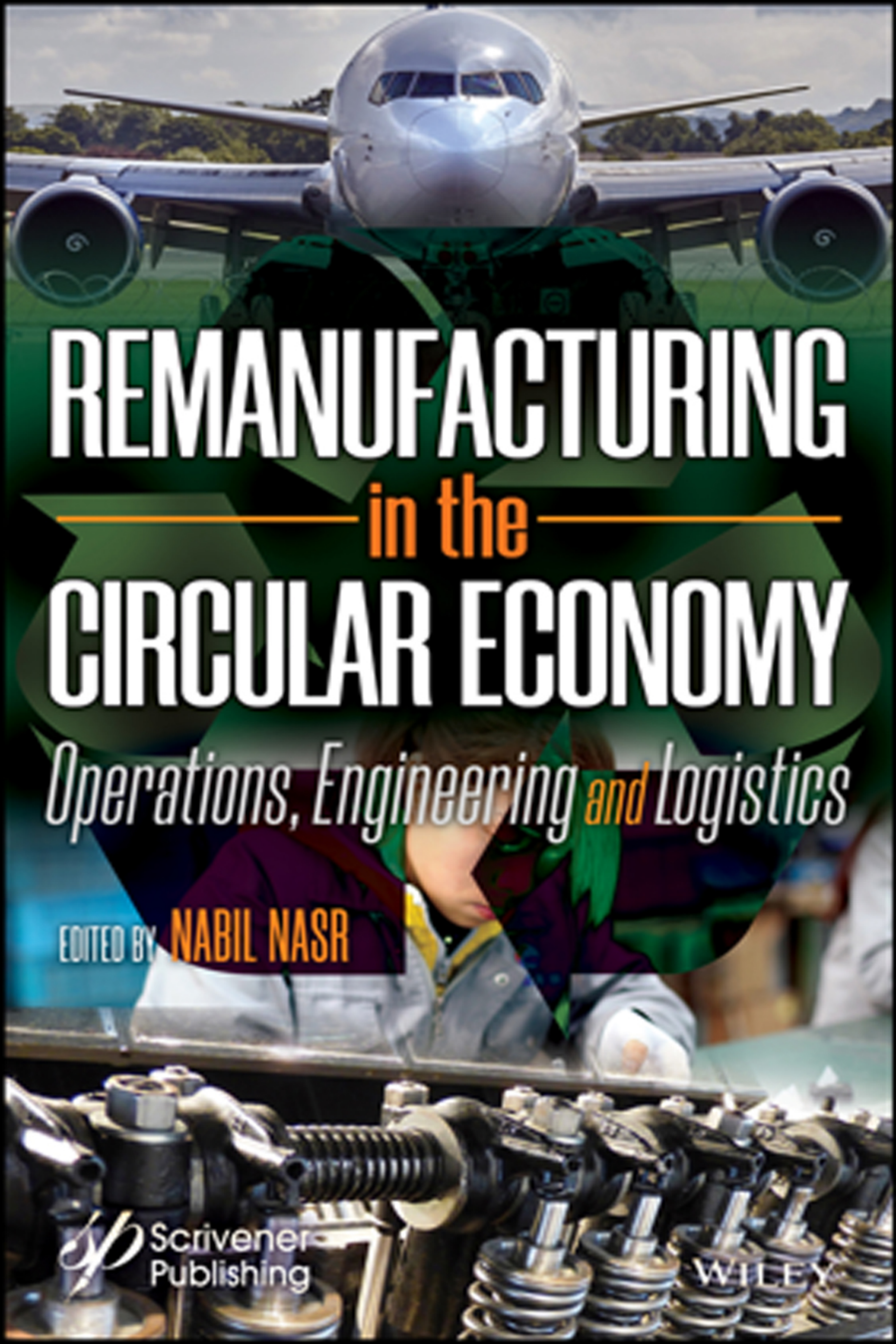

REMANUFACTURING in the CIRCULAR ECONOMY

Operations, Engineering and Logistics

EDITED BY NABIL NASR

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Preface

Over the past thirty years or so, I've discovered firsthand that it can be difficult to explain the fundamentals of remanufacturing in simple, succinct ways. Remanufacturing is a unique field because it draws upon a broad array of skillsets, technologies, processes, and business models. It is highly technical as an industrial system while also deeply conceptual when approached through a sustainability lens. All this makes describing it to the many business leaders, engineers, and policymakers that I have worked with across the globe no easy task, as they all have different perspectives and levels of expertise across varied disciplines.

As an engineer, I am drawn to a problem in need of a solution. This is why I am so pleased to introduce a book that will present remanufacturing fundamentals to a wide audience in an accessible, useful way. The contributors to this book present a diverse set of expertise, bringing significant knowledge to the topic areas they cover. Of course, any project that attempts to capture the whole of a complex, fast-changing area is going to run into barriers and this book is no exception.

Introduction to Remanufacturing

Remanufacturing is an industrial process that restores used, worn and retired products or modules to a like-new condition. The restoration is typically a highly engineered process done in an industrial setting through which products are systematically disassembled, cleaned, and inspected for wear and degradation. Damaged or degraded components are either restored to their original specifications or replaced, feature upgrades can be incorporated, and the product is reassembled. Finally, reliability and quality testing are performed to ensure that performance meets original product specifications.

Remanufacturing has inherent benefits over recycling. Recycling reduces products into raw material which can then be used again. This in fact brings significant environmental and possibly economical value. However, in contrast, remanufacturing retains the geometrical shape and function of the products and components, and is therefore able to capture both the materials and the value added (the labor, energy, and manufacturing processes) which had become embodied in the original product.

