2017

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TECHNOLOGY ROADMAP

for Remanufacturing in the Circular Economy

Prepared by:
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With Support from:
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About this Roadmap

The goal of this roadmap is to develop a plan aimed at identifying opportunities to enhance the industry competitiveness and advancement and addressing the significant technical challenges facing the remanufacturing industry. The content of this report is derived from an extensive industry analysis, comprehensive survey, technology forecasting, industry site analysis and two industry workshops held on September 29, 2015 and a final workshop held on September 29th and 30th, 2016, bringing together leaders in remanufacturing to share ideas and identify common priorities. The resulting *2017 Remanufacturing Roadmap Report* is published by the Golisano Institute for Sustainability (GIS) at the Rochester Institute of Technology (RIT), with support from the United States National Institutes for Standards and Technology (NIST) Advanced Manufacturing Technology Consortia (AMTech) grant program.

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The 2016 workshop was organized and facilitated by Dr. Hansen and a team from Energetics, Incorporated, in collaboration with the RIT team. RIT would also like to recognize support from the Remanufacturing Industries Council (RIC), and appreciation is extended to the workshop subject-matter experts and industry representatives, listed in Appendix A, who volunteered their valuable time to contribute expertise to this effort. In addition, the project team would like to acknowledge the support and assistance of the Industrial Advisory Committee (listed in Appendix C).

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Acknowledgement and Data Reliance Description

The creation of this report was funded by the U.S. Department of Commerce, National Institute of Standards and Technology (NIST). The opinions, results, findings and/or interpretations of the data contained herein are the responsibility of Rochester Institute of Technology (RIT) and do not necessarily represent the opinions, interpretations or policy of the sponsor. Generally, where data is supplied, referenced, and/or relied upon the data was obtained from RIT-conducted survey data, publicly available sources, government agencies, standard estimating practices, and individual communications with resource providers or industry leaders if the citation is noted accordingly.

The data supporting this report and its conclusions was considered the best available at the time this report was written. It is offered for purposes of this remanufacturing roadmap project and informational purposes based on industry expertise

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and experience. Forecasting economic and industrial directions and outcomes in a complex world economy with multiple economic, political, and technological variables affecting possible outcomes always involves inherent uncertainties.

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Executive Summary

Industry Overview

Remanufacturing was pioneered over 80 years ago in the U.S. and since has enjoyed significant growth. Between 2009 and 2011, the value of U.S. remanufactured production grew by 15 percent, reaching $43B and supporting 180,000 full-time U.S. jobs. The remanufacturing industry is also diverse, with 12 remanufacturing-intensive sectors accounting for the majority of remanufacturing activity in the United States. These sectors include: aerospace, consumer products, electrical apparatus, heavy-duty and off-road equipment, information technology products, locomotives, machinery, medical devices, motor vehicle parts, office furniture, restaurant equipment, and retreaded tires.

As material availability, energy, and resource efficiency emerge as critical challenges, and in effort to reinvigorate the U.S. manufacturing industry's competitive advantage on a global scale, the benefits of remanufacturing are factors that can help and contribute to the growth and resource efficiency of the American industry. From economic value preservation to environmental impact avoidance and social development, remanufacturing—the process of collecting valuable products at the end of their useful life and restoring them to like-new condition and functionality—holds considerable potential to support new ways of creating value that promise to support the sustainable growth and competitiveness of the U.S. manufacturing industry.

Research Need

For all this potential, however, the U.S. remanufacturing industry is currently challenged to keep pace as competition, technologies in manufacturing and product markets across industry continue to advance at an unprecedented rate. In addition, market access challenges continue to present obstacles to industry growth. Since remanufacturing necessarily begins at the end of the product life cycle, the flow of information, process technology, and technical capability from new product development to remanufacturers is inherently delayed in many cases. As a result, the U.S. remanufacturing industry is constantly challenged to maximize the value it is theoretically able to preserve, recover, and create. To remedy this, new approaches and technologies must be developed and deployed to meet the unique needs of remanufacturers and transform their role within the broader industrial economy. Importantly, this technology research must be supported by advanced models of industry collaboration so that its fruits may be broadly accessible.

Goals

This roadmap serves to address the challenges facing the remanufacturing industry by identifying cross-cutting deployable technologies that can lead to advanced capabilities of U.S. firms and advance the transition to a circular economy. This technology roadmap offers a tangible, actionable plan to overcome the technical and market barriers currently inhibiting the growth of an advanced remanufacturing sector.

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Roadmap Development

The Golisano Institute for Sustainability (GIS) at the Rochester Institute of Technology (RIT) has developed this roadmap through analysis of the most critical challenges and opportunities to advance the industry and offer a prioritized research, development, and deployment (RD&D) plan to address them. To develop the roadmap content, GIS conducted a quantitative survey, substantive literature reviews, site visits, and telephone interviews with remanufacturers of all sizes across the country and throughout the various industry sectors. Through this work, GIS identified four critical focus areas for further study:

- Design and Information Flow
- Condition Assessment and Reliability Engineering
- Remanufacturing Process Technology
- Business and Market Issues

At the conclusion of the project, a final expert workshop hosted by GIS and facilitated by Energetics Inc., which brought together subject-matter experts and industry representatives to identify key technical challenges, and develop RD&D projects based on the significant analysis conducted during the duration of this project. The roadmap integrates the ideas generated at this workshop into a comprehensive plan for future RD&D.

