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Enabling a Circular Economy

A Guide to Asset Remanufacturing

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Introduction

The combination of increasing demand, finite resources, unsustainable practices, and environmental impacts is leading to the outpacing of the world's use of raw materials over Earth's ability to regenerate them, posing significant challenges for the sustainability of our planet.

In a linear economy, products are designed and manufactured for single-use, with little consideration for their end-of-life disposal. Once a product is no longer useful or desired, it is typically discarded and sent to a landfill, resulting in a significant amount of waste and resource depletion (Figure 2).

Contrary to the linear economy, a circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems. In a circular economy product are designed to be reused, repaired, remanufactured, or recycled, rather than disposed of as waste. This promotes resource efficiency, reduces waste and emissions, and creates economic opportunities by keeping materials in use for as long as possible.

102B Total flow of raw materials into the economy in 2015, in tons

67% Percentage of industrial materials lost through pollution or waste in 2015

500B Global consumption of virgin materials, in tonnes, 2015 – 2021 **(6 years)**

70% In 2021, more virgin materials were extracted from the Earth than can safely be replenished

4x Growth in global use of materials, 1972 – 2022 **(50 years)**

2x By 2030, we will be using double the amount of natural resources available to us

Figure 1: Source: National Geographic: How a Circular Economy Could Save the World

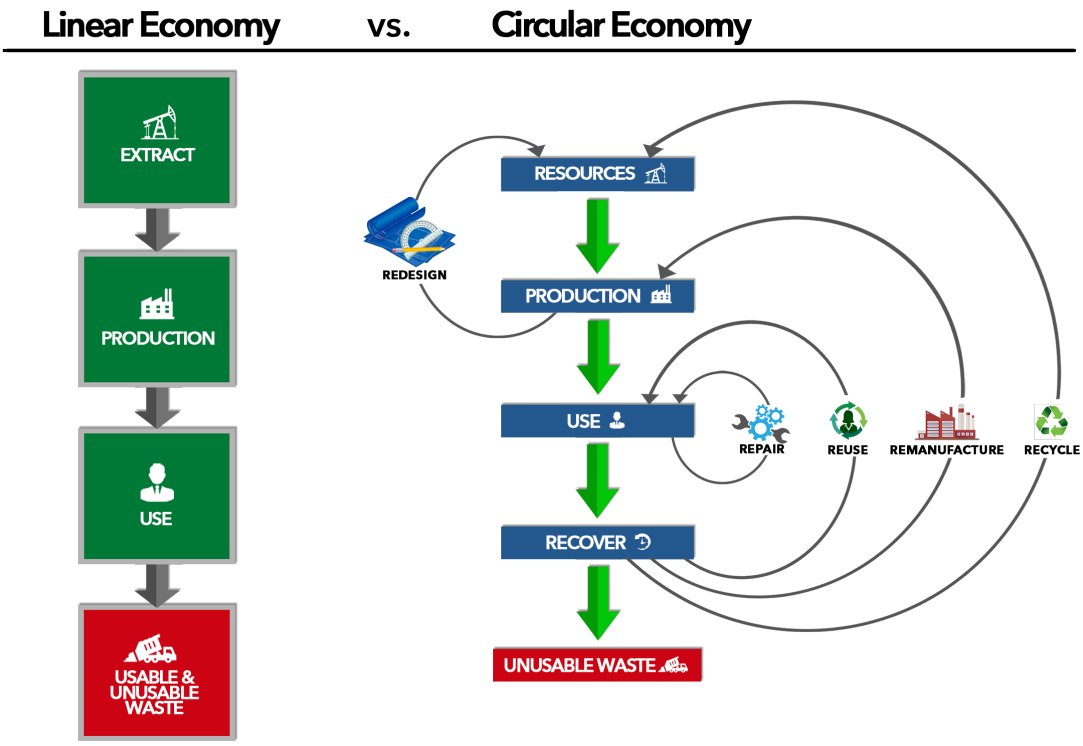


Figure 2: Linear Economy vs. Circular Economy

Adopting a circular economy requires a fundamental shift in the way we produce, consume, and dispose of goods and resources. Accelerating the shift towards a circular economy is a focus on sustainability. The United Nations Brundtland Commission defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." True sustainable solutions include the consideration of environmental, social, and governance (ESG) factors.

A circular economy is closely linked with sustainability because it aims to minimize the negative impact of economic activity on the environment and society, and can accelerate sustainability by promoting resource efficiency, reducing emissions, promoting regenerative practices, driving economic growth, and providing social benefits.

The circular value chain is a concept that refers to the various stages and processes involved in the circular economy, from resource extraction and production to consumption, circulation, and waste management. Within circular value-chains for industrial products, remanufacturing retains the highest value.

Adopting a circular economy requires a fundamental shift in the way we produce, consume, and dispose of goods and resources.

This guide explores the importance of industrial product remanufacturing within a circular economy and its potential to generate economic, environmental, and societal benefits. This article examines the challenges and barriers faced by various stakeholders across the remanufacturing ecosystem, the opportunities for digitalization within the system, and a solution to address these issues with a trusted platform that facilitates information sharing among stakeholders, and an analytics framework for optimal decision-making by the stakeholders.

Circular Economy Benefits

Transitioning to the circular economy can catalyze the most transformational economic, social, and environmental changes since the First Industrial Revolution.

Environmentally, circular economy can transform the way we interact with the environment through the promotion of regenerative practices and the reduction of waste and pollution and as a result protects biodiversity, combats climate change, and promotes a healthier planet.

Economically, circular economy promotes resource efficiency, circular business models, and sustainable practices, driving economic growth and innovation while reducing the negative impact of economic activity on the environment and society.

Socially, circular economy transforms social structures by promoting more sustainable and resilient communities, creating green job opportunities, reducing inequality, and improving health and well-being.

1. Ellen MacArthur Foundation
2. European Commission, "Closing the Loop: An EU Action Plan for the Circular Economy."
3. Accenture, "Taking the European Chemical Industry into the Circular Economy"
4. McKinsey & Company, "Growth Within: A Circular Economy Vision for a Competitive Europe"
5. Accenture Strategy, "Automotive's latest model: Redefining competitiveness through the circular economy"

In governance, circular economy promotes sustainable and inclusive policies and practices through multi-stakeholder engagement, innovative policies and regulations. In turn, these policies and practices incentivize sustainable practices, transparent reporting of environmental and social impacts to ensure governance decisions are not only informed by accurate data, but can also be used to hold organizations accountable for their actions, collaborative partnerships, and the creation of circular cities and regions that benefit people and the planet.

In addition to ESG, a circular economy can be a catalyst for technological and cultural transformation, thereby creating a self-reinforcing value chain with sustainable opportunities throughout the ecosystem.

Circular Economy Business Models

Five new business models have been identified relating to the stages in a circular economy value chain:

1. **Circular Inputs** refer to the materials and resources being sustainably sourced and used to create products that are designed for durability, recyclability, and ease of repair, with the aim to minimize waste and maximize resource efficiency.

2. **Servitization** is a shift from selling products to selling products as-a-service to increase the resource productivity throughout the whole lifecycle.

