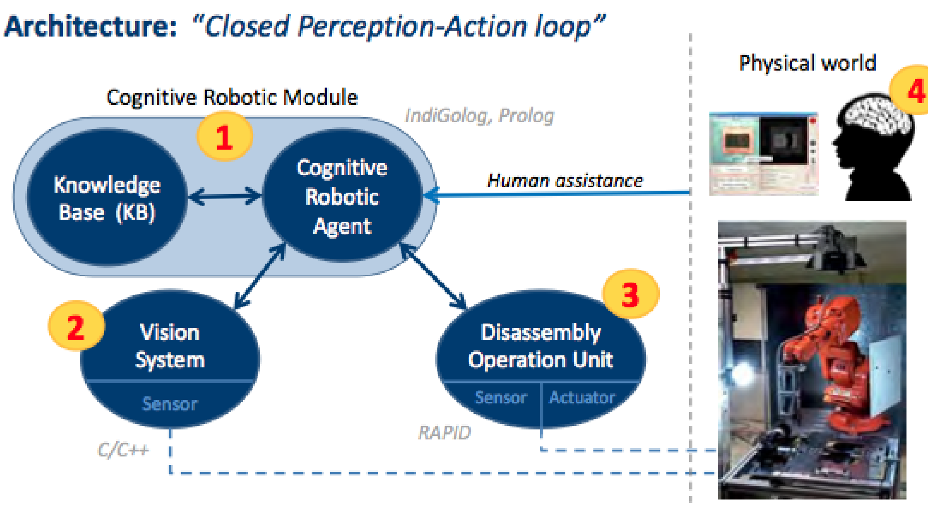


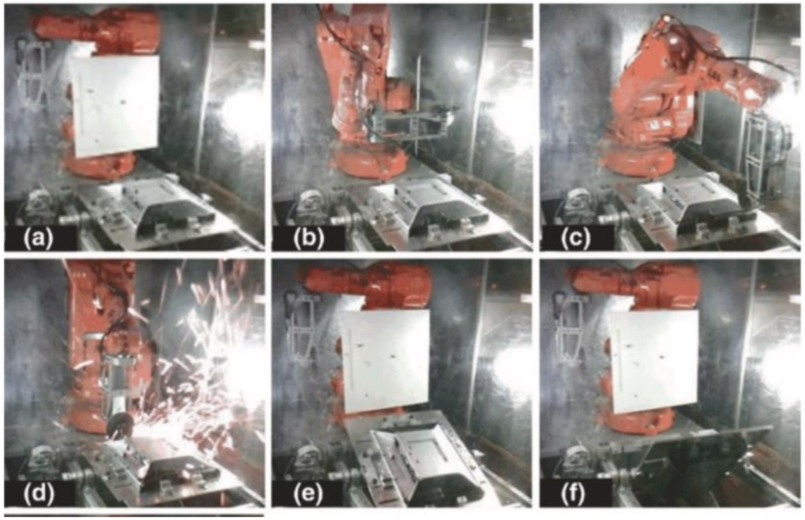
The most promising physical and digital emerging technologies towards **smart de-and remanufacturing systems of the future** are:

Process Stage	Emerging Enabling Technologies
Materials and functions liberation (disassembly and size reduction)	Automated disassembly via cognitive robotics; Human–Robot cooperation; Active disassembly
Sorting and Separation	Automatic Sorting; Robotic Sorting
End-recovery	Solid-state recycling
Inspection	Hyper-Spectral Imaging; Multi-sensor systems; Embedded Sensors; Internet of Things (IoT)
Cleaning	/
Reconditioning	Additive manufacturing; Hybrid additive and subtractive technologies
Logistics	Flexible and reconfigurable automation; Distributed control; Cyber-physical Systems

Emerging technologies - Disassembly

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

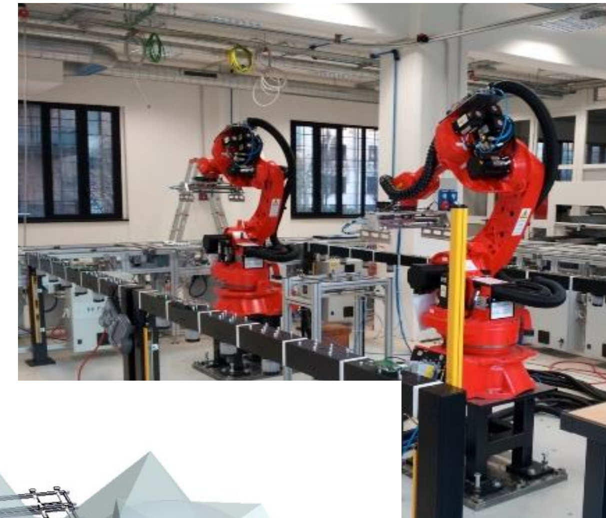


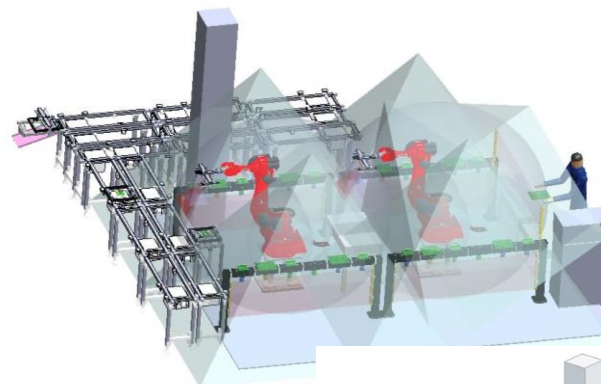


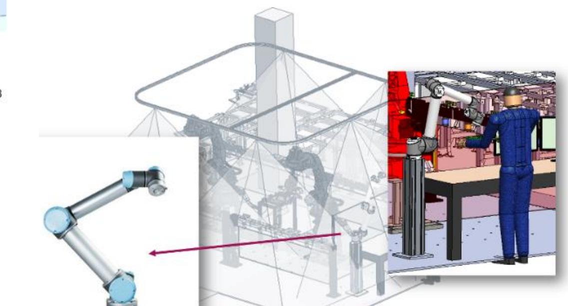
Vongbunyong S, Kara S, Pagnucco M, 2013, Application of Cognitive Robotics in Disassembly of Products" CIRP Annals - Manufacturing Technology 62/1:31–34.
Vonbungyong, S., Kara, S., Pagnucco, M., 2012, Basic Behaviour Control of the Vision-based Cognitive Robotic Disassembly Automation, Journal of Assembly Automation, 33/1:38-56.

Emerging technologies - Disassembly

Emerging Technology: Collaborative disassembly by human-robot cooperation	Shared workspace between the robot and the human.
	The robot executes low value tasks, while the human performs knowledge-intensive tasks (e.g. extraction of valuable components)
Contribution to smart de-and remanufacturing systems	High system flexibility
	Process plans re-allocation between the human and the robot to handle variability
	Applicable to small lots
Current TRL	TRL: 7-8
Limitations and challenges	- Operators' safety issues - Installation costs - Need skilled operators





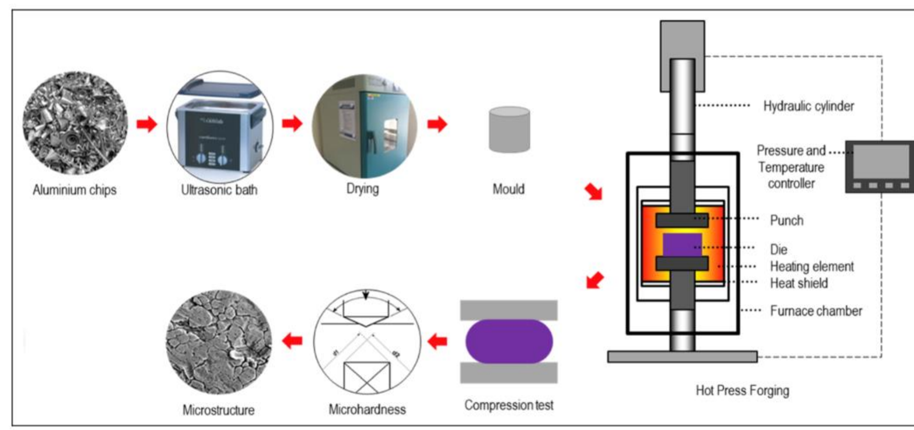


Robot-Human Cooperation in PCBs disassembly

Kruger, J., Lien, T.-K., Verl, A., 2009, Cooperation of human and machines in assembly lines, Annals of the CIRP, 58/2:628–646.
Pellegrinelli, S., Moro, F.-L., Pedrocchi, N., Molinari Tosatti, L. Tolio, T., 2016, A probabilistic approach to workspace sharing for human–robot cooperation in assembly tasks, Annals of the CIRP, 65/1:57–60.