High-Priority RD&D Projects

This roadmap identifies 11 high-priority projects intended to focus and direct RD&D work toward addressing the most critical technical, market, and business challenges facing the industry. The projects are designed to lead to transformational pre-competitive solutions that can be implemented near and long-term. The 11 high-priority project areas that compose the RD&D plan are as follows:

- Develop and Integrate Design for Remanufacturing Concepts within Engineering Tools
- Standards Development and Remanufacturing Certification
- Inspection Process Development and Optimization
- Low-Cost Additive Manufacturing Process
- Advanced Surface Cleaning Technologies
- Nondestructive Evaluation
- Electronic Systems Condition Assessment
- Overcome Data Silos
- Provide Validated Information to Inform Policy and Decision Makers
- Methodology and Tools to Model Global Lifecycle Value/Impacts of Remanufacturing
- Multi-Level Remanufacturing Marketing Campaign

These projects, outlined in Figure ES-1, are highly interconnected and ultimately serve as the roadmap that will take the U.S. remanufacturing industry from where it stands today—capable, but stratified—to where it must be in order to ensure strong competitiveness and sustained position.

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Ensuring Sustainability

Effective implementation and successful deployment are essential for these RD&D projects to benefit industry. However, deployment is challenging and comes with high risks. Therefore, this roadmap offers a Remanufacturing Research Consortium Sustainment Plan, which envisions how the roadmap will be disseminated, implemented, sustained, reviewed, and updated—with a heavy focus on fostering the collaborations and industry engagement critical for success.

At the center of this plan is the Remanufacturing Research Consortium, which was established in late 2015. The Consortium is an industry-sustained collaborative, and it serves as the coordinating and oversight body for roadmap implementation. The Consortium will help the research teams stay informed, funded, and on track.

Path Forward

Implementing these pre-competitive research projects is beyond the scope of a single organization. Each project will require significant financial and technical resources, making it imperative for the diverse remanufacturing industry to join this effort and collaborate to carry out these RD&D projects. Therefore—in addition to providing critical guidance for future RD&D efforts—this roadmap serves as a call to action for industry-wide collaboration.

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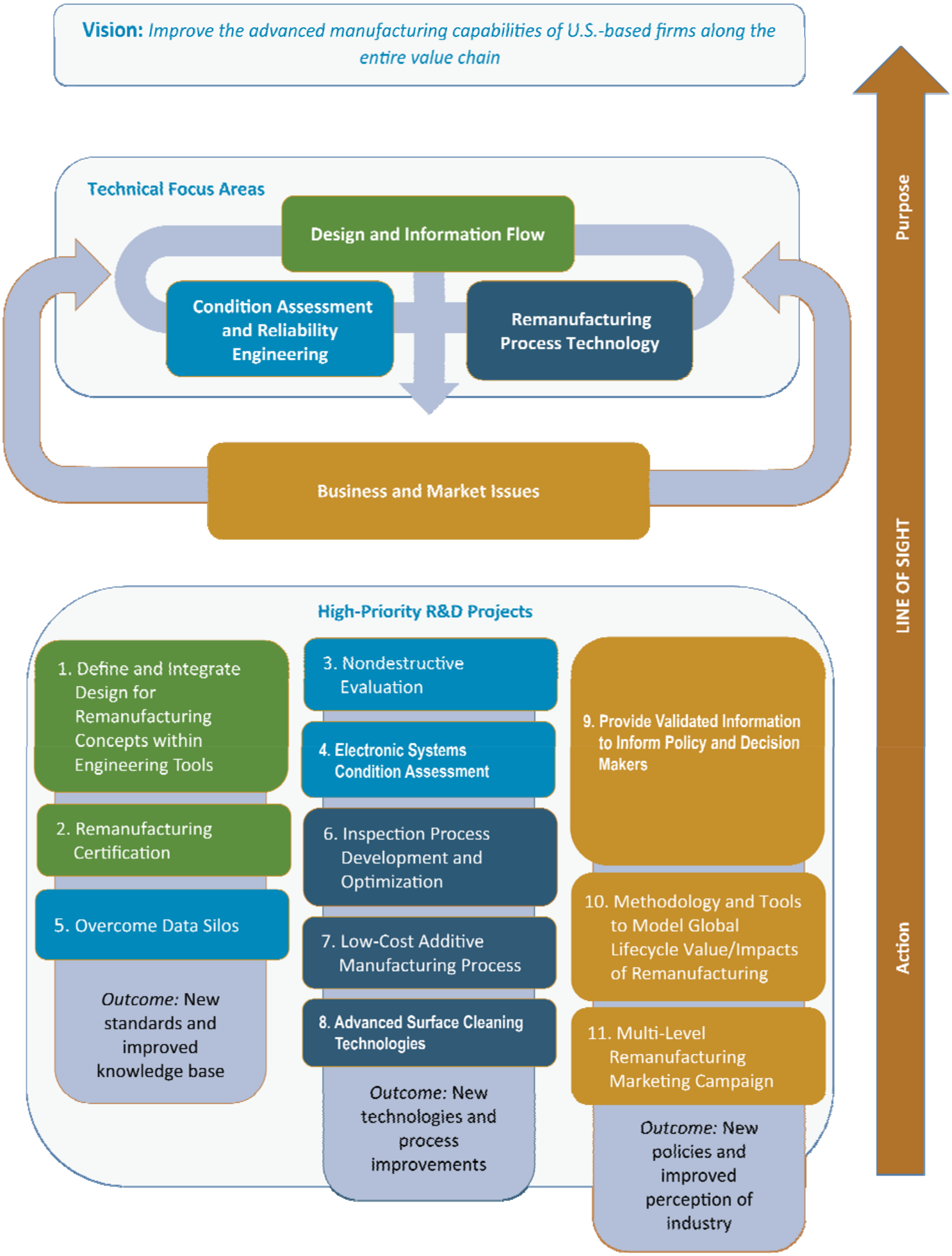

Figure ES-1 Integrating Graphic

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1. INTRODUCTION

Remanufacturing was pioneered over 80 years ago in the United States as a means to conserve value and reduce cost. Remanufacturing gained significant expansion during World War II as a means to conserve critical resources and reduce costs. Over the course of global industrial development, these resource and cost-saving strategies have emerged into an industry, experiencing significant growth due more to its economic viability than wartime necessity.[1] In the last 50 years especially, advances in manufacturing technology were met with concurrently increasing awareness of the need for environmental protection and sustainability, expanding the scope of the industry and driving its growth.