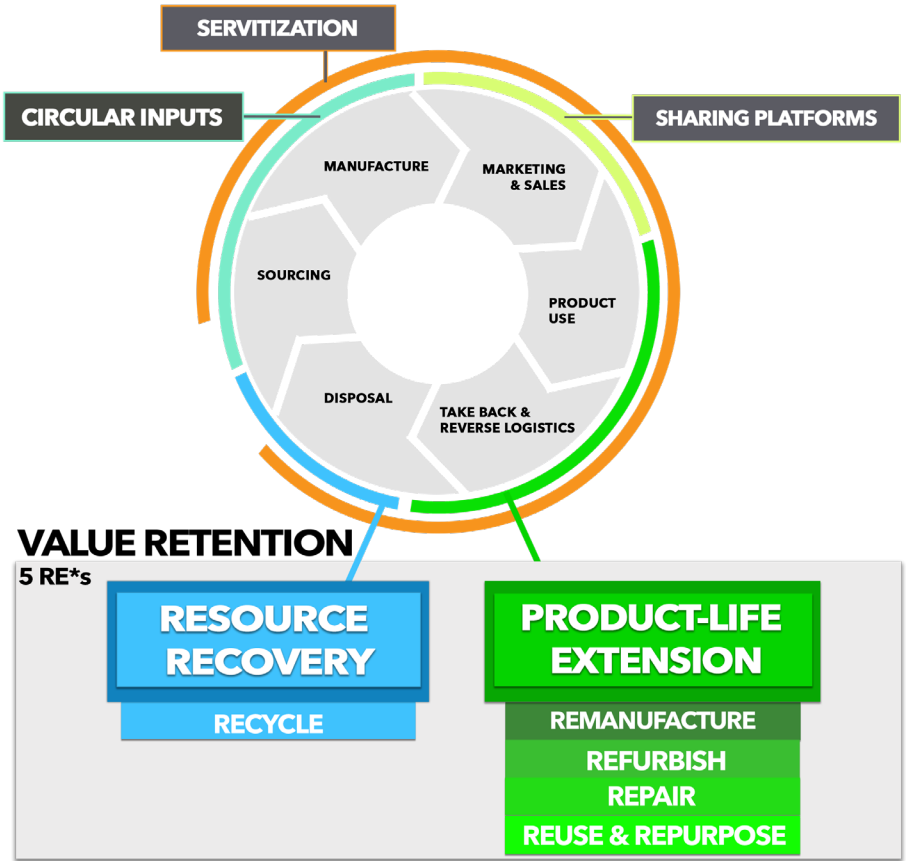


Figure 3: Circular Economy Business Models

3. **Sharing Platforms** enable the sharing, renting, and borrowing of goods and services. These platforms connect individuals and businesses, creating a more efficient use of resources and reducing waste.

4. **Product-Life Extension** is the process of extending the lifespan of a product through maintenance, repair, refurbish, or upgrading to reduce waste and promote resource efficiency by maximizing the use of existing products.

5. **Resource Recovery** is the process of recovering and reusing valuable resources from waste streams and involves collecting, sorting, and processing waste materials to extract and remaining value and reuse it in new products.

Each business model has distinctive features and can be utilized individually or in conjunction to help businesses attain significant resource productivity improvements. This can also enhance differentiation and customer value, decrease the cost of ownership and service, create fresh revenue streams, and lower risks. From the five business models, resource recovery and product-life extension are two key strategies that enable the circular economy (Figure 3).

Product-Life Extension and Value Retention

There are five key value retention processes collectively referred to as RE*:

Repair returns a faulty or broken product or component back to a usable state.

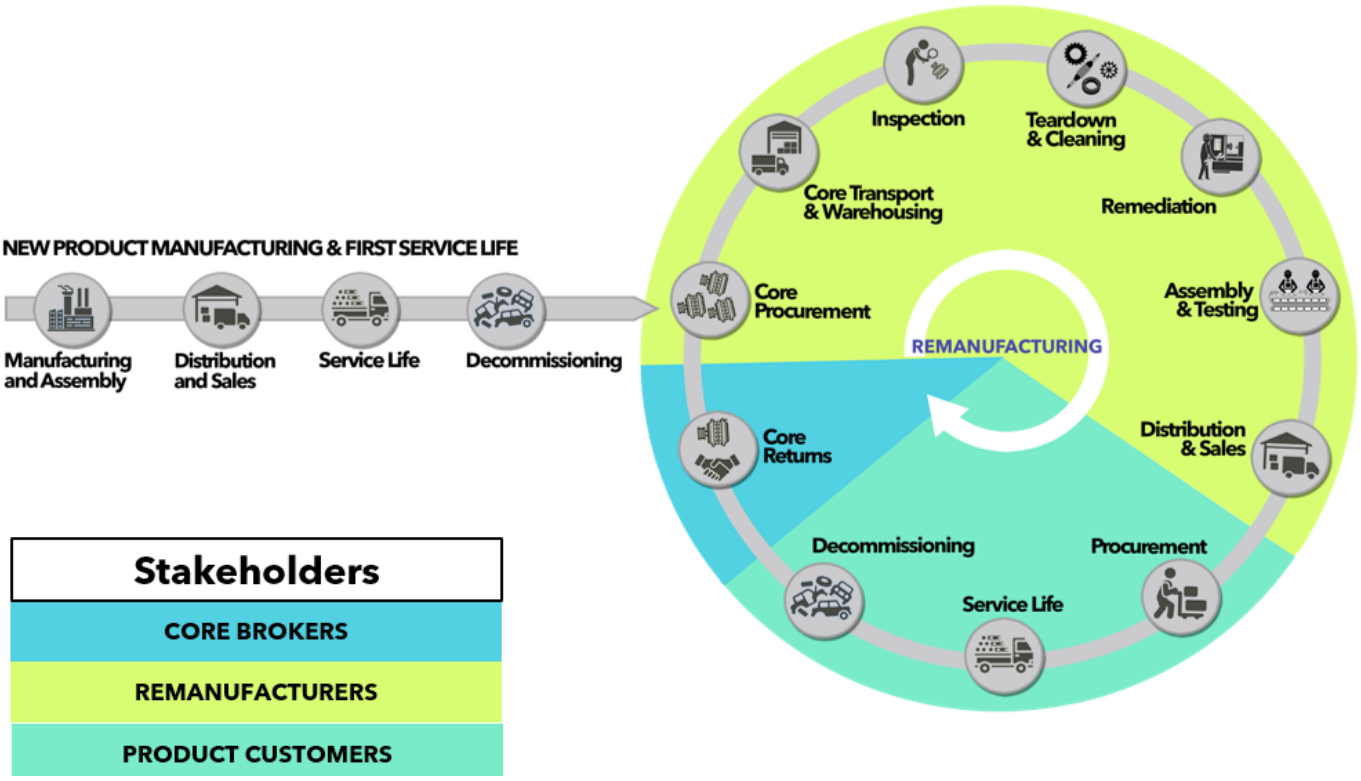


Figure 4: Remanufacturing Process

Reuse and repurposing entails utilizing or reselling the product for the same or a different application.

Refurbishment improves a product through cosmetic fixes and limited upgrades to functionality.

Remanufacturing restores a used product or a component to as-good-as-when-new or better condition by way of a standardized process in an industrial setting.

Recycling is the recovery of materials and energy contained in end-of-life products.