Emerging technologies – End-recovery

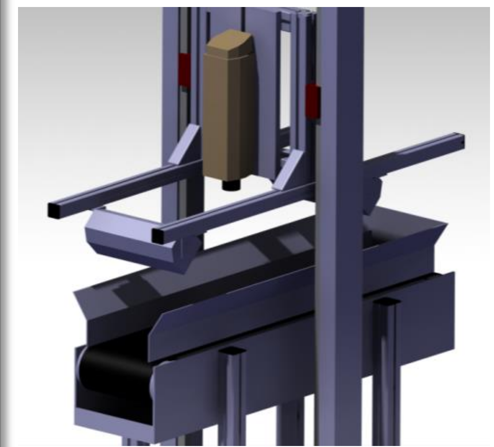
Enabling Technology: Solid-State Recycling	Re-production of light metals in bulk and sheet components without material fusion
	Provides an energy-efficient alternative to metallurgical processes
Contribution to smart de-and remanufacturing systems	Direct forming of the recovered material into the final component
	Enables manufacturer re-use of recovered material and waste
Current TRL	TRL: 8-9
Limitations and challenges	Needs highly purified material in input (e.g. metal chips) Applicable only to a small range of metals

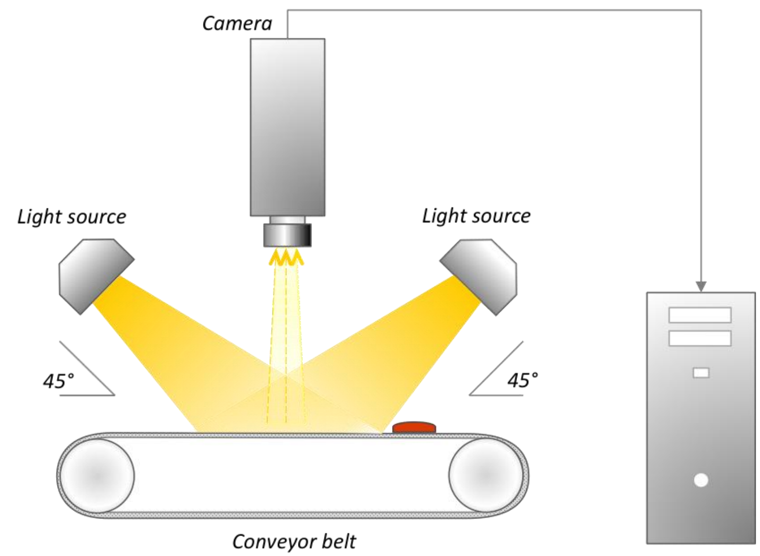


Shamsudin, S., Lajis, M.-A., Zhong, Z.-W., 2016, Solid-state recycling of light metals: A review, Advances in Mechanical Engineering, 8/8:1–23.
Duflou, J.-R., Tekkaya, A., Haaseb, M., Weloc, T., Vanmeenseld, K., Kellensa, K., Dewulf, W., Paraskevasa, D., 2015, Environmental assessment of solid state recycling routes for aluminium alloys: Can solid state processes significantly reduce the environmental impact of aluminium recycling?, Annals of the CIRP, 64/1:37–40.

Emerging technologies – Inspection

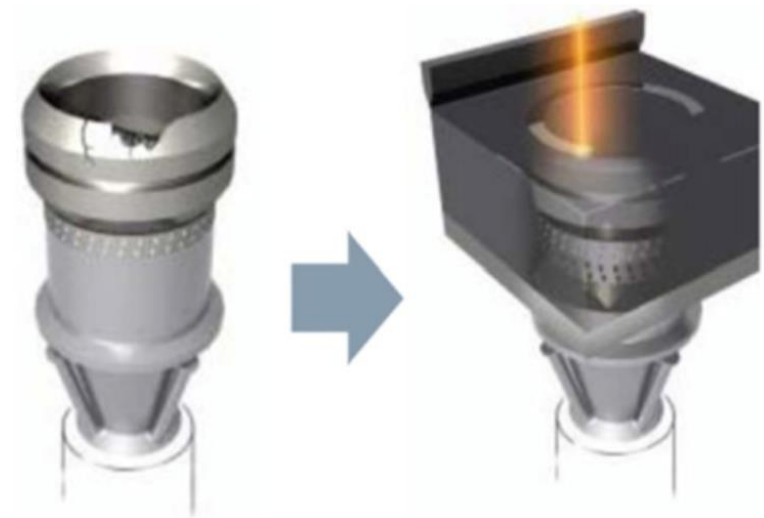
Emerging Technology: HyperSpectral Imaging	Detection (signal)
	Recognition (objects)
	Classification
	Material Characterisation
Contribution to smart de-and remanufacturing systems	On-line material characterization: full material data storage and traceability
	Enables in-line monitoring and process control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



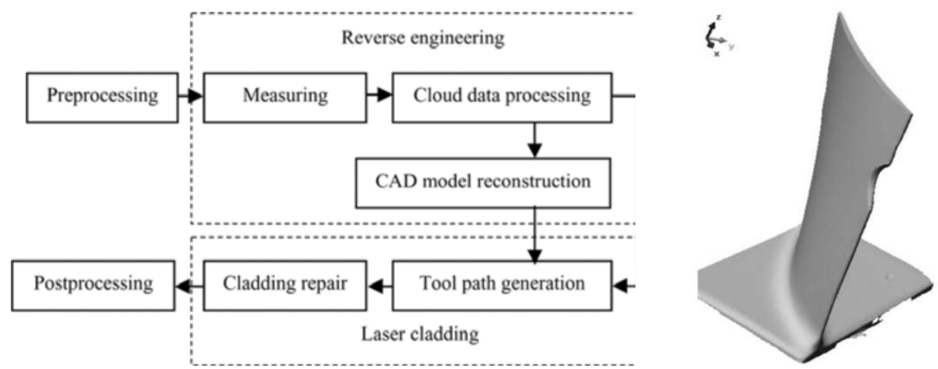


Picón, A., Ghita, O., Bereciartua, A., Echazarra, J., Whelan, P.-F., Iriondo, P.-M., 2012, Real-time hyperspectral processing for automatic nonferrous material sorting, Journal of Electronic Imaging, 21/1.
Picón, A., Ghita, O., Whelan, P.-F., Iriondo, P.-M., 2009, Fuzzy Spectral and Spatial Feature Integration for Classification of Nonferrous Materials in Hyperspectral Data, IEEE Transactions on Industrial Informatics, 5/4:483-494.

