WORLD ECONOMIC FORUM

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White Paper

Making Manufacturing Sustainable by Design

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Reuse, remanufacturing and recycling – a hidden pathway to a more circular economy

Although more than 50% of the world's total energy is consumed by manufacturing-related activities, advanced manufacturing technologies offer companies dramatic opportunities to boost productivity and competitiveness while simultaneously reducing the environmental impact of manufacturing.

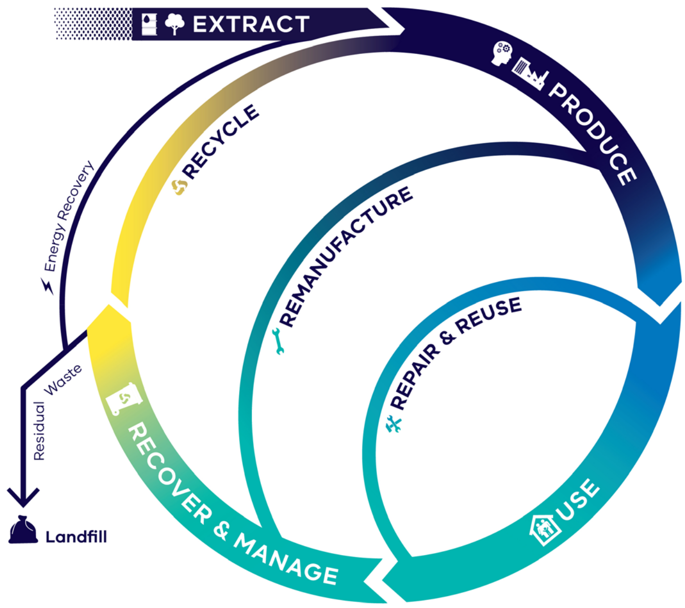
Digital infrastructures enabling efficient manufacturing, longer product life and practical resource recovery are the backbone of the Fourth Industrial Revolution.[1] A perfect example is the use of new technologies to allow design processes for reuse, remanufacturing and recycling ("Re-X")[2] to complement longer product lifetimes. Advanced manufacturing technologies can support Re-X; for instance, additive engineering is being applied to engine and turbine remanufacture, and robotic disassembly to components such as automotive transmission control systems and telecom equipment.

Remanufactured products can save up to 98% of CO_2 emissions compared to equivalent new products, and significantly support our vision of a zero-waste stream. Encouragingly, as a business, remanufacturing already represents a €30 billion market in Europe. Yet in the sectors surveyed, remanufacturing represents approximately 2% (by value) of the manufacturing equivalent. It is probably significantly higher than 2% in the defence sector, which, for reasons of security, is excluded in many analyses. The 2% estimate has been confirmed by a similar earlier study in the USA.[3] Almost all remanufacturing activity is within the business-to-business (B2B) sector, which raises the question of whether the sector can be expanded both within the B2B sector and in the business-to-consumer (B2C) sector.

The challenge perhaps is how to imitate the effort made since the 1980s to increase the rate of some specific material recycling from less than 5% to something closer to 50% today, which required developments in technology, education and policy. There are numerous technical challenges to increasing the level of Re-X associated with advanced manufacturing. Current products and manufacturing processes are generally not designed with any Re-X in mind. Furthermore, at product end-of-life, there is a lack of reliable tools to assess the product condition and the potential for Re-X.[4] From a starting point of less than 2%, it may be possible to make better use of product value retention through reuse, remanufacturing and material recycling a more integral aspect of the economic model.

The current paper focuses on the education and policy aspects of making Re-X an integral part of product design, manufacturing processes and consumer culture. With global temperatures remaining on course to likely exceed the catastrophic 2ºC increase, action by the manufacturing sector remains too slow. If the remanufacturing opportunity were seized by companies and policy-makers, the manufacturing sector would contribute dramatically to the reduction of CO_2 emissions. A key enabler will be a change in thinking via education, and encouragement of Re-X by policy.