Today, the United States is the leading remanufacturer in the world, and the industry is still growing. Between 2009 and 2011, the value of U.S. remanufacturing production grew by 15 percent, reaching $43 billion.[2] In the same period, U.S. remanufacturing supported approximately 180,000 full-time jobs, many coming from small, independent businesses where nearly 5,000 such companies employ fewer than 20 people.[3,4] Beyond traditional markets, U.S. remanufacturing also serves the defense industry as its largest single segment; including the value of work focused on sustaining military ground vehicles, ships, aircraft. U.S. remanufacturing overall is estimated as a $100 billion industry.

Despite its history and recent growth, remanufacturing remains underrepresented in many areas including research, technological development, and government investment. To stay competitive and, indeed, become more competitive, U.S. remanufacturing requires significant technology improvements that can address the complex technical challenges facing the industry. These challenges are cross-cutting between industry sectors, and therefore cannot be solved with a single, unilateral initiative; rather, they require widespread, pre-competitive collaboration to develop transformative solutions that can benefit the entire industry.

The objective of this study was to identify common areas of interest and opportunity applicable across industry sector boundaries, and therein to provide guidance for research and collaboration models needed to develop meaningful solutions. The following roadmap identifies specific research and development pathways that are most likely to yield positive impacts to advance the state of U.S. remanufacturing industry and its competitive advantage.

[1] N.Nasr and M. Haselkorn, 2014. *Remanufacturing.* Presentation for Golisano Institute for Sustainability, Rochester Institute of Technology

[2] Office of Industries. 2012 .*Remanufactured Goods: An Overview of the U.S. and Global Industries, Markets, and Trade*. Investigation No. 332-525. USITC Publication 4356. Washington, D.C.: U.S. International Trade Commission. https://www.usitc.gov/publications/332/pub4356.pdf

[3] EOL Product Remanufacturing and Reuse Economics: Consumer Side and Producer Side. Proc. ISSST, Malima Isabelle Wolf, Timothy G. Gutowski. http://dx.doi.org/10.6084/m9.figshare.805095. v1 (2013).

[4] Ibid.

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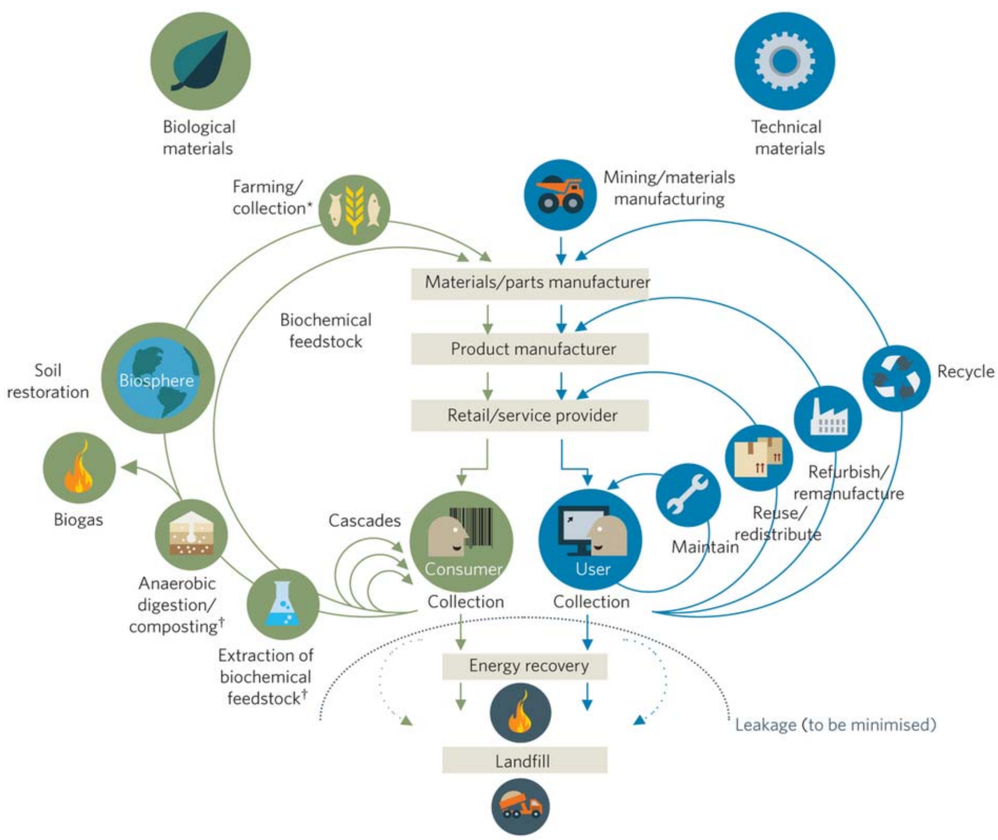
Remanufacturing and the Circular Economy

Forward-looking businesses and governments recognize that the current linear economic model is unsustainable both environmentally and financially. Consequently, the Circular Economy (CE) has rapidly gained attention worldwide. CE refers to an "industrial economy that is restorative by intention; aims to rely on renewable energy; minimizes, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design".[5] CE is a paradigm shift from linear, to systems thinking. "The linear 'take, make, dispose' model relies on large quantities of easily accessible resources and energy, and as such is increasingly unfit for the reality in which it operates."[6] In addition to environmental implications, there is a combined annual *trillion* dollar opportunity globally in net material cost savings for companies making the transition to a CE[7].