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



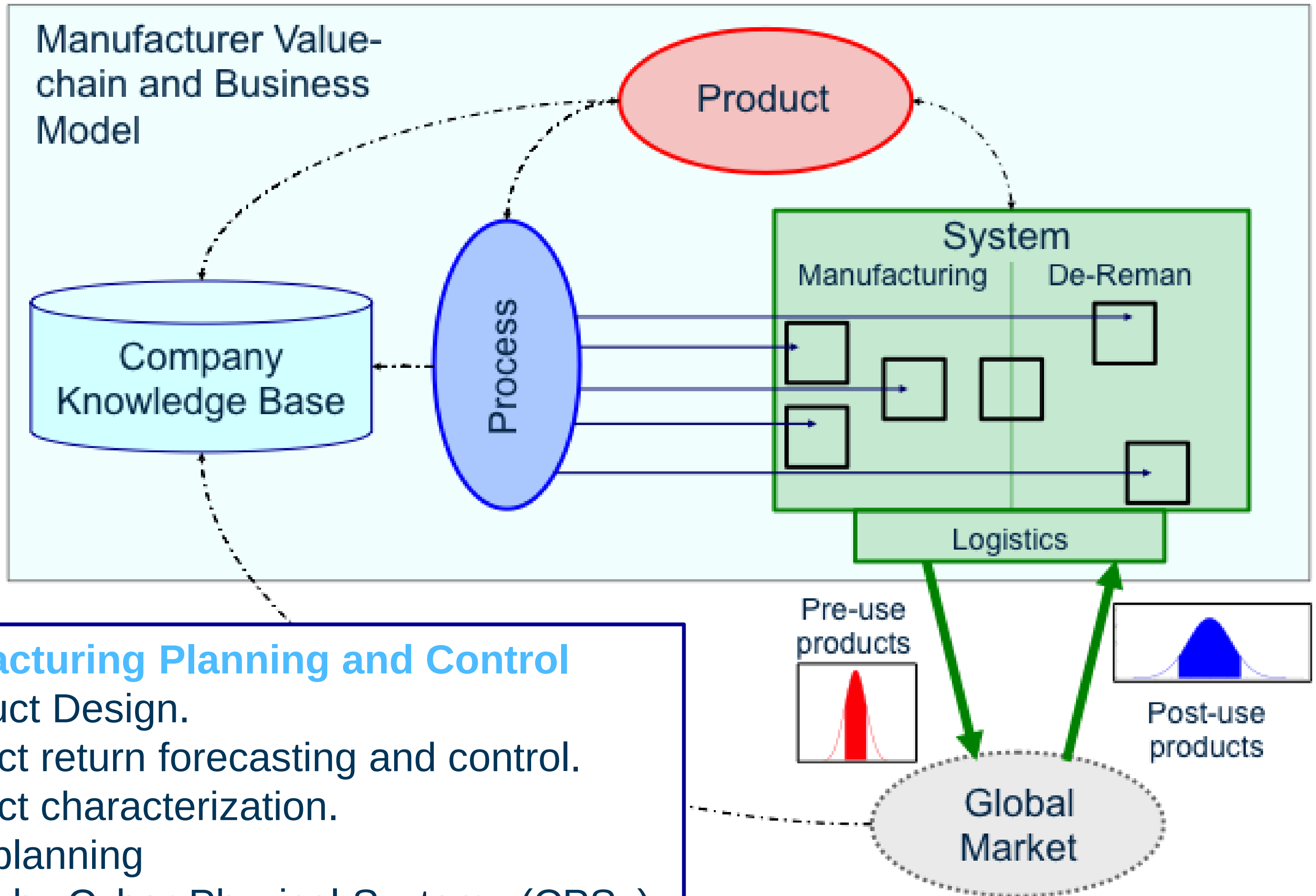
Gas turbine burner tip repair (Siemens AG 2014)



Aeronautics turbine blades

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

De-and Remanufacturing design, planning, and control



De-and Remanufacturing Planning and Control

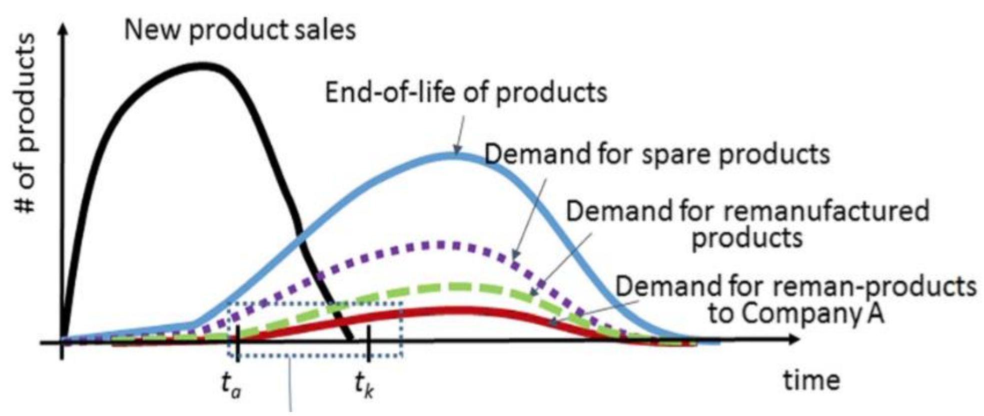
- Impact of Product Design.
- Post-use product return forecasting and control.
- Post-use product characterization.
- Process-chain planning
- Process control by Cyber-Physical Systems (CPSs).
- Production planning and control.

De-and Remanufacturing System Design

- Business Models.
- System engineering.
- Reverse logistics network configuration.

Post-use product return forecasting and control

Problem: how can the quantity and quality of return products be forecasted and controlled for robust de-and remanufacturing planning?



Statistical methods and tools have been developed to forecast product returns as a function of:

- **Technological factors:** innovation cycles, product reliability and durability.
- **Non-technological factors:** social factors, users' behavior.

Matsumoto, M., Umeda, Y., Tsuchiya, S., Tang, L., 2016, Development of Demand Forecasting Model for Automotive Electric Component Remanufacturing, Electronics Goes Green EGG Conference, Berlin, Germany.

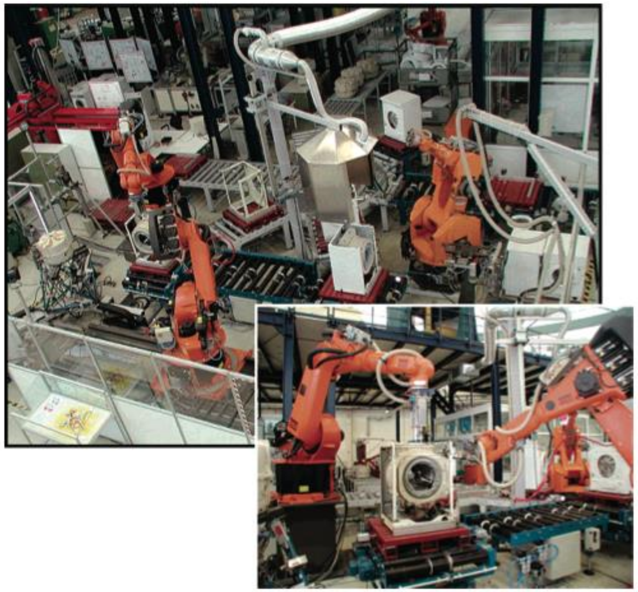
Takata, S., Sakai, T., 2009, Modelling product returns taking sales modes into account, International Journal of Automation Technology, 3:71-76.

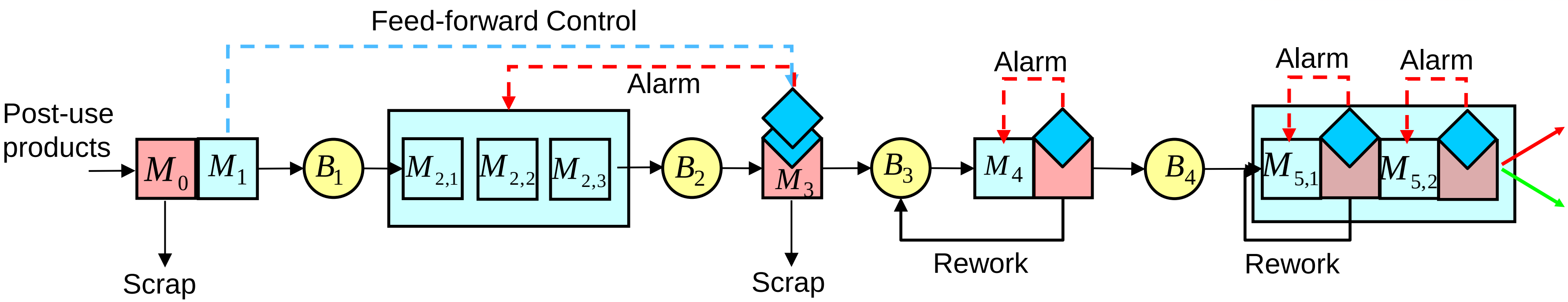
Kara, S., Mazhar, I.-M., Kaebernick, H., 2004, Lifetime Prediction of Components for Reuse: An Overview, Int. Journal of Environment and Technology, 4/4:323-348.