To seize the potential of new technologies and accelerate the sustainability agenda, the World Economic Forum Global Future Council on Advanced Manufacturing and Production (GFC) identified a series of existing programmes that could be accelerated, and developed a set of recommendations to help remove existing constraints and provide new incentives to allow remanufacturing, reuse and recycling to take off.



Source: Victoria State Government, https://www.environment.vic.gov.au/sustainability/circulareconomy

Existing initiatives in support of reuse, remanufacturing and recycling

The regulatory frameworks and business models of the past century have generally incentivized the traditional "production and consumption" model of the current linear economy and not the one of "share and care". The entire recycling, reuse and remanufacturing goal is hampered by the business model of designing for a limited life without upgradability or repairability, leading to short-term product replacement, less value to consumers, and waste, including toxic waste, in landfills and oceans around the world.

A number of policies over the past few decades have been devised to encourage and support Re-X. The earliest examples were primarily locally driven efforts towards recycling, which included significant aspects of consumer education. As mentioned earlier, this has been successful in increasing the recycling of some materials to as high as 50%. More recently, there have been initiatives to decrease the environmental impact through practices, policy and education to support all aspects of Re-X, which might serve as models for future work.

Some policies, such as the Restriction of Hazardous Substances (RoHS) directive, had an indirect but arguably positive effect on all aspects of Re-X. RoHS applied to electrical and electronic products sold in the EU and thus had a global impact on manufacturers, increasing the recyclability of products by removing the burden of hazardous materials.[5] Similarly, the Basel Convention, designed to minimize the amount and toxicity of wastes generated, was amended in 2019 to make global trade in plastic waste more transparent and better regulated. This regulation will hopefully stimulate consideration of end-of-life issues during the design of products.[6] Similarly, "Right to Repair" legislation,[7] under consideration in Europe and in some US states, is intended to reduce volumes of waste and push manufacturers to make dependable, longer-life products that are easier to maintain. Manufacturers would also have to offer replacement parts, and in some cases repair goods when they fail.

Note that the above policies and regulations are relatively new and their impacts are yet to be fully determined.

A number of opportunities supporting education and the provision of design tools have been developed by a variety of non-profit and business organizations. Green Business Certification, a third-party verification organization, has since 2017 administered "TRUE Zero Waste" certification, a programme for businesses to assess performance in reducing waste and maximizing resource efficiency.

The Designed for Discard (D4D) programme of the Environmental Research and Education Foundation promotes research and educational initiatives to promote recycling practices of manufactured products. D4D provides opportunities to transform the way manufacturers, brands, retailers, waste companies and consumers work together to recover maximum economic and environmental value from waste materials.[8] Prize competitions, such as the US Department of Energy's "Battery Recycling Prize",[9] have been shown to be effective in stimulating novel approaches to the challenges in this arena.

More corporations are developing programmes to enable better transparency and environmental stewardship through labelling of products and educating their customers. For example, Schneider Electric developed its Green Premium™ programme, with a target to cover 75% of its sales by 2020, so that customers have a clear understanding of both the environmental and business impacts of their choices. The programme also allows Schneider and its customers to stay ahead of regulations across numerous international markets.[10]

The examples above are models for how education plus design and analysis tools can be used to educate both consumers and industrial designers, enabling companies to assess the impact of their products and processes.

Opportunities for companies, governments, academia and civil society

The vision is to build an efficient, effective end-of-life system to retain material and energy value. This will require reconfiguring supply chains and partnerships to enable the option of product take-back with value retention services. To be effective, more products will have to be designed with a predetermined end-of-life value, balanced with the use of the product and potential impacts. A major factor enabling success is the infrastructure available for consumers to return the used product by a method that will become a resource, whether that is by returns to manufacturers or via local recycling collection. The following actions can enable success.

- Require support from companies either directly or via third parties to take back any type of major manufactured product.