As shown in the figure below, remanufacturing is a fundamental component of the CE. This is because one of the most serious challenge in future manufacturing is material availability. Remanufacturing holds huge potential for reducing consumption of materials, offering an economic and environmental approach to address this problem. The proposed technology roadmap addresses the technical materials side of CE, focusing on technology challenges in the remanufacturing industry.



5 Towards the Circular Economy, Vol. 2. Ellen MacArthur Foundation. 2013

6 The circular model - an overview. July 8, 2013. Ellen MacArthur Foundation, http://www.ellenmacarthurfoundation.org/circular-economy/circular-economy

7 Towards the Circular Economy, Vol. 3. Ellen MacArthur Foundation. 2014

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Roadmap Development

Foundational roadmapping data was collected from multiple sources, from industry literature to personal interviews and direct observation. GIS first performed a situational analysis by identifying the barriers to industry growth and conducting a quantitative survey. This analysis was supported by an extensive literature review, as well as state-of-the-art site assessments at remanufacturers in each sector to develop an on-the-ground understanding of the current challenges, priority technology needs, and opportunities for state-of-the-art advancement in the U.S. remanufacturing industry. The information drawn from these efforts helped to develop the roadmap, and also guided topic selection for a two day workshop, which brought together leaders in remanufacturing to share ideas and identify common priorities. See Figure 1 for the roadmap process development. The following subsections provide a short summary for each process step.

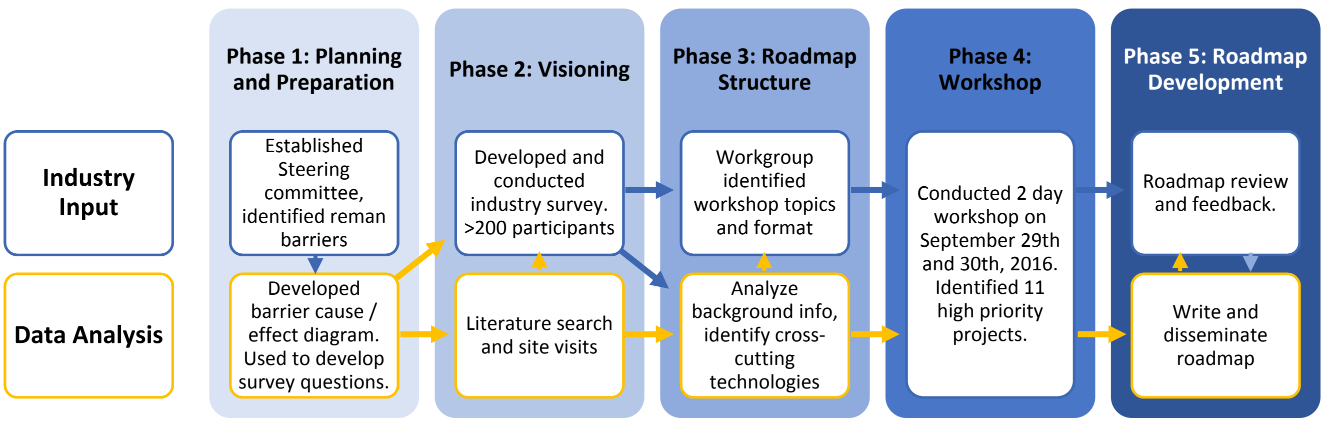

Figure 1: Roadmap Process Development

Phase 1: Planning and Preparation

An Advisory Group kickoff meeting was held in Michigan in September of 2015. At the meeting, the project details were presented and the group discussed potential categories for pre-competitive collaboration, including: technology, reverse logistics (e.g. tracking, transportation, core acquisition, valuation of core/accounting, identification of core, free movement of cores), remanufacturing awareness & recognition, legal and legislative issues, public awareness, workforce education & training, market access, and policy integration. These categories were then grouped into major categories and used to develop a cause-and-effect diagram capturing the barriers to remanufacturing growth. (See Section 2) The cause-and-effect diagram provided the basis to develop the subsequent survey questions, formed around each of the major diagram categories. The Advisory Group participants are listed in Appendix C.

Phase 2: Visioning Technology Research

GIS conducted an industry survey, and collected industry insights through literature and remanufacturing site assessments in order to provide a comprehensive view of the diverse U.S. remanufacturing industry. The *GIS 2016 Remanufacturing Industry Survey* targeted representatives from 12 major industry sectors in effort to provide a comprehensive view of U.S manufacturing activities. It was administered online and was distributed via industry associations, trade organizations, and existing networks of manufacturing-sector contacts. These sectors include:

1. IT & imaging products
2. Machinery
3. Consumer products
4. Electrical apparatus
5. Medical Devices
6. Locomotives
7. Motor vehicle parts
8. Office furniture
9. Restaurant equipment
10. Heavy-duty and off-road equipment
11. Aerospace
12. Retreaded tires

The survey garnered responses and many individual pieces of qualitative feedback from a diversity of industry players, from large Original Equipment Manufacturers (OEMs) to small independent remanufactures. The survey results are summarized in Section 3 of this report.

In addition to provide a baseline foundation from which to build the roadmap, GIS also engaged in industry-wide investigations of both current performance and future needs. These investigations included extensive research of technologies both available and in development, and a substantial review of academic literature, industry publications, and current technology research trends. This research is summarized in Section 5.

Phase 3: Roadmap Structure

GIS analyzed all of the data from the Phase 2 activities to determine which focus areas would best serve the workshop and roadmap. Through this investigation, GIS identified intersections of technology across industry sectors that showed great promise for widespread applicability and, through collaborative development, exhibited potential to transform the industry and create mutual benefit.