Kara, S., 2010, Assessing Remaining Useful Lifetime, Wiley Encyclopedia of Operations Research and Management Science, 1-14.

De-and Remanufacturing systems engineering

Problem: to design de-and remanufacturing systems in order to achieve target performance goals.





Available methods usually consider **different circular economy options in isolation**, lacking a manufacturer-centric view.

Colledani M., Tolio T., "*Integrated Process and System Modelling for the Design of Material Recycling Systems*", CIRP Annals - Manufacturing Technology, Volume 62, Issue 1, 2013, Pages 447-452.

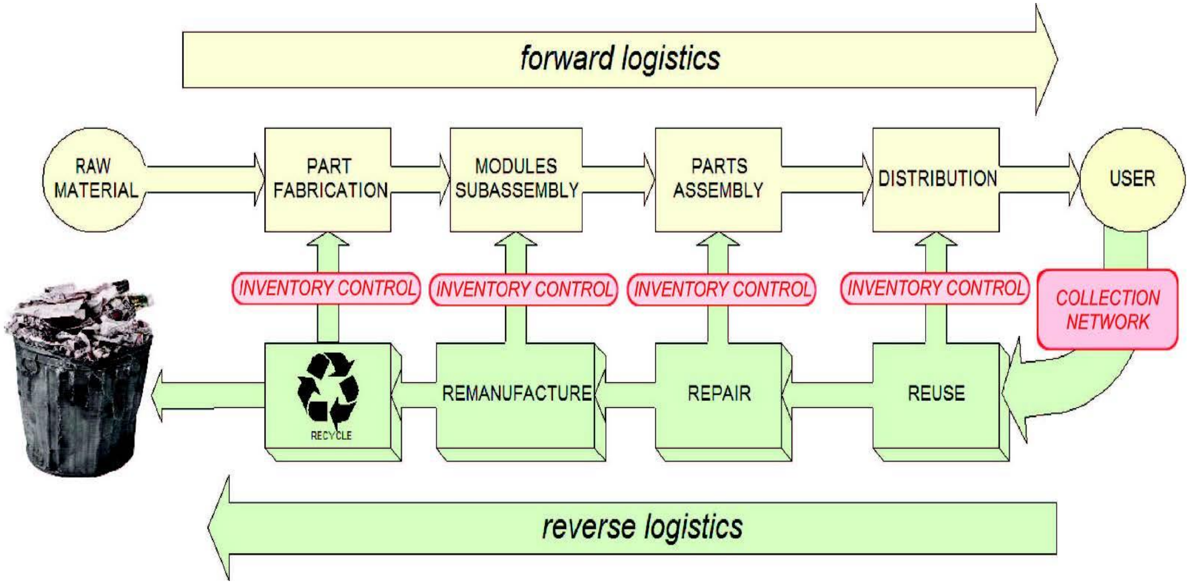
Bouzon, M., Rodriguez, C.-M., Queirez, A. 2012. Cell layout applications in product recovery: A lean proposal to increase efficiency in in remanufacturing, China business review, 11/5:467-475.

Choi, J.-N., Fthenakis, V., 2011. Design and Optimization of Photovoltaics Recycling Infrastructure, Environ. Sci. Technol., 44:8678–8683.

Aksoy, H.-K., Gupta, S.-M., 2010, Near optimal buffer allocation in remanufacturing systems with N-policy, Comp. and Industrial Eng., 59/4:496-508.

Reverse Logistics Network configuration

Problem: to (i) select the number and location of facilities, including collection centers, disassembly and recovery facilities, and distribution centers, to (ii) determine their capacity and (iii) the material flow, in order to gurantee the overall network efficiency.



Most recent approaches consider **a manufacturer-centric hybrid forward and reverse logistics network**, operating pre-use and post-use product distribution.

Kara, S., Rugrungruang, F., Kaebernick, H., 2007, Simulation Modelling of Reverse Logistics Networks, Int. Journal of Production Economics, 106:61-69.
Mirmajlesi, S.-R., Shafaei, R., 2016, An integrated approach to solve a robust forward/reverse supply chain for short lifetime products, Comp. & Ind. Eng., 97:222- 239.

Future Research Priorities

Relevant gaps have been identified which constitute future research priorities in view of the implementation of new manufacturer-centric circular economy businesses.

- **Circular Economy Engineering**
- **Design of circular factories**
- **Zero-defect de-and remanufacturing**
- **Automation level in de-and remanufacturing systems**
- **Adaptable de-and remanufacturing systems**
- **Digital factory technologies**
- **Legislation aware de-and remanufacturing design and planning**
- **New circular business models and value-chains**

Social benefits of De-and Remanufacturing

Developing new technologies, systems and strategies for De-and Remanufacturing will bring social benefits worldwide:

- **New jobs** coupled with technological and automation innovations, due to the increased competitiveness for the manufacturers;
- **New efficient and effective technologies and systems** to be exported also to emerging countries;
- **Cheaper products (frugal innovation. e.g. Philips Healthcare):** it enables manufacturers to offer affordable high-quality products in the emerging global markets.
- **Customers Loyalty** by offering to customers a range of services covering more than just the sale and maintenance phases.
- **Environmental and Energy savings:** raw material extraction is much more demanding from an energy point of view;
- **Robustness** in terms of independency from fluctuations and turbulence in the primary material market (e.g. for rare earths).

For more information:

<u>Tullio Tolio</u>, *Alain Bernard, Olga Battaia, Marcello Colledani, Joost Duflou, Sami Kara, Guenther Seliger, Shozo Takata*

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Design, Management and Control of Demanufacturing and Remanufacturing Systems