Each of these value-retention processes is distinct in terms of costs involved and how it affects product lifecycle, retains material value, and generates utility for the user.

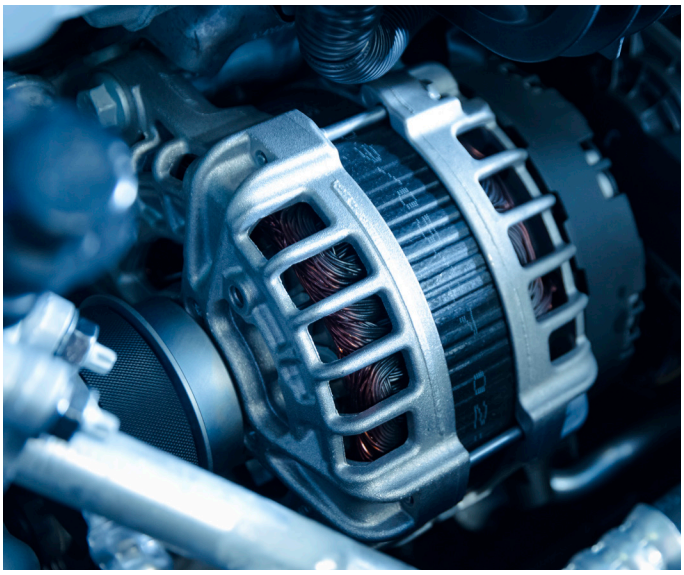
Reuse, repair, and refurbishment only extend the initial life of a product by a finite time after which disposal is needed, and hence have limited value-retention impact. Remanufacturing is the only approach which although requiring more resources provides a full new life to the product and can potentially enable multiple service lives.

Hitachi's Commitment to a Circular Economy

As a top manufacturer of industrial equipment, and provider of remanufacturing and repair services, and digital solutions, leading the adoption of circular economy reinforces Hitachi's commitment to deliver social, environmental, and economic value. Hitachi's vision is to be a leader in creating technologies and solutions for accelerated adoption of a circular economy.

Remanufacturing is the only approach that provides a full new life to the product and can potentially enable multiple service lives.

Hitachi is building solutions that leverage digital transformation to address the challenges of resource recovery (establishing closed loops) and product-life extension, both key circular economy enablers. Our goal is to make resource recovery and product-life extension efficient and thereby increase their adoption. Our initial customer focus is on remanufacturing as it retains the highest value in the circular economy.



With over 110 years of experience creating innovative solutions in transportation, energy, digital technologies, operating technologies, and manufacturing, Hitachi is the experienced partner businesses can trust to leverage its expertise to help customers transition to a circular economy.

Remanufacturing

In a circular economy, remanufacturing plays a critical role in keeping products and materials in use for as long as possible. Remanufacturing is a key strategy for extending the lifespan of products and reducing waste, as it allows for the recovery of valuable materials and components from discarded products, promoting closed-loop systems, and driving innovation. By doing so, it reduces the need for new resources, decreases environmental impact, and creates economic benefits. It involves the process of refurbishing and restoring used products or components to their original or better-than-original condition (Figure 4).

The remanufacturing industry is poised for substantial growth, bringing costs savings and economic benefits to adopters.

- According to a report by MarketsandMarkets, the global remanufacturing market was valued at $89.1 billion in 2019 and is projected to reach $162.8 billion by 2025, growing at a compound annual growth rate (CAGR) of 9.2% during the forecast period (2020-2025).

- Grand View Research reported the global automotive remanufacturing market size to be valued at $427.5 billion in 2022 and expected to reach $133.8 billion by 2027, growing at a CAGR of 4.0% from 2023 to 2030.

- A study by the United Nations Environment Programme reported that remanufacturing activities in the machinery and equipment sector generated approximately $43 billion in sales in the United States alone in 2019.

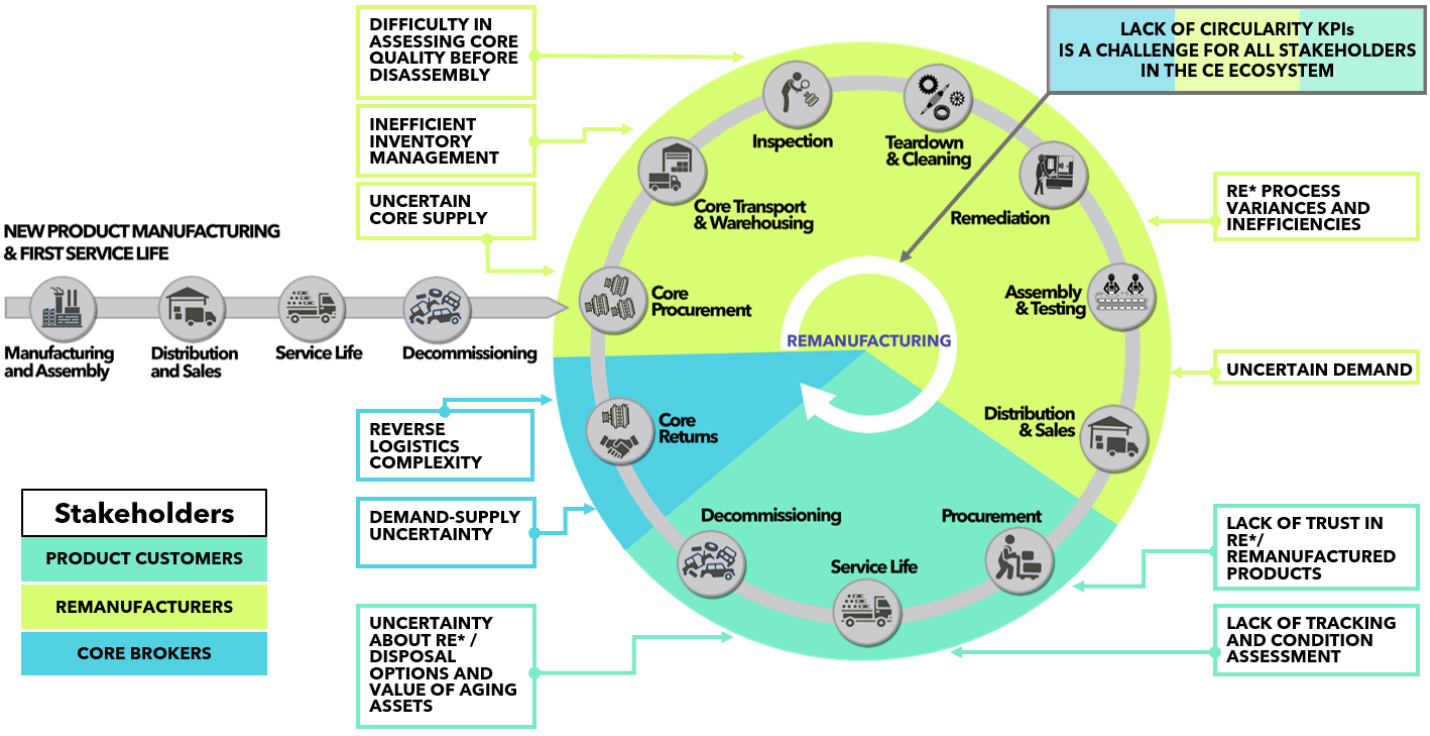


Figure 5: Remanufacturing Challenges

The United States boasts the largest remanufacturing market in the world. According to the U.S. International Trade Commission (USITC), remanufacturing activities in the United States accounted for about $43 billion in sales, $15.9 billion in value-added GDP, and supported 180,000 full-time jobs in 2018.