Recapturing the value-added component of a product is often both environmentally and economically beneficial. In fact, remanufacturing, while very different than recycling, is oftentimes referred to as the "ultimate form of recycling" because it is able to preserve the embodied energy and value add contained in a product. Typically, at the end of its service life, a product would be destined for landfill, incineration or recycling. But by implementing a remanufacturing strategy, disposal costs can be avoided, the value still embodied in a product can be recouped, and resources can be used more efficiently. In addition, a fact that is often not mentioned, remanufacturing is a gateway for recycling, as when end of service products, called cores, are returned to a remanufacturing facility, products are disassembled and components often properly separated and identified. The components that are not suitable for reuse in the remanufacturing process are then properly sent for recycling with significantly better separation of like materials, thus significantly improving the recycling recovery and output.

Growth of an Industry

It is widely accepted that the United States has the most diverse and developed remanufacturing industry sectors in the world.

Much of this development stems from the industrial revolution and the subsequent invention of mass production. A good example can be seen by looking at the history of Ford Motor Company. World War II brought significant material availability challenges which resulted in significant growth for the remanufacturing industry due to the significantly lower virgin material needed and high reuse rate of used materials. Once Ford had produced and sold millions of Model T cars in the early 1900s, it made practical business sense to create separate facilities to remanufacture old motors and a distribution system to support their customers with economical like-new engines and service parts.

This pragmatic approach to integrating remanufacturing into global product support strategies continues to this day. Thousands of product categories including aerospace, automotive, military systems, office furniture and equipment, transportation, construction and electrical equipment; medical devices; machine tools, compressors, other heavy machinery and others account for the global remanufacturing business activity. Major corporations such as Caterpillar, John Deere, Xerox and General Electric all generate significant business through remanufacturing programs related to their products. Conservative estimates show more than $60 billion of remanufactured goods are sold each year in the United States alone and more than 500,000 people are employed by the remanufacturing industry.

Remanufacturing's Environmental Benefits

Many manufacturers have begun looking for new ways to increase efficiency and reduce costs while developing manufacturing processes that reduce or eliminate negative environmental impacts. This interest in sustainable production inevitably leads these organizations to explore the opportunities and benefits of reuse, remanufacture, and recycling of manufactured goods and products.