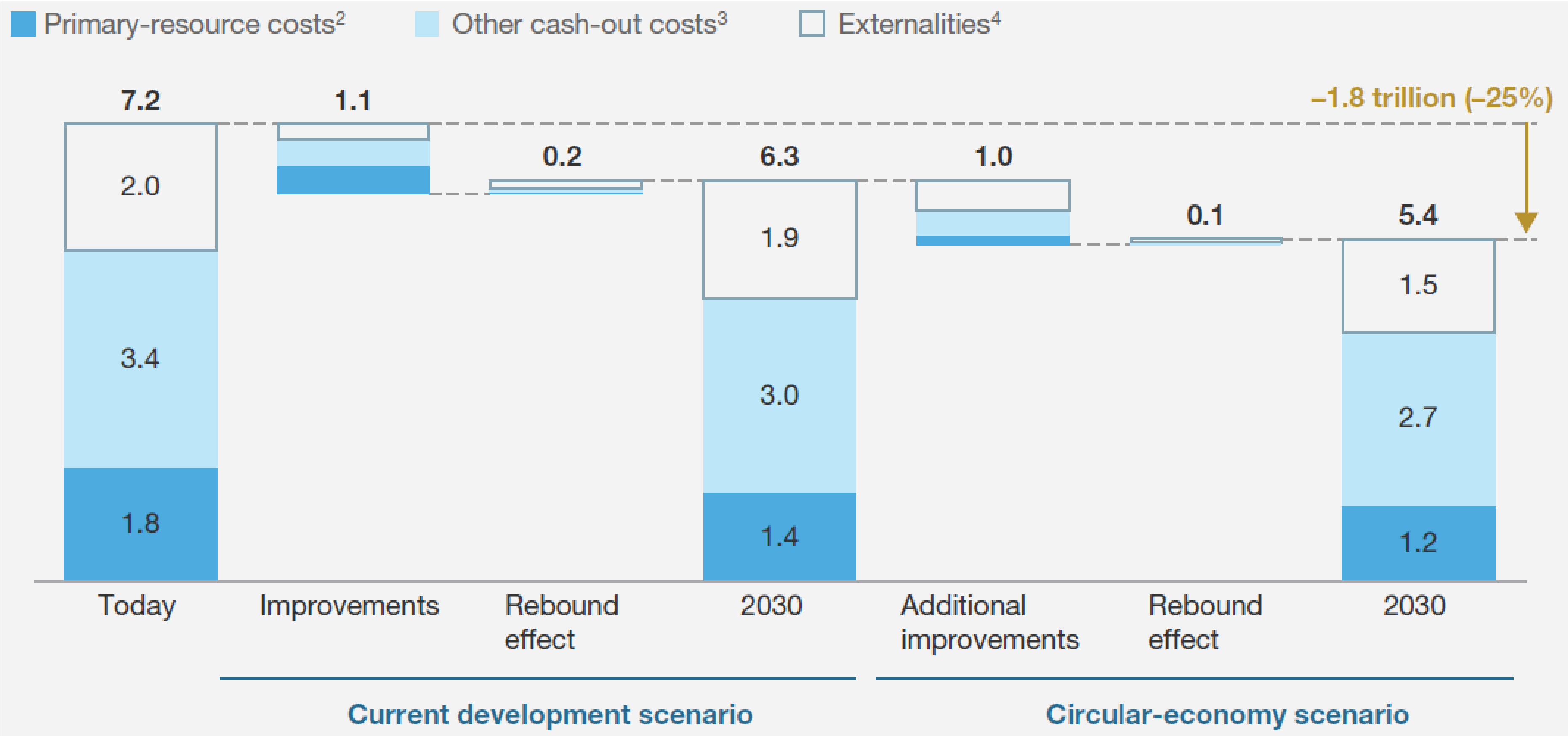
Tullio Tolio*[1,2] (1), Alain Bernard[3] (1), Olga Battaia[7], Marcello Colledani[1,2] (2), Joost Duflou[6] (1), Sami Kara[4] (1), Guenther Seliger[5] (1), Shozo Takata[8] (1).

1 Politecnico di Milano, Department of Mechanical Engineering, Via la Masa, 1, 20156, Milan, Italy.
2 ITIA-CNR, Institute of Industrial Technologies and Automation, Via Bassini 15, 20133, Milan, Italy
3 Ecole Centrale de Nantes, 1, rue de la Noë, 92101, Nantes, France
4 The University of New South Wales, Faculty of Engineering, 2052, Sydney, Australia.
5 TU Berlin - IWF, Pascalstr. 8-9, 10587, Berlin, Germany
6 KU Leuven, Celestijnenlaan 300, 2422 3001 Heverlee – Leuven, Belgium
7 Institute Superieur de l'Ae´ronautique et de l'Espace, ISAE-Supaero, Toulouse, France.
8 School of Creative Science and Engineering, Waseda University, Tokyo, Japan.

2017 Cross-STC Keynote Paper.
Supporting STCs: STC O, STC Dn, STC A.

Economic Benefits of Circular Economy

Shifting toward a circular economy model would deliver better outcomes for the European economy and yield annual benefits of up to €1.8 trillion by 2030.

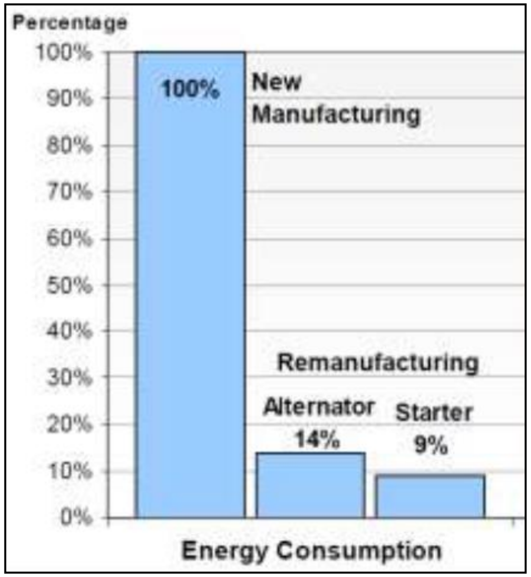


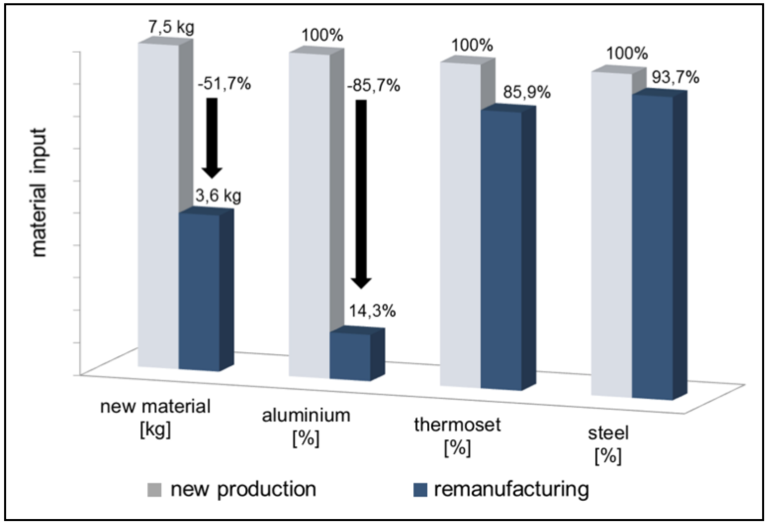
Annual total cost of producing and using primary resources, EU-27, euros trillion

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

Environmental benefits of De-and Remanufacturing

De-and Remanufacturing supporting Circular Economy practices have potential to bring 80%–90% savings in raw materials and energy consumption with respect to the production of the same goods in the traditional linear model.



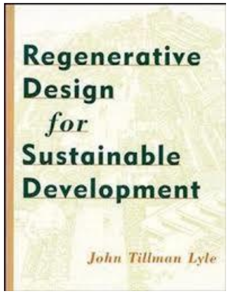


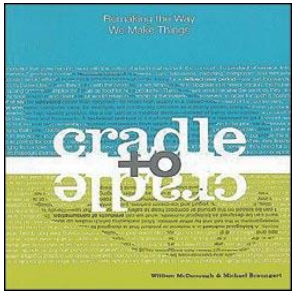
Example: Benefits of Remanufacturing in the automotive industry (Electronic Air Control unit).
[*Source Kohler: D., Mechatronic Remanufacturing at Knorr-Bremse Commercial Vehicles Systems (CVS*)].

Without a rethinking of how society uses materials in the linear economy, elements such as gold, silver, indium, iridium, tungsten and many others vital for industry could be depleted within the next 5 to 50 years.

Evolution of the concept of *Circular Economy*

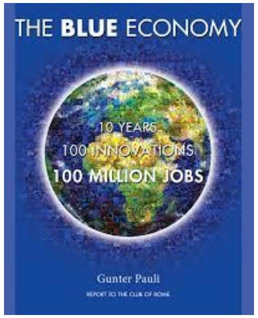
Theory of “***Regenerative Design***” by Lyle introduced in the late 70s the idea of linking sustainable development to the concept of resource regeneration.





“***Cradle-to-Cradle***” design: It is an economic, industrial and social framework that aims at creating systems that are not only efficient but also essentially waste free. This model was applied to industrial design and manufacturing, social systems and urban environments.