- Ensure infrastructure is available and easy to use for recycling simple, high-value or high-energy content items such as aluminium beverage cans.

- Include exceptions for products that have complexities (e.g. medical supplies or potentially infectious products, which would necessitate a different disposal stream).

Capturing the full value of Re-X will require many changes to current business practices, some of which are described below. Encouragement and education by governments and universities, and sharing by companies, on product and manufacturing process design for minimal impact on the environment and climate change, less material use, repairability, and recovery of both embedded energy and critical materials at end-of-life, are vital.

– **Design products for longer effective life**
  Integrate design for repairability and durability into the product design process. Performance-based (non-prescriptive) regulations are especially desirable to promote innovation and design optimization, as well as ensuring access to safe, secure repair and refurbishment operations. Additional upfront costs are accounted for by reduced lifetime costs in this approach. Higher-quality products designed for long life also make reuse and remanufacturing more effective and cost-efficient. CYBERDINE Inc., for example, is designing modularized products to preserve interchangeability when updated/improved device components need to be replaced. Their remanufacturing procedure allows to reuse 73% of product parts, which result in a saving of costs up to 88% compared to manufacturing the device anew.

– **Explore new business models – products as a service**
  Transitioning from product sales models to models that encourage product returns and extended use can facilitate transition to a circular economy. For example, rental or performance models (including subscriptions, leasing, product-as-a-service etc.) where equipment remains under the ownership of the manufacturer/trader. Other models include trade-in programmes that incentivize consumers to return their old products when they upgrade. Product-as-a-service models may be easiest for earliest implementation for B2B or those consumer products where the producer has a direct relationship with the customer.

– **Develop agreed-upon terminology to facilitate alignment**
  A common understanding of terms is the foundation of communication. Legal definitions of terms such as *remanufactured*, *refurbished*, *recovery* (in the sense of recovering value from waste materials), *the circular economy*, *environmental impacts*, *waste* etc. should be created at the international level, acknowledging the work that standards development organizations such as ASTM International and the International Organization for Standardization (ISO) carry out. This effort is fraught with challenges, as exemplified by the numerous efforts to define the single term "remanufactured" along with implications for trade and taxes etc.[12]

– **Adopt standards to facilitate industrial development and trade**
  Established standards are needed to encourage innovation and eliminate bottlenecks in industrial development and trade (e.g. guides to remanufacturing and refurbishing products, guides to waste reduction, guides to implementing circular economies, guides to assessing and comparing the economic, social and environmental impacts of alternative technologies etc.).

– **Disseminate best practices around advanced manufacturing technology**
  Successful manufacturing technology practices around design for recycling, reuse and remanufacturing should be widely publicized, especially among small manufacturers who may not be aware of cutting-edge developments. These practices are easier to disseminate and implement on a broad scale if they are developed as standard guides or standard practices by a standards development organization. Other creative approaches to disseminate and educate regarding best practices are also needed.

– **Raise consumer and customer awareness**
  Standard guides or practices from standards organizations (e.g. ASTM or ISO), plus educational programmes on how best to report the environmental impacts of materials and manufacturing processes to consumers, would help to simplify the message to consumers and help them to avoid deceptive marketing.

– **Increase business awareness of sustainable procurement**
  Raise awareness of best practices – such as allowing OEMs to supply remanufactured substitutes should a new product fail during its guarantee period – and of practices that have unintended consequences – such as non-local procurement or supply chains unnecessarily involving long shipping. These general rules should also be balanced with a full assessment (see "Monitoring the effectiveness of new approaches" below). Sometimes non-local procurement may be environmentally preferable due to resource location, processes implemented and production efficiency. Guides on assessing and comparing economic, social and environmental impacts are needed.