Four critical focus areas emerged as common high-level denominators from which most current barriers to growth stem:

1. Design and Information Flow
2. Condition Assessment and Reliability Engineering
3. Remanufacturing Process Technology
4. Business and Market Issues

Phase 4: Remanufacturing Roadmap Workshop

GIS brought together leaders from remanufacturers across the industry sectors in an open forum to understand how these technologies and perspectives could be applied in the real-world. GIS conducted a workshop, facilitated by Energetics Incorporated to assist in the planning and execution of a 2-day, in-depth concluding workshop on September 29–30, 2016, in Troy, Michigan. Workshop participants are identified in Appendix A. The workshop brought together these industry representatives with business decision-makers as well as subject-matter experts. The professional facilitators aided stakeholders to

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hone in on cross-cutting challenges, to identify and reach consensus around the remanufacturing industry advanced technology objectives, and to set research priorities. Within the workshop, groups of industry representatives rotated through breakout discussion sessions in alignment with the four key areas that had emerged from GIS' survey and foundational research. In these sessions, GIS leaders disseminated research findings and facilitated discussion between groups and stakeholders within the context of these results, encouraging them to discuss and explore ideas and priorities, as well as to reevaluate their ideas and priorities in light of new insights. Each breakout group used a voting scheme to indicate which projects had the greatest potential impact and likelihood success. The projects that earned the most votes—the high-priority projects—were then examined in detail.

Phase 5: Roadmap Development

The information gathered from all sources is synthesized into this technology roadmap, which includes short and long-term goals and a sustainability plan. This roadmap will be broadly disseminated to establish a foundation to pursue research projects to meet the objectives identified in the roadmap.

The roadmap outputs are designed to support long-term, pre-competitive, basic, and applied research to develop broadly deployable technologies that can improve the advanced manufacturing capabilities of U.S.-based remanufacturing firms. Accordingly, this roadmap presents high-priority research and development efforts determined to have the greatest potential for overcoming the technical barriers inhibiting the growth of the remanufacturing industry. In order to ensure the economic feasibility of industry participation, the scope of this research is limited to projects that could be implemented and lead to advancement in the short and long-term.

What are pre-competitive solutions?

Pre-competitive solutions address obstacles that are common across one or many entire industry sectors. By encouraging co-operation and equitable access, pre-competitive development ensures that small and large enterprises alike may benefit from advanced technologies, tackling opportunities no single entity can address on its own. Pre-competitive solutions typically do not produce new products, but rather provide new tools, processes, information, and data to overcome obstacles. By establishing a common technological platform from which various competitors can develop their own competitive products, industry players may therefore interact more effectively without the technical barriers that presently inhibit growth, ultimately creating mutual benefit.

Transformative research often has a high cost and/or a risk of failure, often creating a deterrent for many companies. As a result, pre-competitive collaboration and academic -government support are critical to the success of research efforts.

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2. BARRIERS TO REMANUFACTURING

The roadmap development started with discussions from the Advisory Group kickoff meeting (September 2015) and considered potential areas in which pre-competitive collaboration may create industry-wide benefits. (See Appendix C for a list of participants in the Advisory Group) The group discussed focus areas that are barrier to remanufacturing growth, including: process technology, reverse logistics (e.g. tracking and identification, transportation, acquisition, and valuation), market awareness & recognition, legal and legislative issues, workforce education & training, market access, and policy integration.

RIT then continued the evaluation, identifying potential causes for each barrier. This work was documented and illustrated as a cause-and-effect diagram, or fishbone diagram, in Figure 3, capturing the causes and barriers to remanufacturing growth. This diagram provided the basis for the subsequent survey development.

What is Remanufacturing?

Remanufacturing is an industrial process that restores used products to a like-new or better-than-new condition, thereby recovering the value and reducing the environmental impact of the product. Remanufacturing therefore reduces the need to source virgin material to produce a new product as well as reducing the energy and emission required to produce new products. To do this, end-of-life products are systematically disassembled, cleaned, and inspected for wear. Damaged components are restored or replaced, feature upgrades can be incorporated, and the product is reassembled and re-qualified. Figure 2 depicts the remanufacturing lifecycle.

Figure 2. Remanufacturing Process Flow

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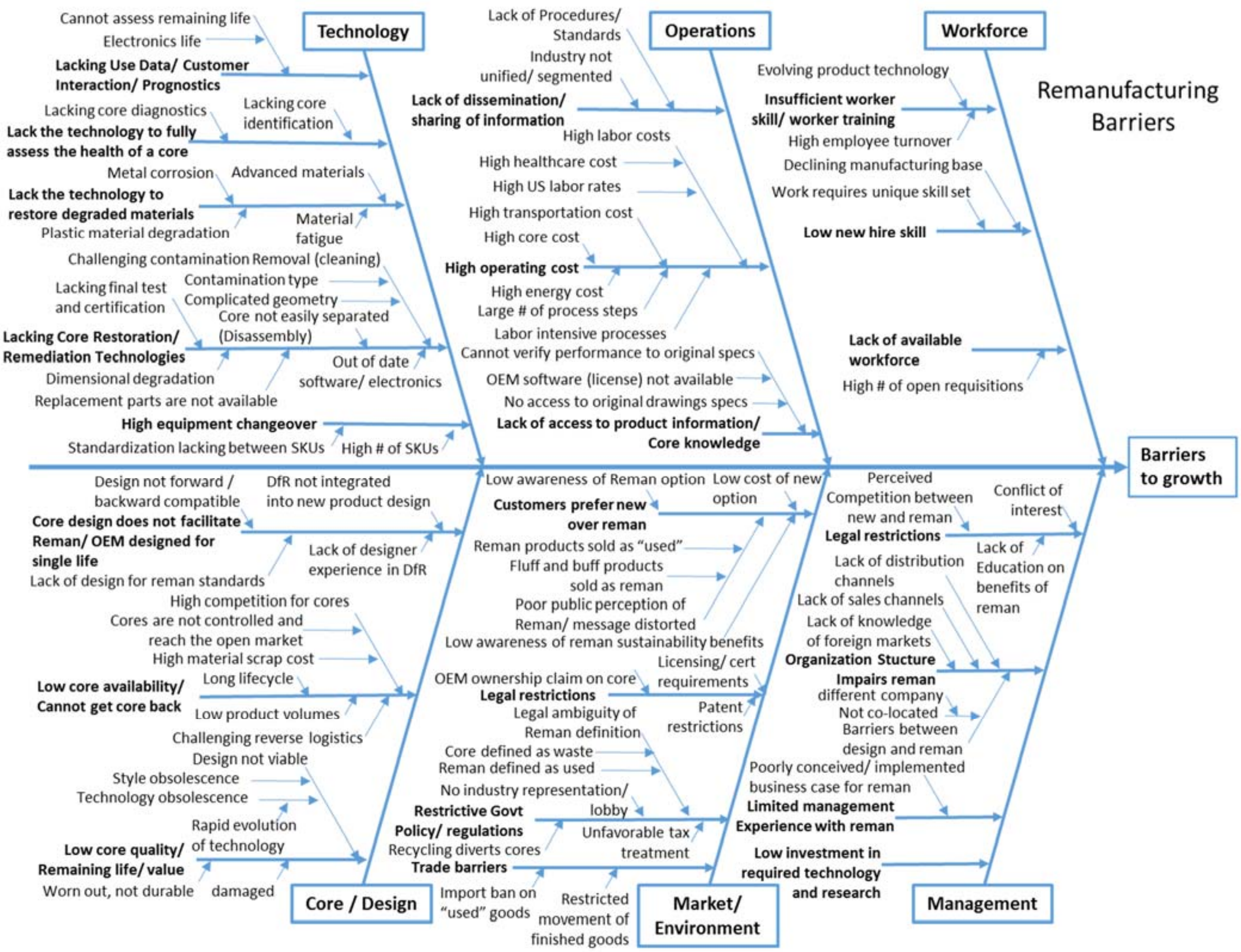