Remanufacturing Challenges

We interviewed over 100 experts and practitioners from different industry sectors to better understand asset recovery challenges. Although the process of remanufacturing has existed for many decades, process challenges have hindered its uptake.

Remanufacturers are crucial to increasing the life of a product and closing the loop. They often buy used goods and parts directly from manufacturers or through middlemen like core brokers, and then recoup and restore the value of these items. To truly transition industrial products to circularity requires a systemic change across the value-chain.

Currently, the value-chain lacks integration due to stakeholders operating in isolated silos and engaging in one-off transactions. To achieve circularity, it is essential for multiple stakeholders to collaborate and work towards shared goals. This requires stakeholders to optimize their operations within the broader context of the entire value-chain, rather than solely in their own limited context. To achieve this, stakeholders need improved visibility and access to information from other parts of the value-chain, while also capturing and sharing more information with their counterparts.

Remanufacturers

Remanufacturers experience several obstacles: core supply uncertainty, core quality uncertainty, difficulty adjudging reuse, and uncertainty in demand for remanufactured products. Aside from these challenges, remanufacturers contend with post-sales forward integration and product-life-cycle tracking Remanufacturers frequently lack up-to-date information regarding the installed products, including their configuration, maintenance history, ownership, and current condition, due to siloed systems operated by downstream stakeholders.

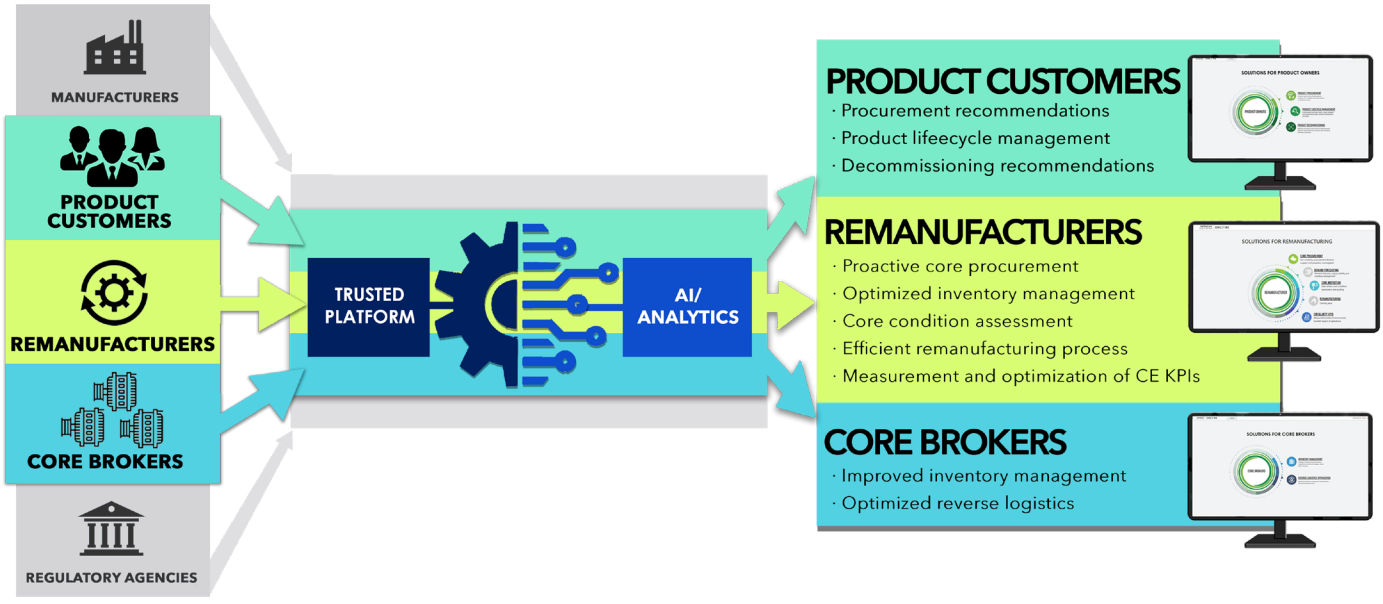


Figure 6, A Trusted, AI/Analytics Solutions Platform for Stakeholders in the CE Ecosystem

Figure 7: Hitachi's Solution for Industrial Product Circularity's Homepage

Product Customers

Product customers, who use and lease/rent the product to others, face several challenges throughout the product's lifecycle. A lack of trust in refurbished (RE*) products due to concerns about quality, limited information, and availability compared to new products are prominent barriers facing product customers.

Additionally, customers need track and trace capabilities and condition assessment during the use phase, particularly if they share or rent the product, to monitor performance and detect contractual violations. Furthermore, managing ageing products presents difficulties in maximizing return on investment, determining residual value, deciding on the optimal timing for disposal, and selecting the appropriate channel (e.g., remanufacture, sale, scrap) for handling

Addressing circular economy and asset remanufacturing challenges requires a coordinated effort among stakeholders.

operational and maintenance costs.

Core Brokers

Concerning specific industrial products, core brokers are responsible for gathering used product cores from customers and supplying them to RE* providers. Core brokers face challenges such as inaccurate demand forecasts, difficulty in obtaining an adequate supply of cores, and frequent inventory imbalances of overstocking or understocking.

In situations where products are sold through dealers, these dealers play a crucial role in the reverse logistics process by facilitating the return of used products to complete the recycling loop.

Aside from the previously mentioned challenges, all parties involved are facing mounting pressure to report on sustainability, carbon-neutrality, and circular economy Key Performance Indicators (KPIs). These reporting requirements often involve collecting data from suppliers upstream and customers downstream.

However, stakeholders throughout the value chain lack the necessary systems and processes to effectively gather the required data and measure these KPIs. Furthermore, the definitions of these KPIs are still in the early stages of development. These challenges result in process inefficiencies, material leakage, and loss of value for stakeholders, which ultimately hinders the achievement of circular economy (CE) objectives.

Existing manufacturing systems such as Enterprise Resource Planning (ERP) and Product Lifecycle Management (PLM) are ill-equipped to address these challenges because they were designed for new manufacturing processes rather