– **Promote certificates and clear labelling programmes**
  Raise consumer awareness of both green aspects and reliability via voluntary certificates and labels for buyers of remanufactured products or components. Promote this so that labels are widely recognized and used, and guarantee the same warranty and tax breaks for consumer products and industry. Clear labelling of products and components detailing the percentage of

parts remanufactured or made from recycled materials is also needed. The effectiveness of this nascent practice is demonstrated in the shoe industry, where consumers pay a premium for shoes made of recycled plastic.[13] This could again be developed as a standard, in particular, creating guidelines and a standardized labelling scheme for recycled/remanufactured content to create a standard method for assessment and labelling on which consumers can rely. In addition, third-party companies are likely to begin to create certification programmes – as has already been undertaken with compostable plastics.

- **Evolve education and training, and develop new tools to facilitate Re-X in design**
  Changes are needed to post-secondary education systems, particularly the training of engineers to focus beyond the standard values of cost and performance, to include minimal environmental impact, climate change, reduced material use, greater repairability, longer life and recovery of critical materials at end-of-life.[14] At present, environmental concerns are typically a speciality or one-off course. The concept needs to be integrated into the thought process in all design. This would likely require a change in accreditation requirements for engineering schools: e.g. to require credit for consideration of these factors in senior design projects.

  New tools for such design considerations are needed. Currently, databases for material properties and cost are widely available, whereas similar information on energy and environmental footprint are not. For example, tools such as Ashby plots,[15] commonly used for optimizing mechanical performance, could be extended to include a dimension on energy content or other environmental impact.

- **Expand extended producer responsibility**
  In the field of waste management, extended producer responsibility (EPR) is a strategy designed to integrate environmental costs associated with goods throughout their life cycles into the market price of the products. Remanufacturing is an optimal approach to EPR, but other aspects of Re-X can be accomplished by recovery and reuse of materials and components.[16] Responsibility could even be extended to products "found" in the environment.

- **Eliminate trade barriers**
  Eliminate regulatory barriers to trade in used products destined for remanufacture, and where possible draw a new distinction between used products and waste. In addition, eliminate trade barriers for products remanufactured to certified international standards.[17]

- **Launch new schemes for regulating products**
  Require minimum recycled material content in new products and permit these minimum targets to be met by using remanufactured components. In addition, amend existing carbon offset mechanisms to include Re-X certified products.

Monitoring the effectiveness of new approaches

Continuously measuring performance is widely considered to be the most effective way to ensure progress towards a goal within an organization. As the circular economy, with remanufacturing and reuse as one cornerstone, becomes a vision for businesses and governments, key performance indicators (KPIs) can be used to align the different stakeholders.

KPIs for remanufacturing and Re-X in general are described in the literature,[18] and in a circular economy include the following as general concepts:

- Environmental: energy efficiency, water and waste management and other externalities to be assessed and improved with environmental profit and loss (EP&L) accounting, providing a broader awareness of the hidden environmental costs and benefits of production and consumption.[19]

- Engineering: design of products to enable industrial-scale remanufacturing; simplification of design to enable repair, reuse and recycling; alignment of international definitions of remanufacturing; design for longer life for transition from sales to lease or performance models.[20]

- Financial: circular procurement approaches,[21] remanufactured goods sold or circular revenue.

- Social: shared metrics and reporting on the benefits of procuring and designing multi-life products; supply-chain transparency, launches of social enterprises, local economic contribution, education of customers and engagement with local communities.

- Policy: specific remanufacturing targets in waste legislation that encourage the use of remanufacturing components; e.g. establishing the legality of providing remanufactured replacements when products fail and enforcing a two-year guarantee on all sales of used goods by businesses; removing regulatory barriers to trade in used products destined for remanufacture; eliminating trade barriers for products remanufactured to certified international standards.[22]

These are some examples; however, a framework is necessary in order to create an alignment between the manner in which companies operate and governments regulate. Such changes in approach will be successful only with coordination between and the support of the top corporate stakeholders.