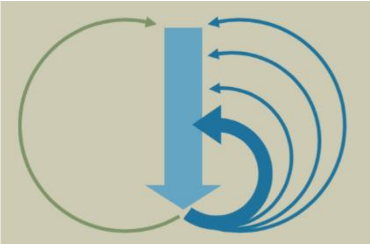
“***Industrial Ecology***”: the study of material and energy flows through industrial systems. It adopts a systemic point of view, designing production processes in accordance with local ecological constraints, while looking at their global impact from the outset.



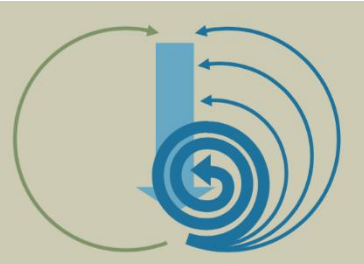
“***Blue Economy***”: Originated by Pauli, collected practical cases where the resources are connected in cascading systems and the waste of one product becomes the input to create a new cash flow.

Circular Economy: Value Creation Mechanisms

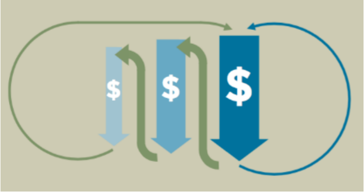
The modern concept of "***Circular Economy***" can be attributed to the MacArthur Foundation. Value is created through four major mechanisms:



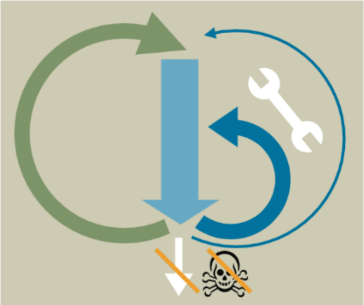
The power of inner circle: the closer the product gets to direct reuse, the larger the cost savings will be in terms of material, labour, energy, capital and the associated externalities.



The power of circling longer: value created by keeping products, components, and materials in use longer within the Circular Economy. This can be achieved by enabling more cycles or by spending more time within a single cycle.

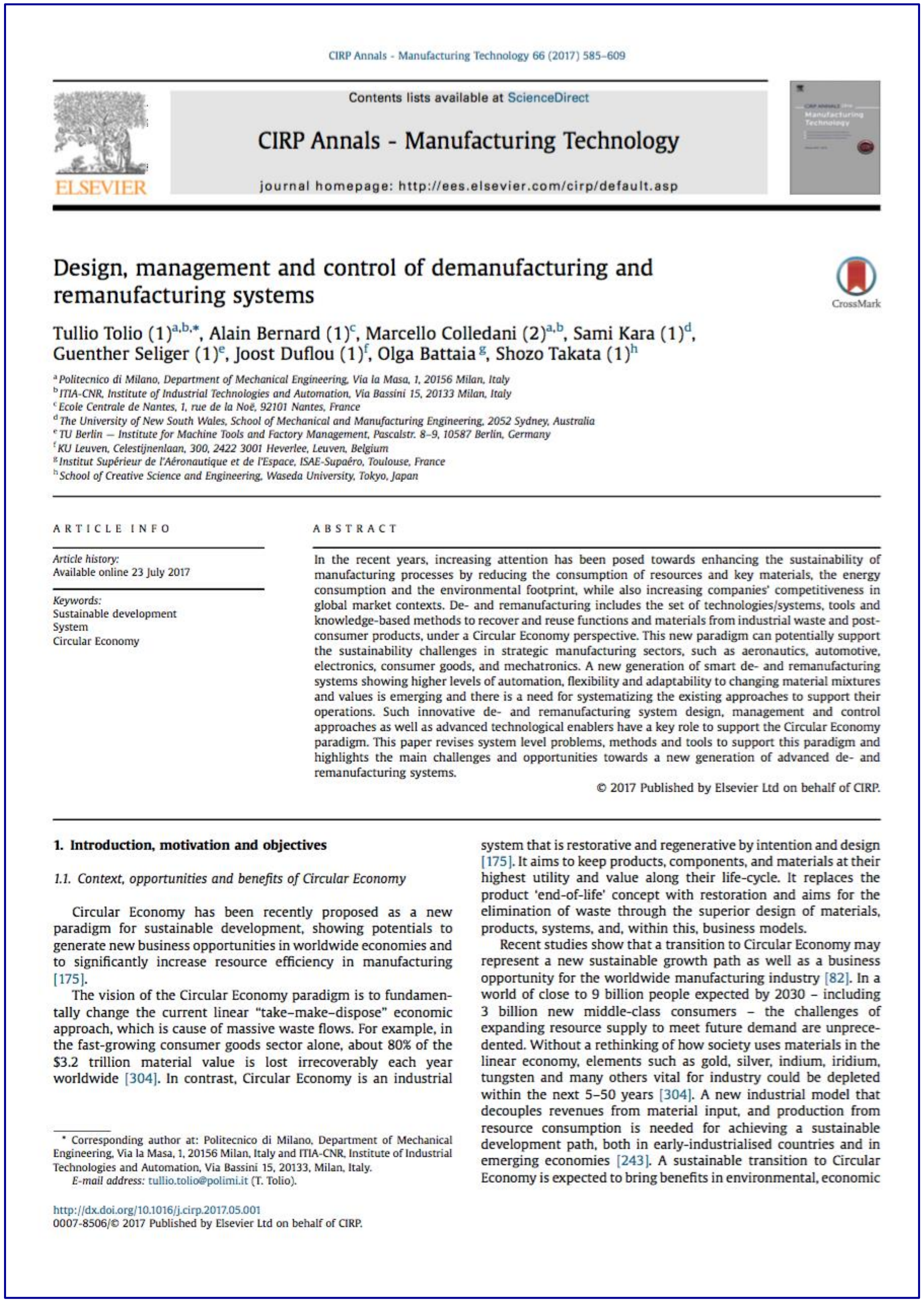


The power of cascaded use: value created by using discarded materials from one value chain as by-products, replacing virgin material in another.



The power of pure circles: uncontaminated material streams increase collection and redistribution efficiency while maintaining quality.

Cross STC Keynote paper in summary



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Design, management and control of demanufacturing and remanufacturing systems

Tullio Tolio (1)[a,b,*], Alain Bernard (1)[c], Marcello Colledani (2)[a,b], Sami Kara (1)[d], Guenther Seliger (1)[e], Joost Duflou (1)[f], Olga Battaia[g], Shozo Takata (1)[h]

[a] Politecnico di Milano, Department of Mechanical Engineering, Via la Masa, 1, 20156 Milan, Italy
[b] ITIA-CNR, Institute of Industrial Technologies and Automation, Via Bassini 15, 20133 Milan, Italy
[c] Ecole Centrale de Nantes, 1, rue de la Noë, 92101 Nantes, France
[d] The University of New South Wales, School of Mechanical and Manufacturing Engineering, 2052 Sydney, Australia
[e] TU Berlin — Institute for Machine Tools and Factory Management, Pascalstr. 8–9, 10587 Berlin, Germany
[f] KU Leuven, Celestijnenlaan, 300, 2422 3001 Heverlee, Leuven, Belgium
[g] Institut Supérieur de l'Aéronautique et de l'Espace, ISAE-Supaéro, Toulouse, France
[h] School of Creative Science and Engineering, Waseda University, Tokyo, Japan

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ABSTRACT

In the recent years, increasing attention has been posed towards enhancing the sustainability of manufacturing processes by reducing the consumption of resources and key materials, the energy consumption and the environmental footprint, while also increasing companies' competitiveness in global market contexts. De- and remanufacturing includes the set of technologies/systems, tools and knowledge-based methods to recover and reuse functions and materials from industrial waste and post-consumer products, under a Circular Economy perspective. This new paradigm can potentially support the sustainability challenges in strategic manufacturing sectors, such as aeronautics, automotive, electronics, consumer goods, and mechatronics. A new generation of smart de- and remanufacturing systems showing higher levels of automation, flexibility and adaptability to changing material mixtures and values is emerging and there is a need for systematizing the existing approaches to support their operations. Such innovative de- and remanufacturing system design, management and control approaches as well as advanced technological enablers have a key role to support the Circular Economy paradigm. This paper revises system level problems, methods and tools to support this paradigm and highlights the main challenges and opportunities towards a new generation of advanced de- and remanufacturing systems.