Figure 3: Remanufacturing Barriers Fishbone Diagram

3. INDUSTRY SURVEY

The fishbone diagram, in conjunction with input from industry leaders, provided the basis for survey development, distilling several hundred relevant questions into a 32 question survey. The survey was distributed through industry associations, trade organizations, and existing networks of manufacturing sector contacts, and administered online from May to June 2016, accruing over 200 responses. These responses were reviewed for completeness (only surveys with more than 60% of questions answered are used in analyses) data accuracy (e.g., ensuring respondents did not simply fill in "yes" for all answers to achieve completion), industry relevance (e.g., surveys from banks and retailers were removed), and country of origin (U.S. mailing addresses). Resultant sample size was reduced to 120 usable surveys; this report is based on these responses. The figures below further describes the breakdown of respondents by sector.

Of the usable surveys, 117 respondents provided annual revenue values for 2015. Seventeen percent of respondents were categorized as "large" companies with revenues greater than $100 million per year. Of the remaining eighty-three percent of "small-to-medium" companies (SMEs), half reported revenues less than $5 million per year. In this, it is evident that small and medium-sized enterprises (SMEs) were the most prevalent respondents to the 2016 Remanufacturing Industry Survey, and likely represent a similar size distribution across the U.S. manufacturing sector as a whole.

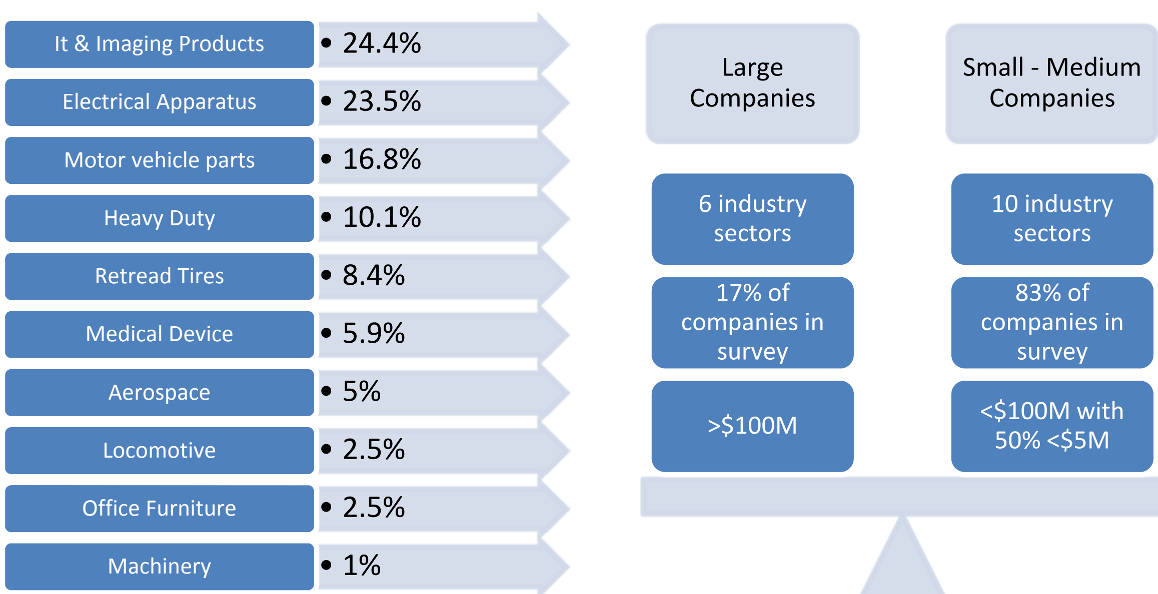

Figure 4: Survey balance by sector and size

Because the 2016 Remanufacturing Industry Survey targeted 12 different specialized industry sectors, topics of interest were accordingly diverse. The following subsections of this report highlight key focus

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areas distilled from the commonalities across industry sector response data. Each focus area is itself inclusive of other cross-cutting opportunities.