Remanufacturing is an important factor in sustainable production because it recovers and preserves much of the expensive value-added component of a manufactured product. Through remanufacturing, nonrenewable resources are kept in circulation for multiple product lifecycles, thus conserving up to 80% or more of the original raw materials, labor and energy embedded in the product. According to an Argonne National Laboratory study, remanufactured products conserve the equivalent of 400 trillion BTUs of energy annually, enough to power 6 million passenger cars each year. This also avoids the generation of 28 million tons per year of the greenhouse gas CO2. These key environmental benefits are readily seen in data from remanufacturing market leaders such as Caterpillar.

Caterpillar is one of the world's largest remanufacturers, processing more than two million units annually and recycling more than 100 million pounds of remanufactured products each year. The company offers remanufacturing services for a variety of products and components to serve Caterpillar and external clients. Their Components business includes undercarriage, ground engaging tools, hose and connectors, hardened bar stock, tubes, specialized products, common components, fluids and filters. Caterpillar points to an engine cylinder head to illustrate the sustainability of remanufacturing. Compared with manufacturing a new cylinder head, a remanufactured head requires 61% less greenhouse gas, 93% less water, 86% less energy, up to 99% less material use, and it contributes up to 99% less space in a landfill.

Remanufacturing Industry Sectors

Remanufacturing activity encompasses thousands of product categories, from cell phones and laptops to jetliner engine parts to armored ground combat vehicles. However, the majority of remanufacturing industry activity is concentrated in 13 large U.S. sectors, which are described in detail in this book.

After decades of relative obscurity, the remanufacturing industry has emerged larger, more diverse, and a bigger contributor to national and global economies than most of us realize or appreciate. And as all industries transition to greater sustainability in the decades ahead, remanufacturing will be an increasingly more powerful driver for change. So, I invite you to become better acquainted with the scope of remanufacturing in America and around the globe.

Acknowledgments

Nothing convinces people so much as living proof. Caterpillar, Inc., is among the foremost remanufacturers in the world. They are committed to building a global remanufacturing infrastructure to enable progress across industries. This book would not have been possible without the support they made possible through the Caterpillar Professorship and the Caterpillar Fund at the Golisano Institute for Sustainability at Rochester Institute of Technology (RIT), where I serve as associate provost and director.

Nabil Nasr
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July 2019

1

Value-Retention Processes within the Circular Economy

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Abstract
The circular economy offers a framework for transforming wasteful and inefficient linear systems into cascading systems that retain the inherent value of products, reduce negative externalities, and improve resource-efficiency. The cycling of technical nutrients within a circular economy can be achieved through product value-retention processes (VRPs) that include direct reuse, repair, refurbishment, and remanufacturing. Product case studies reveal that VRPs offer differing degrees of process and resource-use intensity, and as such, each contributes different economic and environmental benefits and circularity. Value-retention and impact metrics, measured relative to new product options, include new material use (kg/unit), energy use (MJ), emissions (kg CO_2-eq.), production waste (kg/unit), cost advantage (% $USD/unit), and employment opportunity (Full-time Laborer/unit or FTE/unit). When compared to a traditional new product, all VRPs create significant resource efficiency and circularity opportunities. When compared to other VRPs, Partial Service-Life VRPs (direct reuse and repair) require significantly fewer resources,

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and thus result in relatively lower environmental and economic costs than Full Service Life VRPs (refurbishment and remanufacturing); However, more intensive Full Service Life VRPs ensure relatively greater utility, service-life, and value for the customer. Because of these differences, VRPs may be adopted strategically to pursue a range of business and policy objectives.