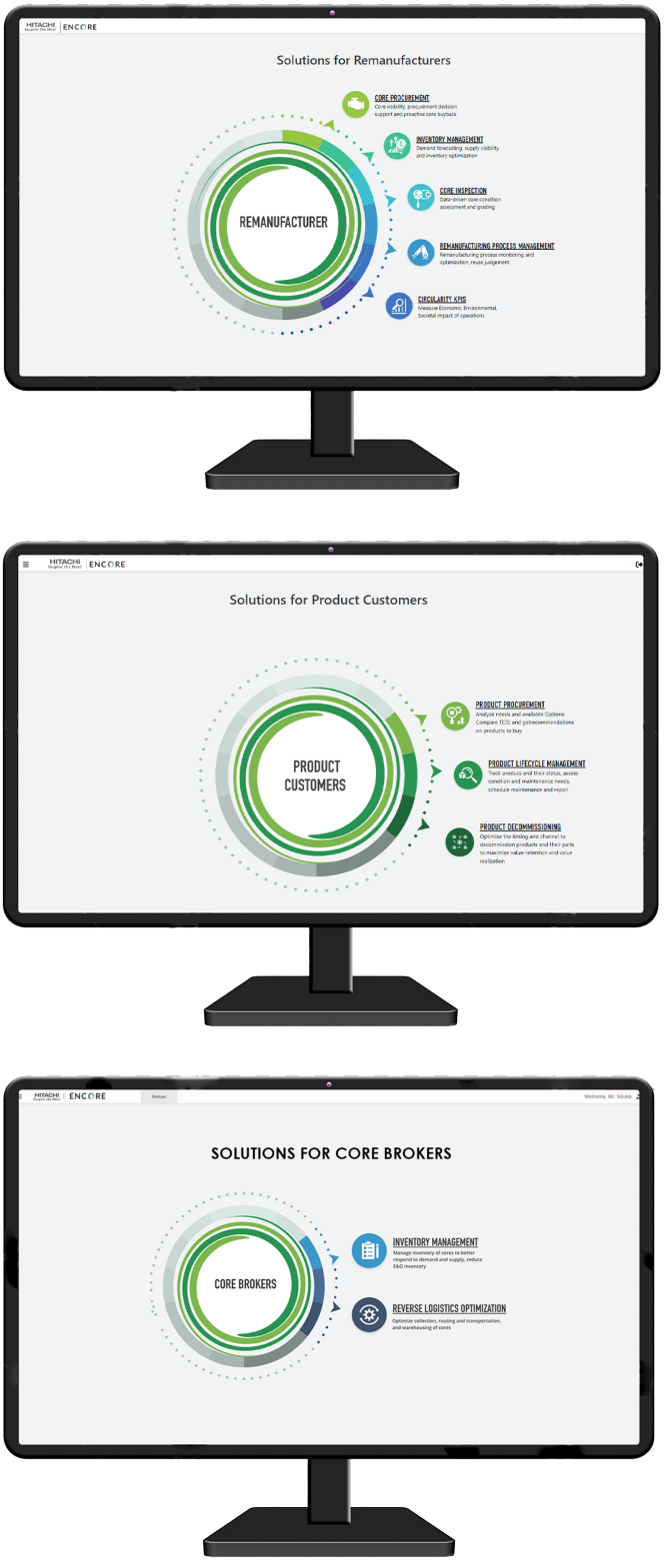


Figure 8, Dashboards for Remanufacturers, Product Owners, and Core Brokers

than RE*). These systems typically focus on a single stakeholder, usually the Original Equipment Manufacturer (OEM). However, RE* operations differ significantly from new manufacturing, as they involve interconnected supply and demand, variable quality, and condition of input materials (i.e., used products), and the need to collect input materials from multiple customers.

These fundamental differences make it extremely challenging to adapt solutions intended for new manufacturing to the complexities of RE* (Figure 5).

Addressing these challenges requires a coordinated effort among the key stakeholders. Many stakeholders have silo-ed systems, disconnected product use and product recovery cycles, and lack of data-driven decision-making.

Hitachi's Innovative Digital Solution

The challenges surrounding Industrial Product Circularity can be addressed by leveraging emerging digital technologies and big-data analytics. By incorporating technologies such as blockchain/distributed ledgers, AI, analytics, and IoT, RE* operations can be made more sustainable and efficient. To meet this opportunity, we created a solution to address these challenges consisting of two main components: a trusted platform, and an AI/analytics framework built on top of this platform.

The trusted platform establishes a unified source of truth for stakeholders involved in a product's