Design for Remanufacturing

Half of all survey respondents stated that products generally lack specific features that enable remanufacturing, and over half of that group suggested that this deficit is a business barrier. Accordingly, nearly half of respondents identify advanced Design for Remanufacturing (DfR) principles as the most potentially beneficial training topic.

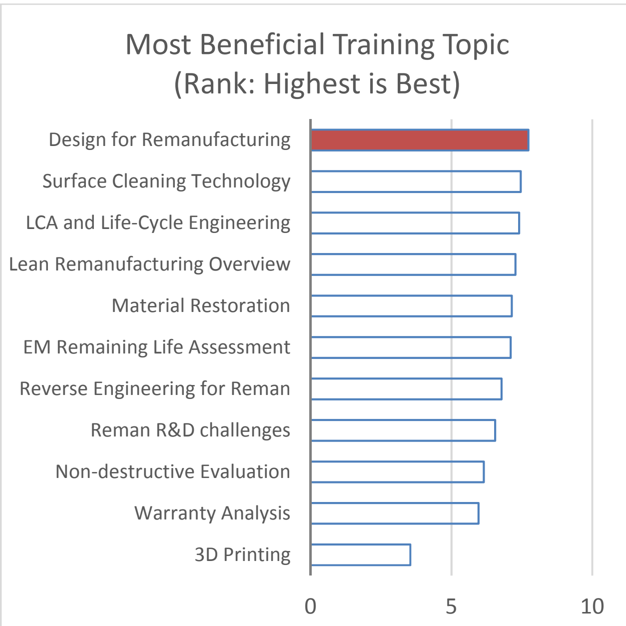

Figure 5: Beneficial training topics

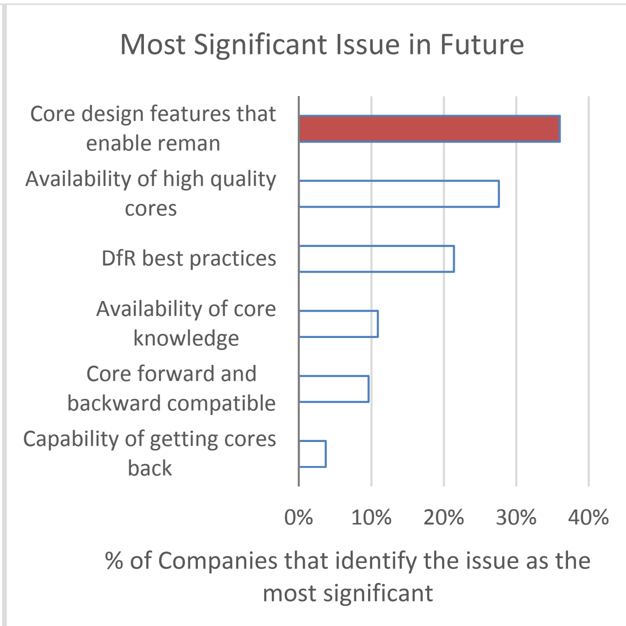

Figure 6: Future issues

This highlights the industry demand for products that are easier to remanufacture, and introduces the notion that the most effective way to make a product easier to remanufacture is through purposeful design.

Remanufacturing Process Technology

The GIS 2016 Remanufacturing Survey also revealed that 31% of all respondents identify remanufacturing process optimization as the most potentially beneficial topic in sustainable manufacturing. Remanufacturing processes rely on many unique steps that are not performed during original product manufacturing and, accordingly, many of these processes have not undergone the same extensive refinement, standardization, and technological optimization implemented by original manufacturers. Process steps such as disassembly, cleaning, condition assessment, physical, mechanical and electrical part restoration, component replacement, reassembly, and validation are fundamental to

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remanufacturing, but have not frequently been the focus of efforts in technological innovation and optimization.

Additive manufacturing is also highlighted by some; half of large companies say restoring worn components to specified dimensions through additive manufacturing is a significant opportunity. See Figure 7.

It is important to recall, however, that 83% of survey respondents were SMEs, and that priorities often differ between large and small companies. The top three most significant innovation opportunities identified by SMEs, for example, are the lowest priorities identified by large companies. See Figure 8.