Keywords: Circular economy, value-retention processes (VRPs), resource efficiency, market transformation, remanufacturing, refurbishment, repair, direct reuse

1.1 Introduction

The full potential value of the circular economy goes beyond the recycling of materials in their raw form; in the circular economy, value is ultimately embedded in our ability to retain the embodied and inherent value of product material, structural form, and ultimate function. Capturing, preserving, and re-employing this value not only offsets virgin material requirements, but also reduces required production activities and instills new value altogether by ensuring the completion of, and/or potentially extending a product's expected life. In this respect, value-retaining production processes that include **arranging direct reuse, repair, refurbishment, comprehensive refurbishment, and remanufacturing** (hereafter referred to as value-retention processes or VRPs) are essential for improving industrial system circularity.

Through the deployment and scaling of VRPs worldwide, important environmental and economic objectives of increased system circularity, and the decoupling of economic growth from environmental degradation, can be successfully pursued. There is no single solution that is at once universally applicable, socially equitable, economically efficient, and environmentally healthy. As such, it is critical, to understand the different ways in which these processes may interact within and affect categorically diverse economies.

The International Resource Panel (IRP), a branch of the United Nations Environment Programme (UNEP) investigated each of these VRPs, including their role in the current industrial paradigm, and their potential to impact the future of the circular economy [1]. This assessment helped to shed light on the contribution that VRPs can make to the pursuit of enhanced resource efficiency and the reduction of environmental impacts associated with primary material production and traditional linear manufacturing. Some of the major insights and outcomes of this IRP Report are covered within this chapter.

1.2 Overview and Evaluation of Value-Retention Processes

VRPs are distinctively different from, and far less understood than recycling. VRPs help to ensure the offset of virgin material requirements, the collection and reuse of valuable materials, and the retention of embodied and inherent value, by ensuring the completion of, and/or potentially the extension of a product's expected service life. Expanding the use of VRP practices can offer substantial and verifiable benefits in terms of resource efficiency, circular economy, and protection of the global environment. However, their intensities and adoption globally have been limited due to significant technical, market infrastructure, and policy barriers.

1.2.1 Defining Value-Retention Processes

One of the main challenges facing VRPs around the world, as corroborated via international market access negotiations [2] and the US International Trade Commission (USITC) [3], is the wide range of definitions and interpretations of different VRPs. There are often multiple issues at stake, including common terminology differentiations made within and across sectors, as well as regulations focused on protecting consumer interests in certain countries. For example, while the VRP activity called '*reconditioning*' in the electronics industry (as preferred by the Professional Electrical Apparatus Recyclers League), '*rebuilding*' by the Federal Trade Commission, and '*remanufacturing*' under a definition accepted by the WTO, the intent for each of these terms is the same: "…*the process of returning the electrical product to safe, reliable condition*…" [4]. Alternately, the medical sector typically uses the term '*refurbishment*' for the same VRP that the aerospace sector would use the term '*overhaul*' to describe; In fact, both definitions are clearly describing what would be considered 'remanufacturing' in other sectors.

Given the potential for confusion, the 2018 IRP Report [1] distinguished between each of the VRPs, and adopted VRP definitions and terminologies that are consistent with internationally recognized sources (where they exist) that include, but are not limited to, the Basel Convention Glossary of Terms (Document UNEP/CHW.13/4/Add.2) [7] and Directive 2008/98/EC [8] (Figure 1.1).

1.2.1.1 Arranging Direct Reuse

Arranging direct reuse refers to: "*The collection, inspection and testing, cleaning, and redistribution of a product back into*

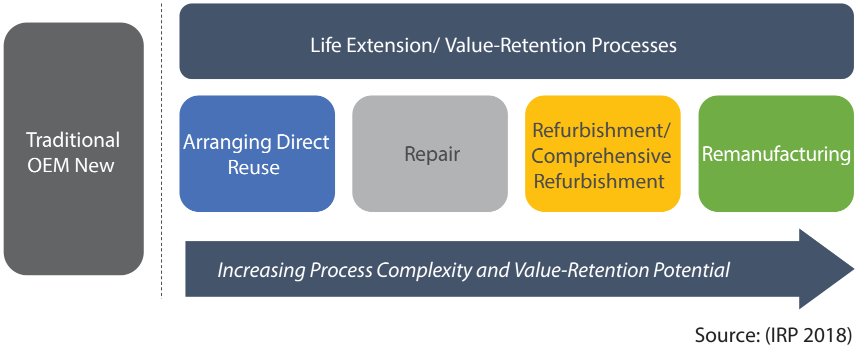

Figure 1.1 Definitions and structure of value-retention processes within this report.