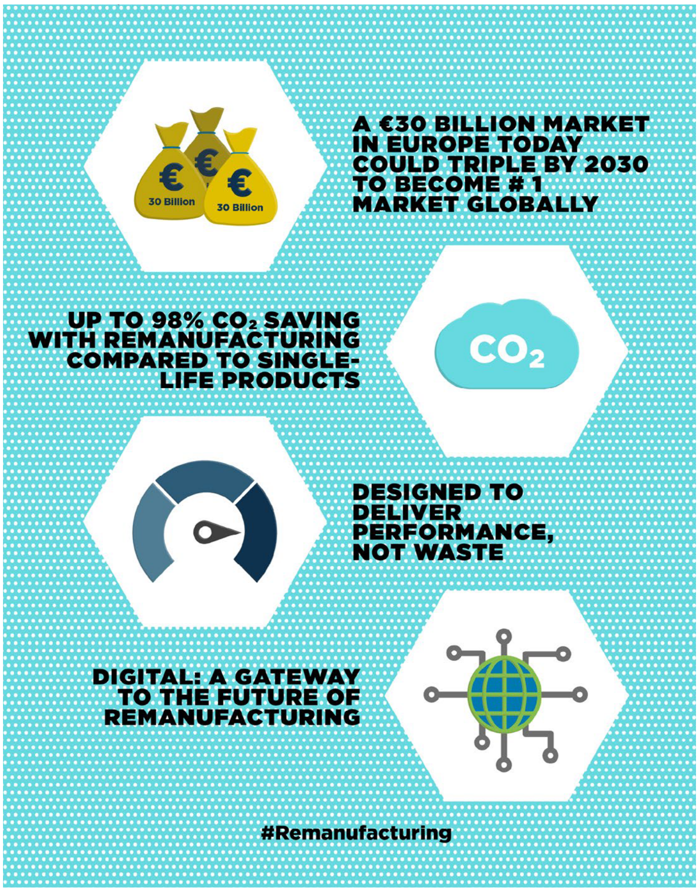
Conclusion and outlook

Through policy changes and the education of consumers and companies, we can use Fourth Industrial Revolution technology to improve the state of the world while improving productivity. We suggest several approaches to education and policy changes that can facilitate the most constructive implementation of new technologies. Accordingly, this report focused on the development of new approaches and practices for addressing the sustainability issues through opportunities in advanced manufacturing.

The intended impact is to encourage organizations to embrace new technological possibilities in an integrated manner along with business models to make the proposed approach attractive with the maximum economic returns on investment, as well as to improve the quality and lifetime of products across the full production supply chain. In that regard, applying these proposed measures ensures that:

- Product design and processes are adapted to enable reclamation and recycling of those materials and products that are most damaging to the environment, whether through their mining or their ultimate disposal via landfills, incineration or dispersion on water or land
- Manufacturers are more accountable and bear the ultimate responsibility for reclamation of materials or products associated with their brand
- Remanufacturing of products becomes more widely used, with an associated dramatic reduction in energy and materials used
- Certificates and labels for buyers of remanufactured products or components are developed and widely recognized and used, guaranteeing warranty and tax breaks, whether for consumer products or the industry itself
- Education and tools are provided to enhance understanding and support for these concepts.

New digital technologies, perhaps coupled with embedded identifiers or critical information on a product, will greatly facilitate the ability to remanufacture products, but policies and consumer education are needed so that remanufactured products are more widely available and accepted. Remanufactured products can result in a dramatic reduction of energy and materials used, and as much as a 98% reduction in carbon footprints.



Source: Ellen MacArthur Foundation, https://www.ellenmacarthurfoundation.org/assets/downloads/BetterThanNew-Reman-White-Paper.pdf

Acknowledgements

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* Identification of brands is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology.
Opinions, recommendations, findings, and conclusions do not necessarily reflect the views or policies of NIST or the United States Government.