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1. Introduction, motivation and objectives

1.1. Context, opportunities and benefits of Circular Economy

Circular Economy has been recently proposed as a new paradigm for sustainable development, showing potentials to generate new business opportunities in worldwide economies and to significantly increase resource efficiency in manufacturing [175].

The vision of the Circular Economy paradigm is to fundamentally change the current linear "take–make–dispose" economic approach, which is cause of massive waste flows. For example, in the fast-growing consumer goods sector alone, about 80% of the $3.2 trillion material value is lost irrecoverably each year worldwide [304]. In contrast, Circular Economy is an industrial system that is restorative and regenerative by intention and design [175]. It aims to keep products, components, and materials at their highest utility and value along their life-cycle. It replaces the product 'end-of-life' concept with restoration and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models.

Recent studies show that a transition to Circular Economy may represent a new sustainable growth path as well as a business opportunity for the worldwide manufacturing industry [82]. In a world of close to 9 billion people expected by 2030 – including 3 billion new middle-class consumers – the challenges of expanding resource supply to meet future demand are unprecedented. Without a rethinking of how society uses materials in the linear economy, elements such as gold, silver, indium, iridium, tungsten and many others vital for industry could be depleted within the next 5–50 years [304]. A new industrial model that decouples revenues from material input, and production from resource consumption is needed for achieving a sustainable development path, both in early-industrialised countries and in emerging economies [243]. A sustainable transition to Circular Economy is expected to bring benefits in environmental, economic

* Corresponding author at: Politecnico di Milano, Department of Mechanical Engineering, Via la Masa 1, 20156 Milan, Italy and ITIA-CNR, Institute of Industrial Technologies and Automation, Via Bassini 15, 20133, Milan, Italy.
E-mail address: tullio.tolio@polimi.it (T. Tolio).

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Summary figures.

- 8 authors from 3 continents.
- 25 pages.
- 7 industrial real cases.
- 15 figures.
- 311 references.

Processes and Emerging Technologies

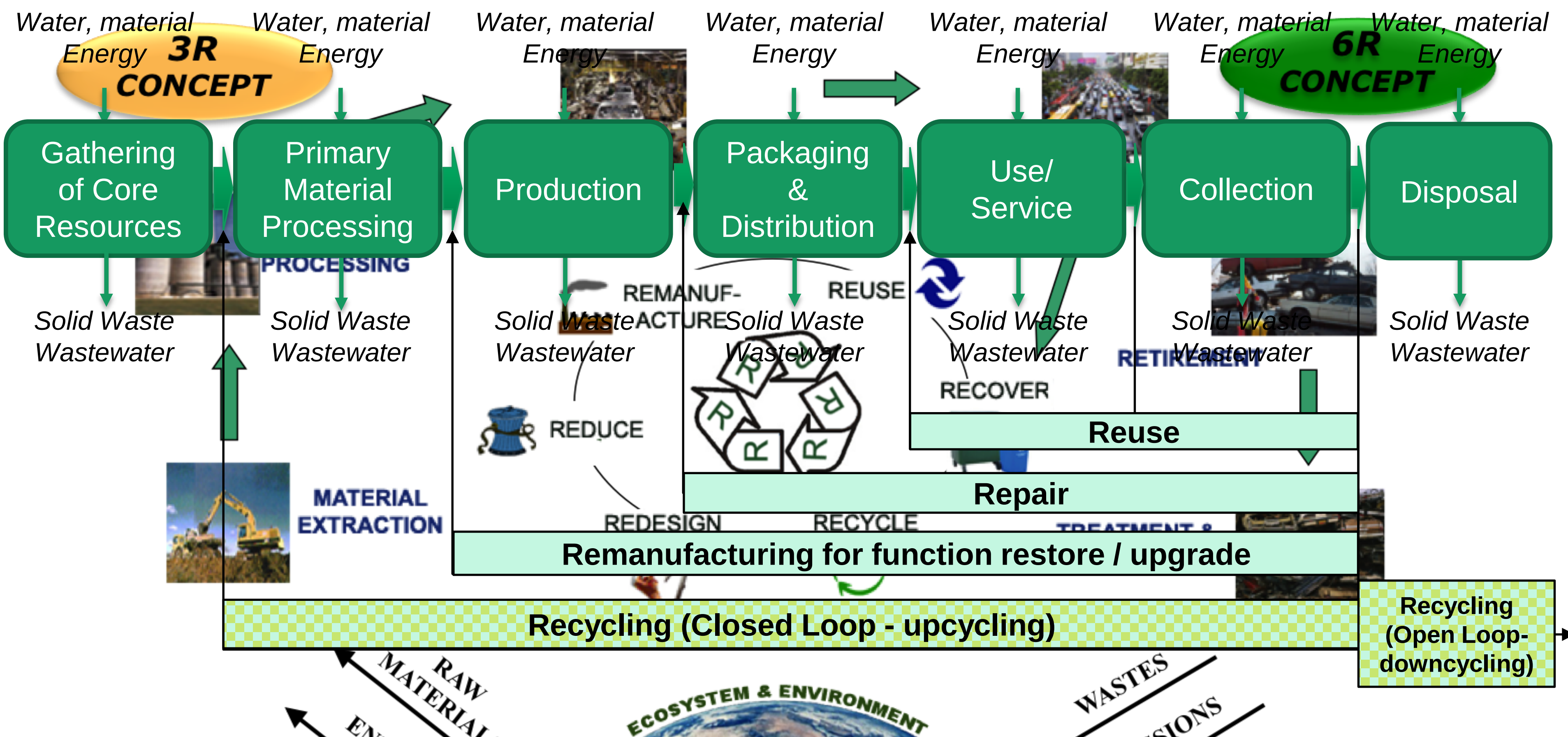
A simple taxonomy of de-and remanufacturing processes is proposed. The goal of this taxonomy is the positioning of each process in a typical de-and remanufacturing process chain, highlighting its function and its scope.

The most promising physical and digital emerging technologies towards **smart de-and remanufacturing systems of the future** are revised.

Process Stage	Emerging Enabling Technologies
Materials and functions liberation.	Automated disassembly via cognitive robotics; Human–Robot cooperation; Active disassembly.
Sorting and Separation.	Automatic Sorting; Robotic Sorting.
End-recovery.	Solid-state recycling.
Inspection.	Hyper-Spectral Imaging; Multi-sensor systems; Embedded Sensors; Internet of Things (IoT).
Reconditioning.	Additive manufacturing; Hybrid additive and subtractive technologies.
Logistics.	Flexible and reconfigurable automation; Distributed control; Cyber-physical Systems.