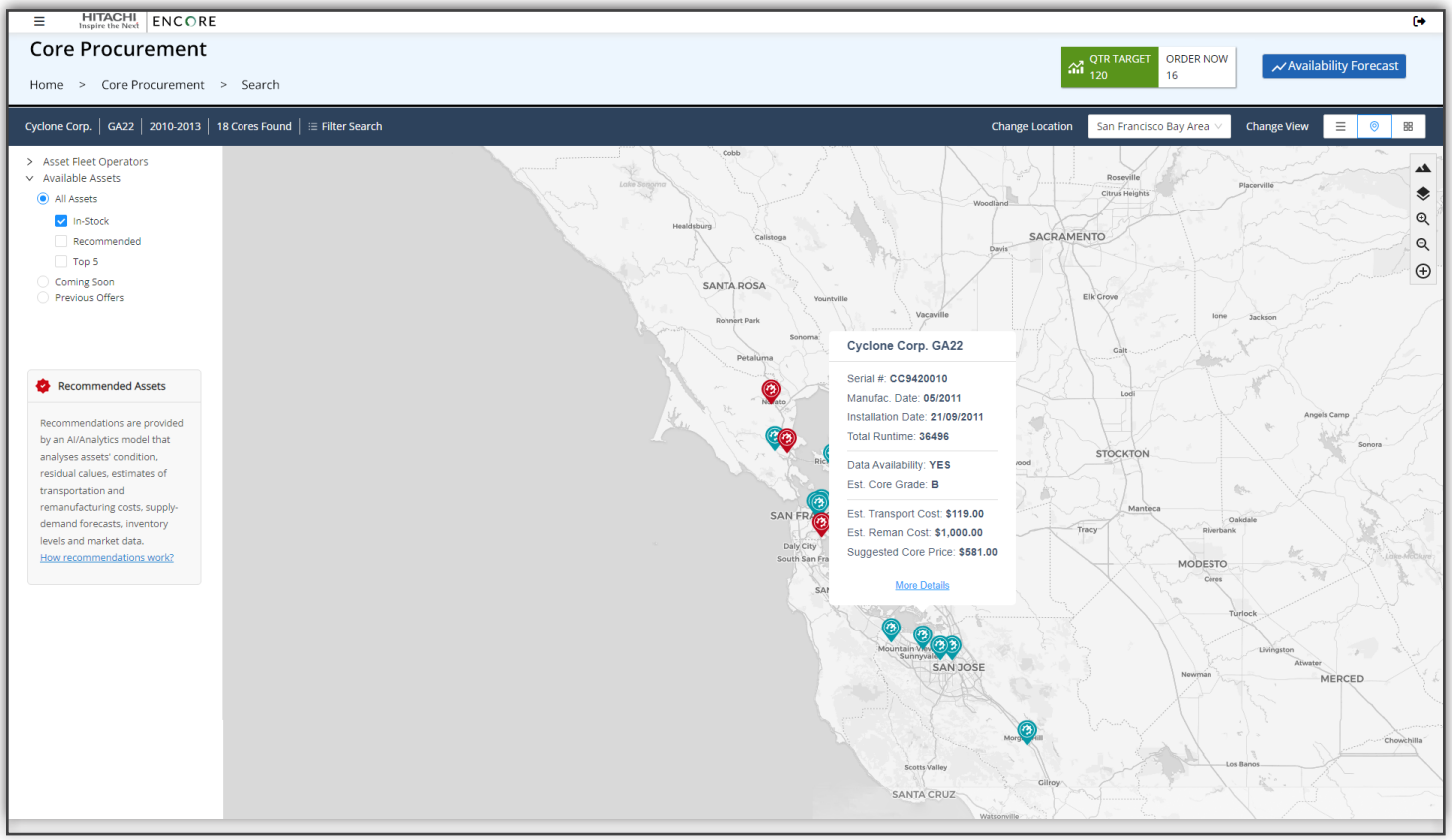


Figure 9: Core Procurement Application for Remanufacturers

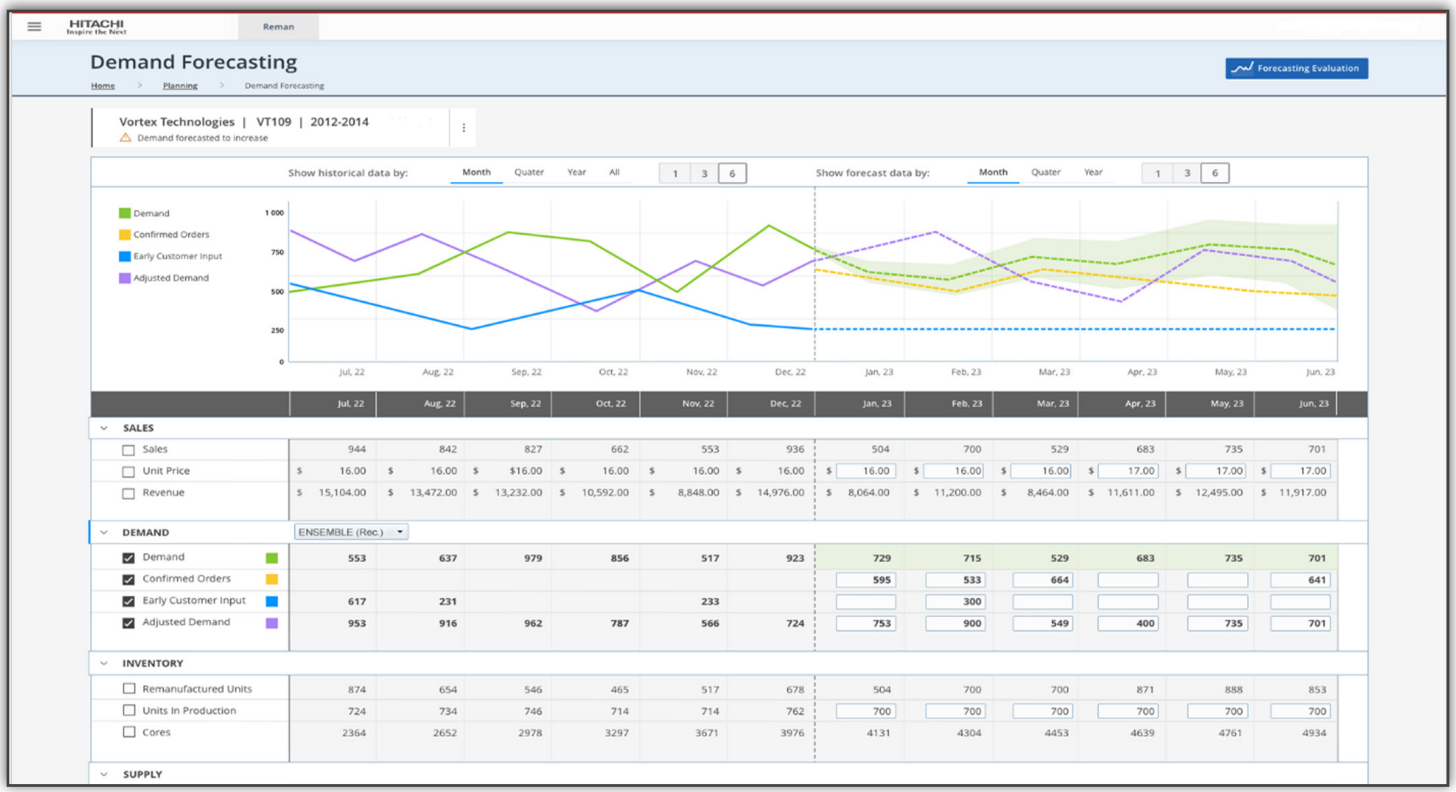


Figure 10: Inventory Management application for remanufacturers

lifecycle across the value-chain, facilitating effective coordination among them. Each participant is only required to share information relevant to circularity on the platform. Business-critical data remains in independent databases off-chain, while the platform ensures secure sharing of data between participants, automating transactions and minimizing friction in the process. The platform enables secure data sharing between users, provides automated transactions, and reduces transactional friction (Figure 6).

AI/Analytics Optimization for Remanufacturing Decision Support

During an Industrial product's lifecycle stakeholders need to make many decisions. For example, the owner of an aging industrial product must determine when to decommission it, understand its residual value, and choose the best option (e.g., sell, remanufacture, or scrap).

A remanufacturer must decide when to purchase an aging or used product, what buyback incentive to offer and how many units to purchase. Buyers must decide between buying new, used, or remanufactured products. These decisions are further complicated by the numerous factors influencing them.

Our solution includes an AI/Analytics layer that provides insights and decision support to the different stakeholders through stakeholder-specific portals and dashboards (Figures 7 & 8).

Outcomes for Remanufacturers

The platform's AI and analytics functions provide insights and decision support for remanufacturers throughout their operations with:

Core Procurement application for improved

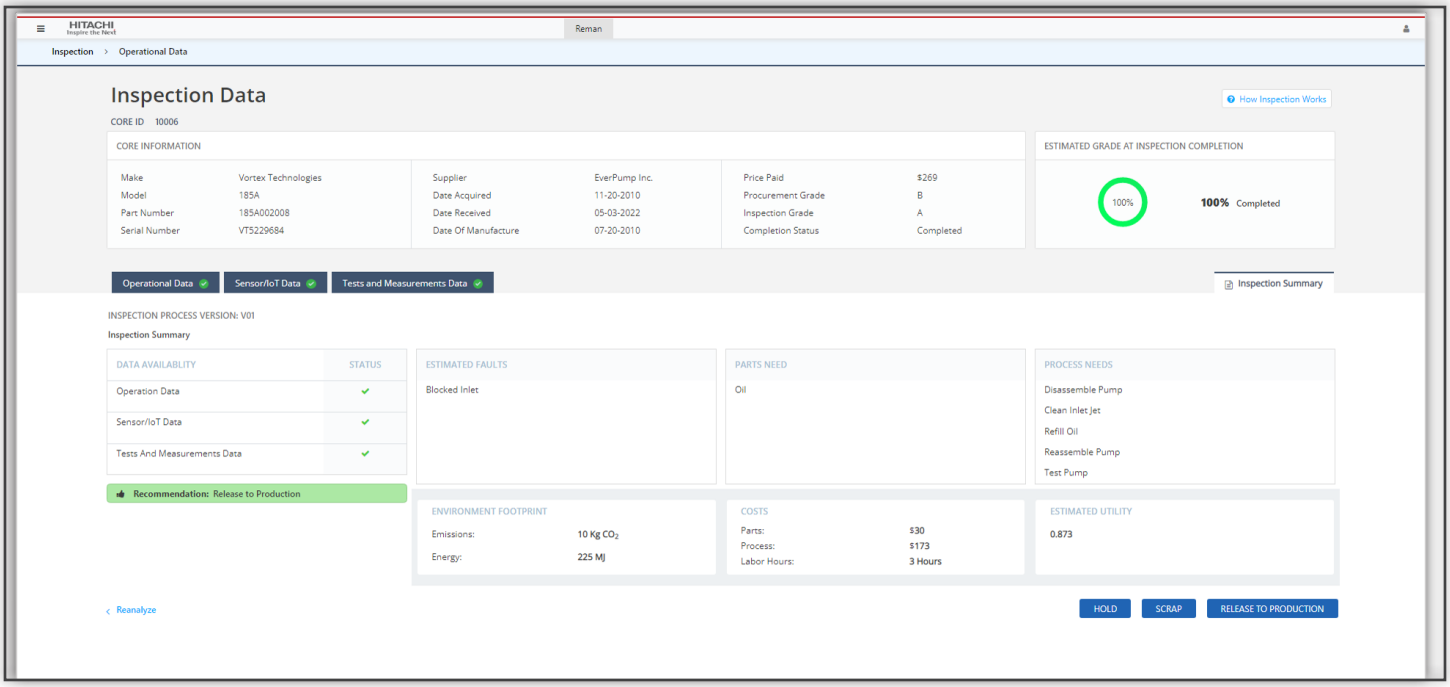


Figure 11: Core Inspection Application for Remanufacturers

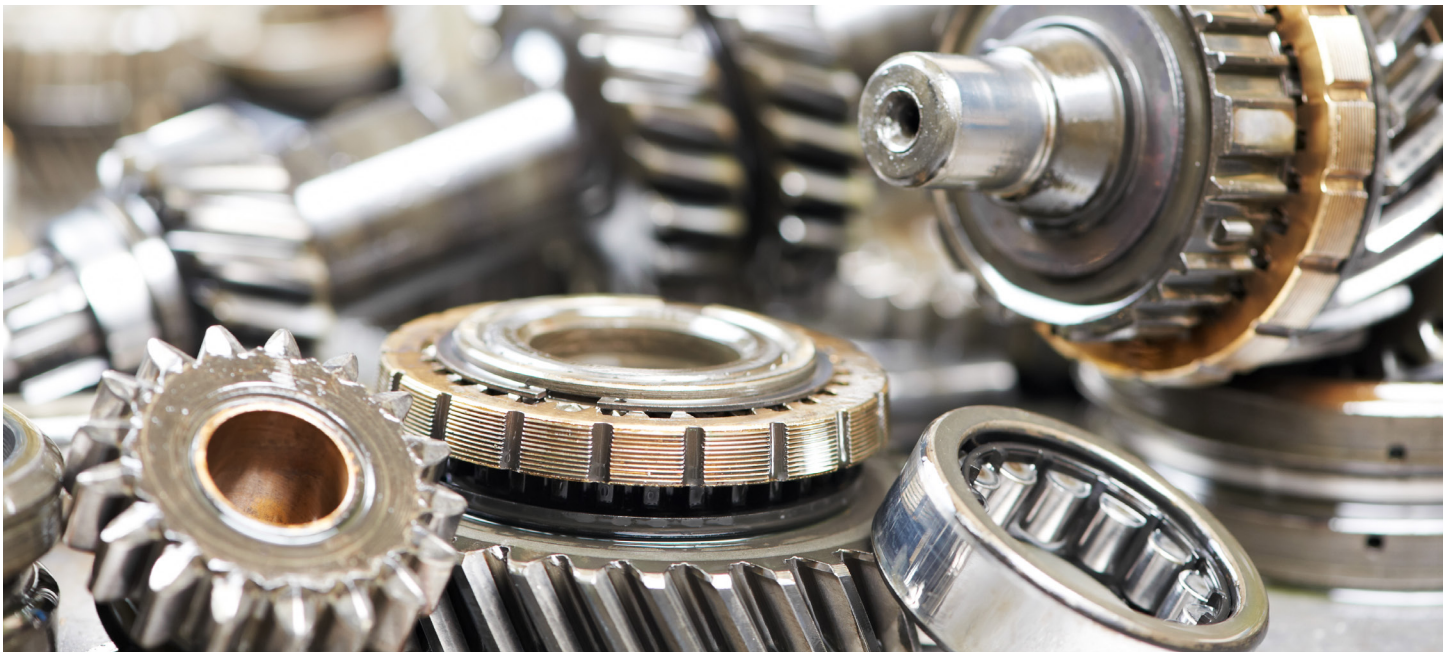
core visibility and sourcing: By monitoring aging products in operation, the process of purchasing cores can be shifted from a reactive approach to a proactive one. Remanufacturers can keep track of the condition of ageing products that can be used as potential cores and make proactive offers for the right quality and quantity of cores at the right time.

The process involves periodically evaluating the core requirements for each product line that is undergoing remanufacturing. The system assesses each monitored product and assigns it a grade based on available data. The product's condition and grade determine the potential remanufacturing cost, estimated using standard operating procedures. The system also computes the logistics cost of bringing the product to the remanufacturing facility based on its location.

Using estimates of remanufacturing and logistics costs, along with current market conditions, the system calculates a buyback incentive that can be offered to the product owner for their used product. Finally, the system identifies which ageing products to purchase based on a combination of factors, such as profit margins, quality, and regulatory needs (Figure 9).

Core Inspection application for data-driven a priori core quality assessment: Remanufacturing is a process with high variability due to differences in the quality and supply of cores, as well as demand for remanufactured products. To prioritize production of cores with the least amount of fallout and resource use, our system assesses the condition of cores before disassembly and uses machine-learning, deep learning, and statistical approaches to analyze a variety of data, such as operational and sensor/IoT data.

It estimates faults, necessary parts and processes, associated costs, and environmental impact, and computes a utility value for each core based on its economic and environmental impact. This enables



prioritization of cores for production (Figure 10).

Remanufacturing Process application for data-driven reuse judgement: When remanufacturing a product, its constituent parts are typically reused, never reused, or reused based on their condition.

The decision about which parts to reuse is usually made by the worker who disassembles, cleans, and inspects the core. However, this is a difficult task that requires experience and skill, and even then, it can be challenging to make a good assessment.

Our system uses data-driven analytics to assist workers in making reuse judgments. The data and analytics used may vary widely depending on the specific product and component. Additionally, sensors and data loggers can be added to products or components to indicate their reusability.

For example, if a component can log the number of actuations or shocks and stresses experienced during its lifetime, this data can be used during remanufacturing to make decisions about reuse from a design for remanufacturing perspective.

Inventory Management application providing improved demand-supply forecasting: Predicting demand and supply is a major challenge for remanufacturers as they are interconnected and come from the same parties. The system we developed addresses this challenge by considering various factors such as historical demand, usage data, breakdown data, customer information, and regulatory conditions. It also considers the product lifecycle and the surviving population of the product model to strategically predict the start and end of a remanufacturing program.

With the application, planners working for a remanufacturing company can anticipate future demand and supply, and use that information to prepare for inventory, procurement, and production (Figure 7).

Circularity KPIs application for measurement and optimization of CE KPIs: The Industrial Product Circularity system incorporates modules designed to measure and optimize circular

economy (CE) Key Performance Indicators (KPIs).

These KPIs play a crucial role in identifying gaps, minimizing material and energy losses, and identifying areas for enhancement.