Endnotes

1. 2018 World Manufacturing Forum Report, Recommendations for the Future of Manufacturing, https://docs.wixstatic.com/ugd/c56fe3_a953a08910e94477832fdd00e0301707.pdf; report https://docs.wixstatic.com/ugd/03d390_b6ae0b7ab0da48ca90903b3817be00e6.pdf (links as of 23/9/19).
2. "Re-X" is shorthand for recovery, reuse, remanufacturing and recycling. The term would include subprocesses such as disassembly, sorting, inspection, cleaning and collection. See the REMADE Institute Technology Roadmap: https://remadeinstitute.org/technology-roadmap (link as of 27/9/19).
3. Remanufactured Goods: An overview of the US and Global Industries Markets and Trade. USITC Publication 4356, October 2012. Investigation 332 525, p.21.
4. The REMADE Institute Technology Roadmap 2019 was developed with broad industry participation and identifies approaches to these technical challenges: https://remadeinstitute.org/technology-roadmap (link as of 27/9/19)
5. ROHS (2003, with updates): https://ec.europa.eu/environment/waste/rohs_eee/index_en.htm (link as of 27/9/19).
6. http://www.basel.int/ (link as of 27/9/19)
7. For instance, C. Gartenberg, "California becomes the 18th state to introduce right to repair bill", *The Verge*, 8 March 2019: https://www.theverge.com/2018/3/8/17097256/california-right-to-repair-bill-apple-microsoft-service-replace-parts (link as of 27/9/19)
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9. DOE 2019 Battery Recycling Prize competition: https://www.energy.gov/articles/energy-department-announces-battery-recycling-prize-and-battery-recycling-rd-center (link as of 27/9/19)
10. https://www.schneider-electric.com/en/work/support/green-premium/ (link as of 27/9/19)
11. https://www.ellenmacarthurfoundation.org/assets/downloads/BetterThanNew-Reman-White-Paper.pdf (link as of 23/9/19)
12. Universal definitions of terms would benefit all parties. However, at this point, several groups are developing definitions, for example, of "remanufacturing": The International Resource Panel of the United Nations Environmental Programme (https://www.resourcepanel.org/reports/re-defining-value-manufacturing-revolution); Basel Convention for Controlling International Shipments of Waste (https://www.pincvision.com/resources/uploads/bestanden/News-imagesfiles/2015-05-bazelconvention.pdf); and the EU/ISO panel on definition of remanufacturing [to be published September 2019] (links as of 23/9/19)
13. https://rothys.com (link as of 23/9/19)S
14. An example is the circular car approach, e.g. https://materialdistrict.com/article/noah-worlds-first-circular-car/ (link as of 23/9/19)
15. https://downloadfiles.grantadesign.com/pdf/teaching_resource_books/2-Materials-Charts-2010.pdf (link as of 27/9/19)
16. https://www.sciencedirect.com/science/article/pii/S0923474813000817 (link as of 27/9/19)
17. https://www.ellenmacarthurfoundation.org/assets/downloads/BetterThanNew-Reman-White-Paper.pdf (link as of 23/9/19)
18. Examples of key performance indicators for remanufacturing are given in https://www.ellenmacarthurfoundation.org/assets/downloads/BetterThanNew-Reman-White-Paper.pdf and https://remadeinstitute.org/technology-roadmap (links as of 27/9/19)
19. EP&L accounting leadership is associated with Puma and parent-company Kering (https://www.greenbiz.com/blog/2014/02/18/environmental-profit-and-loss-new-corporate-balancing-act), and embraced by others; for example, Philips (https://www.innovationservices.philips.com/app/uploads/2018/11/Environmental-Profit-and-Loss-Accounting-whitepaper.pdf) (links as of 23/9/19)
20. https://www.ellenmacarthurfoundation.org/assets/downloads/BetterThanNew-Reman-White-Paper.pdf (link as of 23/9/19)
21. See for example, the EU approach to circular procurement with examples: http://ec.europa.eu/environment/gpp/pdf/CP_European_Commission_Brochure_webversion_small.pdf (link as of 23/9/19)
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