Key definitions in a value-chain perspective

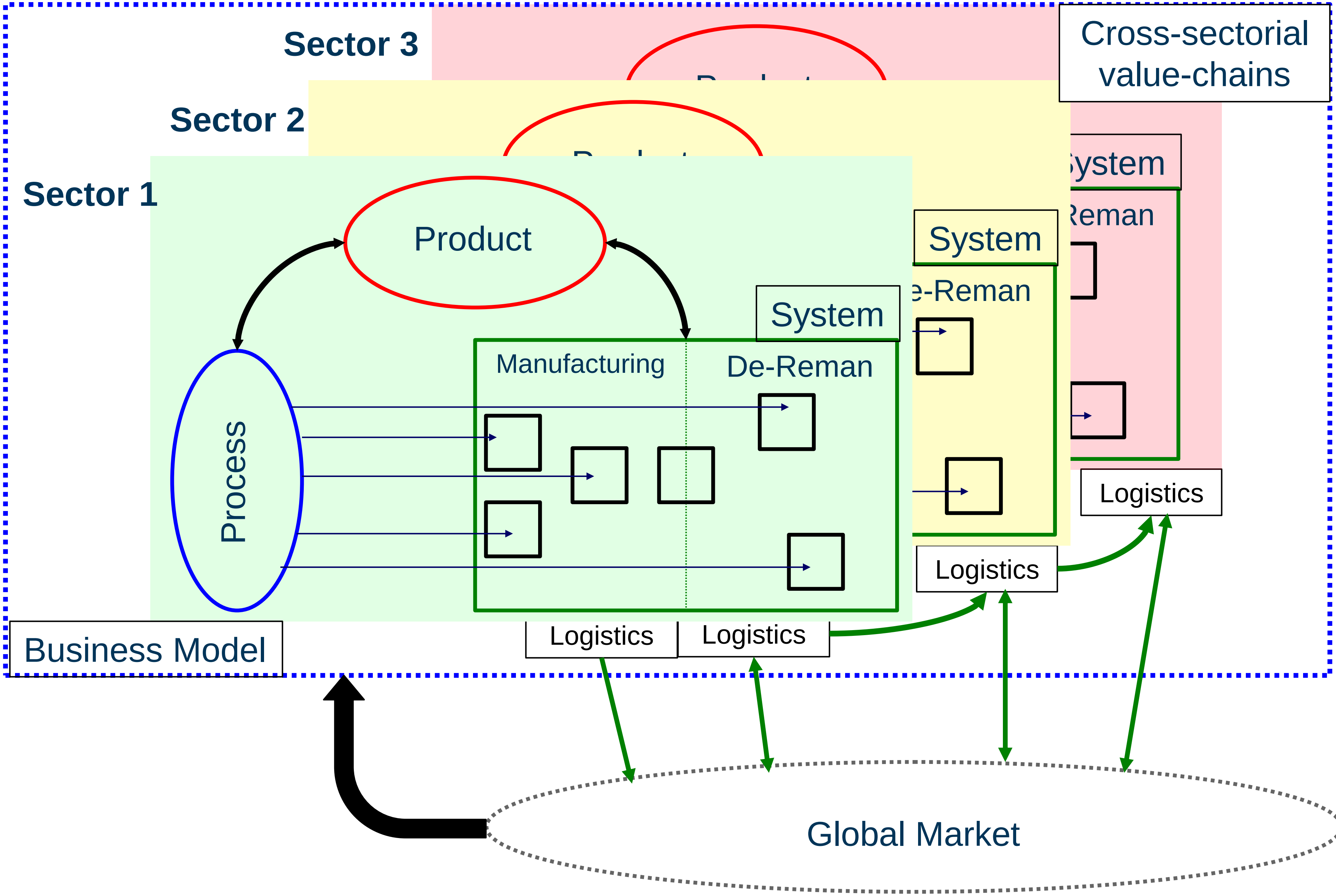
At technical levels, different business options for Circular Economy have been proposed to generate benefits by exploiting different value-creation mechanisms:



What are the operational implications for manufacturers while introducing these Circular Economy business options?

[Parker, D., 2007, An Analysis of the Spectrum of Re-use. Aylesbury, Oakdene Hollins Ltd, for Defra.]
[Parkinson, H.J., Thompson, G., 2003, Analysis and taxonomy of remanufacturing industry practice, Proc. Inst. Mech. Eng., 217:243-256.]
[Apra – Automotive Part Remanufacturers Association, 2012, Remanufacturing Terminology, Remanufacturing Term Guideline.]

De-and Remanufacturing Vision and Objectives



Emerging technologies - Sorting

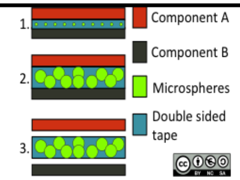
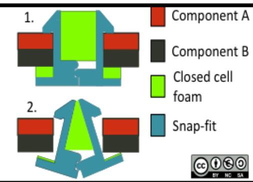
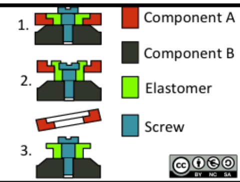
Example: Zen Robotics

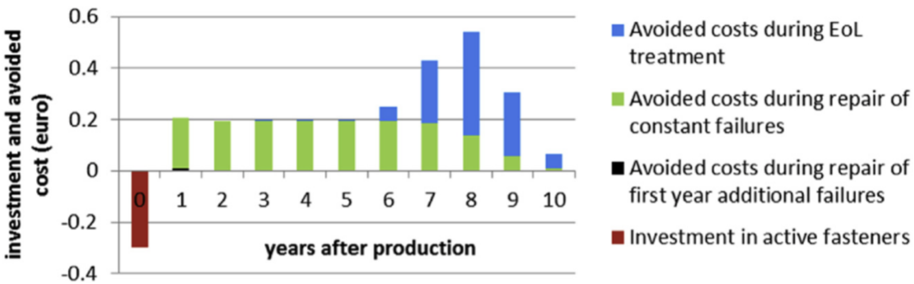
Emerging Technology: automated robotic sorting	Object recognition and robotic actuation of the sorting process
	Easy an safe integration in industrial environment
	Fast sorting
Contribution to smart de-and remanufacturing systems	Easy reconfiguration
	Adaptable to different material properties (size, shape, materials)
Current TRL	TRL: 9 (building waste)
Limitations and challenges	- Complex for small particles. - Complex programming.

Examples Zen Robotics: *Lukka, T.-J., Tossavainen, T., Kujala, J.-V., Raiko, T., 2014,* ZenRobotics Recycler – Robotic Sorting using Machine Learning, Sensor Based Sorting.

Emerging technologies – Disassembly

Emerging Technology: Active Disassembly	Reversible and detachable joints for active disassembly. Life-cycle cost reduction
Contribution to smart de-and remanufacturing systems	Fast localization of fasteners
	Short and repeatable disassembly tasks.
Current TRL	TRL: 7-8
Limitations and challenges	- Complex product design. - Initial cost - Interaction with product operating conditions.

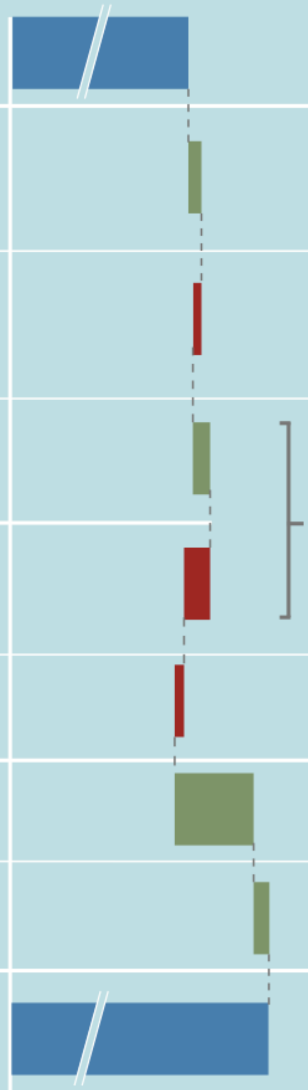
Trigger	Temperature	Pressure	Impulse
Working principle	Phase change materials	Compression of closed-cell foam	Damping by elastomer
Example			
Required installation	Oven	Pressure room	Manual disassembly station



Peeters, J., Van den Bossche, W., Devoldere, T., Vanegas, P., Dewulf, W., Duflou, J., 2015, Pressure-sensitive fasteners for active disassembly, The International Journal of Advanced Manufacturing Technology, 87/5:1519-1529.
Peeters, J., Vanegas, P., Dewulf, W., Duflou, J.-R., 2017, Economic and environmental evaluation of design for active disassembly, Journal of Cleaner Production, 140:1182–1193.
Duflou, J.-R., Willems, B., Dewulf, W., 2006, Towards self-disassembling products - Design solutions for economically feasible large-scale disassembly, Innovation in Life Cycle Engineering and Sustainable Development: 87-110.

Social Benefits at European Level: effect on jobs

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



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

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

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