While economic KPIs have traditionally received the most attention, CE emphasizes the significance of environmental and societal KPIs. To effectively measure these KPIs, comprehensive operational data such as production metrics, material usage, waste generation, emissions, energy consumption, and labor statistics must be systematically tracked.

This data enables the computation of both generic KPIs like material embedded energy and emissions savings, as well as manufacturing process-specific KPIs related to the reclamation and reuse of components or labor utilization in RE* processes. Additionally, industry-specific KPIs tailored to specific product categories and sectors are also considered.

Outcomes for Product Customers

The Industrial Products Circularity system offers a range of features that empower product customers to make well-informed decisions throughout the entire lifespan of the product. The system encompasses the following capabilities:

Product Procurement application: by leveraging a reliable underlying platform that diligently monitors the multiple life cycles of a product, the system offers customers comprehensive information about the origin and previous usage of reclaimed products, instilling trust and confidence in their quality. Furthermore, the system offers valuable recommendations to customers, allowing them to make informed purchasing decisions by comparing different products based on various factors, including cost of ownership, condition, and environmental impact.

Product Lifecycle Management application for improved tracking and maintenance support: through the act of submitting product data

to the reliable platform and sharing it with original equipment manufacturers (OEMs) and service providers, customers gain the ability to monitor the performance of their products, receive timely notifications about potential failures, and benefit from proactive maintenance assistance.

Product Decommissioning application: The system aids product customers in making well-informed decisions regarding decommissioning by examining product data and considering various factors such as usage projections, anticipated maintenance expenses, operational costs, and environmental impact.

Leveraging this information, the system evaluates the condition of the product, assesses its ability to meet usage requirements, and compares it with alternative options.

If decommissioning is deemed necessary, the system presents disposal choices, recommends the appropriate channel (e.g., remanufacture, sale, or scrap), and provides predictions regarding returns or incentives. Utilizing a connected and trustworthy platform, the system facilitates the initiation or acceptance of sale or purchase offers directly within the platform, enabling automated transactions.

Outcomes for Core Brokers

For core brokers, the system enhances visibility into the demand and supply of cores, allowing for improved monitoring of core availability and demand forecasting.

Inventory Management application provides improved demand and supply forecasts based on analysis of both endogenous data (e.g., order history, historical demand and supply data) and exogenous data (e.g., industry activity indicators,

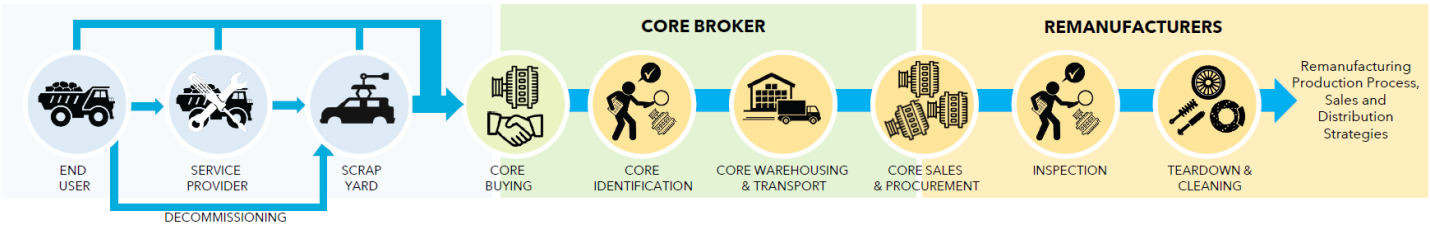


Figure 11: Case Study for a Large Automotive Broker

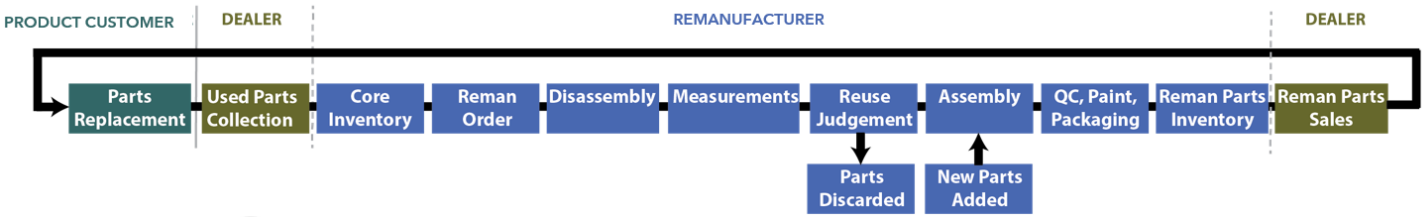


Figure 12: Case Study for a Global Construction and Mining Equipment OEM

market indices). Based on the forecasts it enables optimization of inventory to minimize overstocking and understocking of cores.

Reverse Logistics Optimization application optimizes collection, transportation, and storage of cores to minimize costs, minimize environmental impact and maximize efficiency of operations.

The system evaluates the condition of the product, assesses its ability to meet usage requirements, and compares it with alternative options.

Case Studies

Hitachi R&D is engaged in two proofs of concept (PoCs) with leading companies in the automotive parts, and construction and mining equipment industries.

A large automotive core broker

In the first PoC, Hitachi R&D is working with one of the largest automotive core brokers in the US to develop an AI/Analytics-based core demand forecasting solution. The solution analyzes the broker's endogenous data and generated demand forecasts for future periods on a per SKU basis. These forecasts provide insights to procurement managers, enabling them to optimize core procurement and inventory (Figure 11).

A global construction and mining equipment OEM

In the second PoC, Hitachi R&D is working with a global construction and mining equipment OEM. The OEM has a remanufacturing operation that remanufactures parts that require usage-based replacement and sells them to customers. Hitachi R&D has developed a demand and core returns forecasting model for remanufactured parts that factors in equipment-usage and customer-behavior to predict when parts replacements are likely to happen. The R&D team has also developed an aggregated demand forecasting model to help the OEM management with financial and inventory planning (Figure 12).

Both PoCs demonstrate Hitachi R&D's ability to use AI/Analytics to solve real-world problems for stakeholders in the remanufacturing value-chain.

Conclusion

Our system for Asset Remanufacturing Circularity utilizes digital technology to facilitate the shift towards a Circular Economy, where products are remanufactured and materials are reused and recycled for as long as possible.

The platform is secure and reliable, connecting various stakeholders and enabling transparent communication and transactions. Products are monitored and tracked throughout their entire lifecycle, with their history being recorded on the platform to establish their origin and assist in end-of-life collection efforts.

The system provides traceability and analytics to assist remanufacturers in efficient core buying and inventory management, while also monitoring and optimizing sustainability and circular economy key performance indicators (KPIs).

Collaboration among ecosystem stakeholders is facilitated through better visibility, information sharing, and data-driven decision-making, and helps to prevent sub-optimal decision-making in isolated siloes. This enables stakeholders to realize previously unattainable positive business outcomes and maximize the environmental, economic and social benefits of a circular economy.

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Choose the Right Remanufacturing Solutions Partner

Discover the possibilities of a circular economy with a strategic partner that possesses in-depth knowledge and extensive experience in remanufacturing and digital technologies to effectively address complex challenges. We foster a strong partner ecosystem and deliver comprehensive solutions tailored to your specific needs.

Take the Next Step >>>

Guiding our customers from what's now to what's next.

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