the market under controlled conditions (e.g. a formal business undertaking)" [7] (Figure 1.2). Arranging direct reuse does not include reuse that occurs mostly through the undocumented transfer of a product from one consumer to another. Under arranging direct reuse, no disassembly, removal of parts, or addition of parts occurs. Only those products that are in sufficient working condition, not requiring any component replacement or repair, and to which quick and easy aesthetic touch-ups can be performed, qualify as arranging direct reuse products. These products are not guaranteed to meet original specifications and are typically offered to the market at a significant price discount, with no, or at least a much-modified, product warranty.

Arranging direct reuse becomes possible when a product reaches the end of its useful service life prematurely: the owner may require an upgraded product, may no longer need the product, or may have a change in preferences. Alternately, the usage/service requirement rate may have been less than expected during the products service life. In any case, although the product has reached end-of-use (EOU), it has not yet fulfilled its expected life or potential life. Arranging direct reuse enables the product to continue to maintain productivity through use, instead of being prematurely discarded into a waste or recycling system.

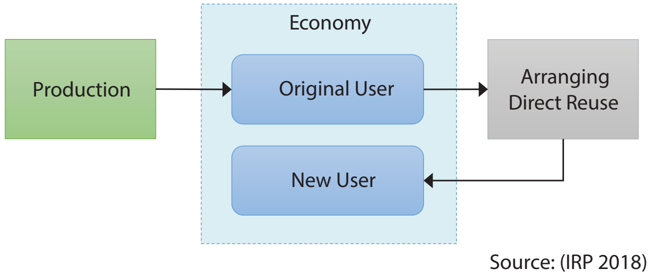

Figure 1.2 Descriptive summary of arranging direct reuse process.

1.2.1.2 Repair

Repair refers to: "*The fixing of a specified fault in an object that is a waste or a product and/or replacing defective components, in order to make the waste or product a fully functional product to be used for its originally intended purpose*" [7] (Figure 1.3). Repair activities include those required for known product issues, which enable the product to complete its original expected life. They also include the maintenance of a product that if left unmaintained, would have a constrained service life and/or utility.

Repair activities are performed at the product-level: an otherwise functional product must have some worn or damaged parts removed and new parts added for it to continue functioning for the duration of its expected life. Rather than the entire product being discarded into a waste or recycling stream due to a worn or damaged part, repair activities bring the entire product back to its original functioning capacity for the continuation of the product's expected life.

1.2.1.3 Refurbishment & Comprehensive Refurbishment

There are differing degrees of refurbishment activity that yield differing levels of material value retention and product utility: Refurbishment and Comprehensive Refurbishment (Figure 1.4).

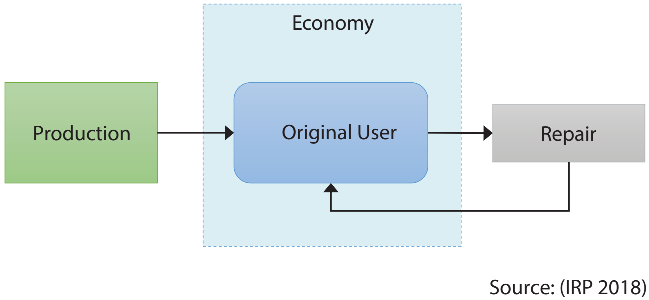

Figure 1.3 Descriptive summary of repair process.