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Review

# A review on the applicability of remanufacturing in extending the life cycle of marine or offshore components and structures

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ABSTRACT

One of the most significant and value-added End of Life (EoL) recovery strategies in the Circular Economy is remanufacturing in which the functionality and performance of products are retained. In the marine industry, the intensity of remanufacturing is low compared to other transportation industries such as aerospace, automotive and rail. This paper discusses current issues on Design for Remanufacturing (DfRem) in the marine industry and provides insights into how remanufacturing plays a significant role in enhancing reliability and safety during the extended life of marine products and structures. Today, with the large number of ships approaching EoL, remanufacturing should be the way forward due to its positive impact on the environment and socio-economy. While marine components such as engines, propeller shafts, compressors and pumps have been successfully remanufactured in many parts of the world, remanufacturing of large structures such as hull and vessels have not been reported thus far. As in all other industries, remanufacturing has to be initiated with a paradigm shift in the business models, designing parts and structures for efficient remanufacturing, and the establishment of relevant policies and standards in order to pave the way towards a more sustainable marine industry in the future.

## 1. Introduction

In today's resource efficient and circular economy, remanufacturing has been identified as one the most promising strategies in delivering an efficient End of Life (EoL) recovery. Circular economy has been defined as an industrial system that is restorative or regenerative by intentions and design by the Ellen MacArthur Foundation (2013):

> *"A circular economy is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, and aims for the elimination of waste through the superior design of materials, products and production systems."*

Morgan and Mitchell (2015) conducted a study on the growth of circular economy and its impact on the UK labor market, noting that one route to improving resource efficiency, is to develop a circular economy as it enables products and resources to be in use for as long as possible through recovery, reuse, repair, remanufacturing, and recycling. Today, the circular economy is not an option but a requirement for continued economic prosperity and ecological balance (Jawahir and Bradley, 2016). The circular economy supports the three pillars of sustainable development; namely the environmental, societal, and economical, by protecting the environment, providing economic benefits through increased resource security, and providing new business and employment opportunities. The role of remanufacturing as one of the most value-added recovery strategy for the circular economy is clearly depicted in Fig. 1.

Guitini and Gaudette (2003) defined remanufacturing as an industrial process that turns used products into products with the same quality, functionality, and warranty as new products. In remanufacturing, used products referred to cores, are restored to their useful life (Sundin, 2004). British Standard BS8887: Part 2 defines remanufacturing as returning a used product to at least its original performance, with a warranty that is equivalent to or better than that of the newly manufactured product. Through remanufacturing, products and sub-assemblies can be restored or even upgraded before entering their next life cycle.

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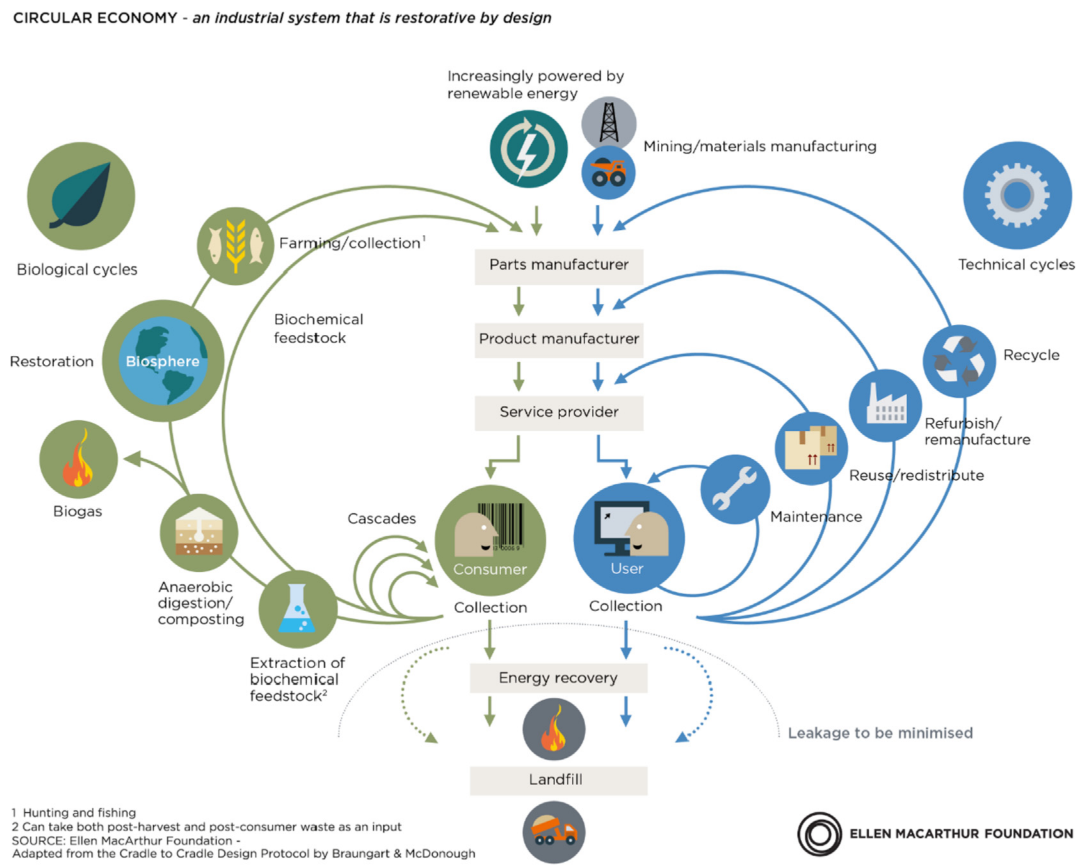


**Fig. 1.** Circular economy (by Ellen MacArthur Foundation).
Source: Nguyen et al. (2014).

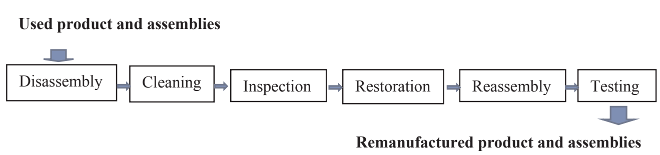


**Fig. 2.** A generic remanufacturing process.

Remanufacturing is more resource efficient than recycling and other EoL recovery strategies, as it retains durable cores in the subsequent life cycles, hence reducing the need to manufacture new components every time. According to Lund (1996), using cores as the main material source instead of consuming virgin materials and conserving their physical form during reprocessing, remanufacturing captures the remaining value of cores in the form of materials, energy and labour. Matsumoto et al. (2016) noted that since remanufacturing retains the geometric shape of products, it preserves the materials and added value embedded in the original products. Remanufacturing involves a thorough process of disassembly, cleaning, inspection, restoration, reassembly and finally testing, since the remanufactured products have to be given a matching warranty. A generic representation of the remanufacturing process is shown in Fig. 2.

The benefits of remanufacturing towards the three pillars of sustainable development, namely environment, economics and social, have been widely acknowledged and reported in literature (Lund, 1996; Sundin and Lee, 2012; European Remanufacturing Network, 2015; Morgan and Mitchell, 2015; Jansson, 2016). Since it does not involve actual production of new products, remanufacturing demands very little raw material, energy, and other production inputs thus reducing the environmental impact of production. Afrinaldi et al. (2017) conducted a study on the environmental and economic benefits from the remanufacturing of a cylinder block of a diesel engine. The study confirmed savings with regard to energy consumption, use of material and air emission, in this case 88–99%. In addition, the price of the remanufactured cylinder block was found to be 39% lower than a newly manufactured cylinder block.

Remanufacturing has also provided employment opportunities as it requires highly skilled workforce, as the processes involved in bringing back the components to as new conditions require compliance to standardised procedures, and informed judgements on the conditions of the incoming parts and assemblies.

CRR (2010) conducted a study on remanufacturing activity in the UK. The sectors include aerospace, automotive, catering & food, construction, ICT equipment, industrial tooling, ink & toner cartridges, lifting & handling equipment, medical, precision & optical equipment, off-road equipment, office furniture, pumps & compressors, rail industry, textiles, tyre re-treading and white goods. It was observed that the aerospace, automotive, and mechanically powered machinery sectors have the largest economic impact, contributing 40%, 11%, and 11% respectively, to the total remanufacturing value. Remanufactured parts and components provide the same as original performance and reliability, at costs typically only 50–80% of a new product. Instant availability gives customers more options at repair and overhaul time, resulting in maximum productivity and lower costs (Matsumoto, 2016).

## 2. Remanufacturing in the transport industry

The transportation industry namely aircraft, automotive, rail and marine, has implemented remanufacturing as one of their EoL recovery strategies. Apart from benefitting the environment and eco-system, this strategy has affected the socio-economy in a positive way. According to the U.S International Trade Commission (2012), remanufacturing occurs across a diverse range of industry sectors but it is more commonly