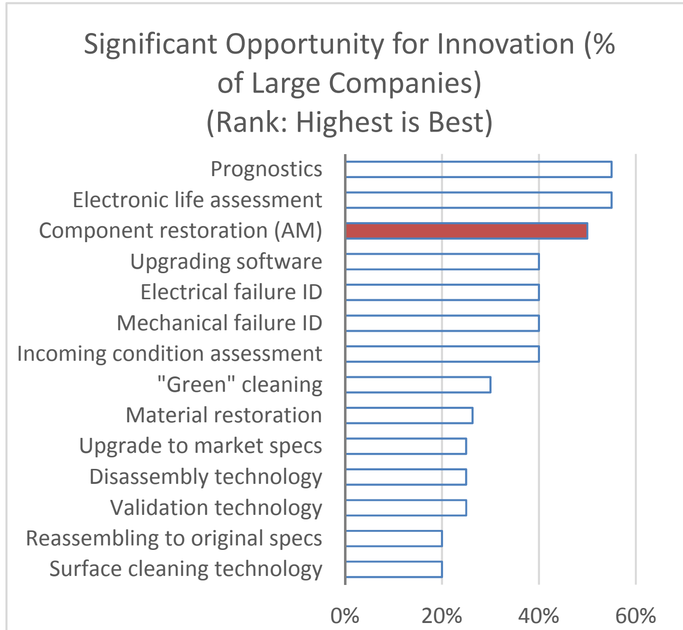

Figure 7: Opportunity for innovation

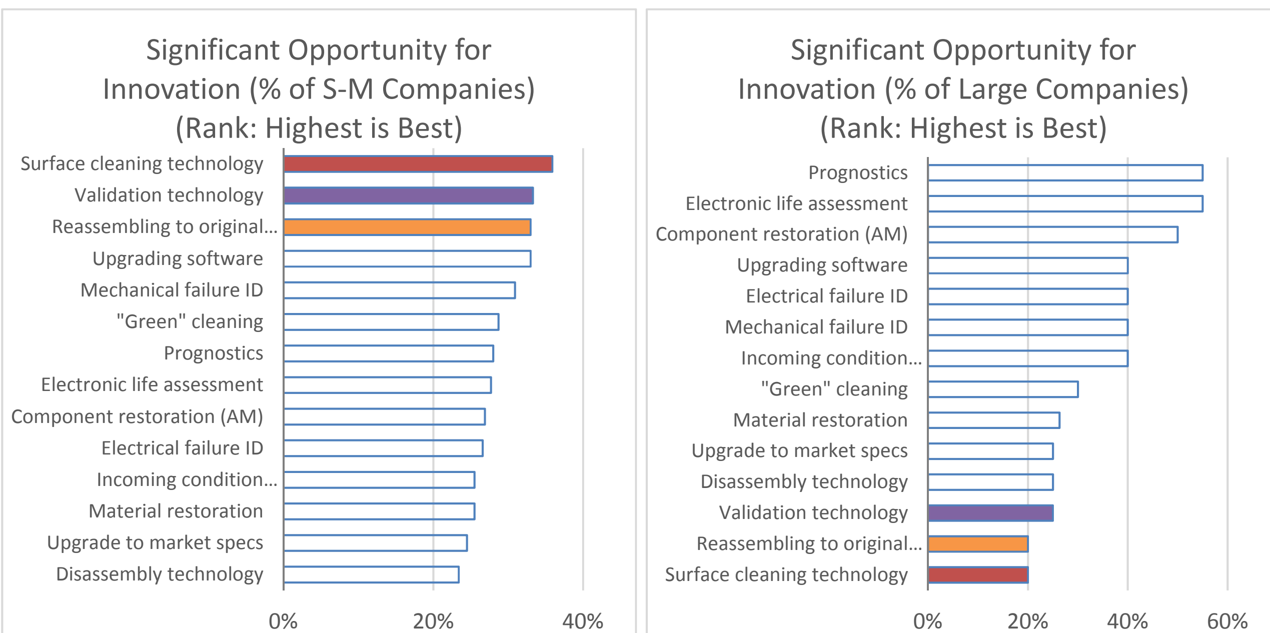

Figure 8: Priority differences

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Still, it is critical to acknowledge that there are some areas of agreement; small and large companies demonstrate considerable overlap in lower priority areas such as the development of technology in upgradability, disassembly technologies, and material restoration. See Figure 9.

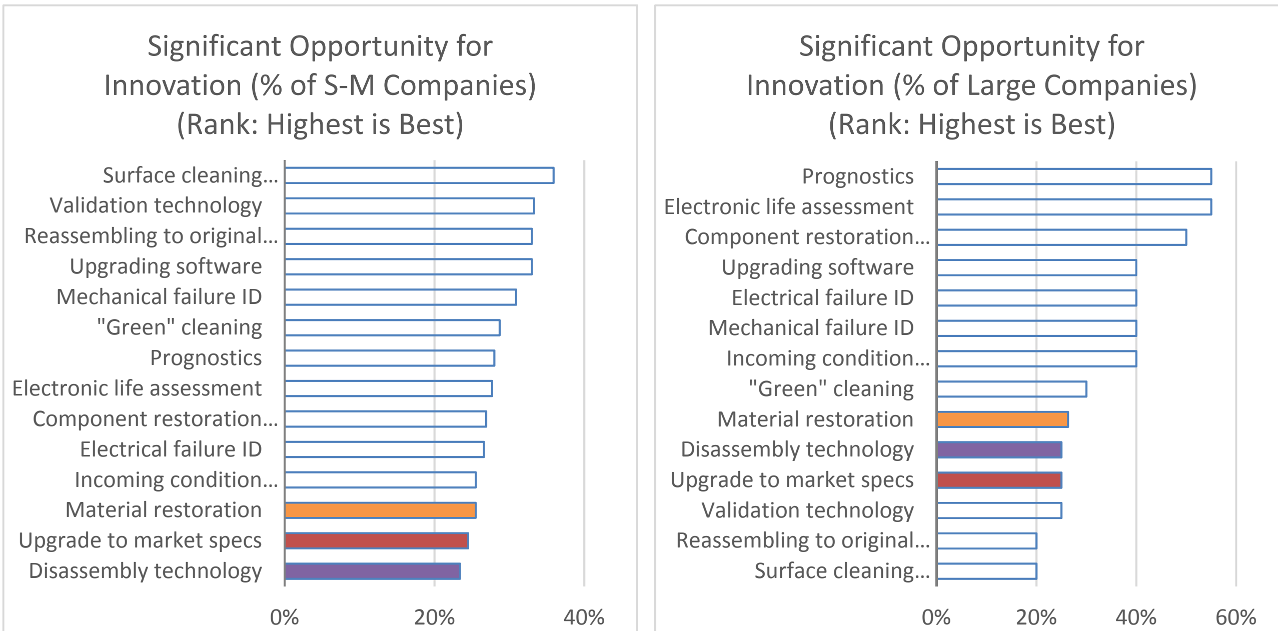

Figure 9: Low priority opportunities

Condition Assessment and Reliability Engineering

Condition assessment includes an analysis of the product function, wear, and potential damage in order to determine the estimated remaining life of the product. Condition assessment is a common practice in maintaining equipment to determine the appropriate time to make repairs or replace assets. However, remanufacturing is unique in that it uses the condition assessment data to determine whether the replaced asset can be restored back to a like-new condition or must be discarded. Technologies in this space therefore have a significant influence over material waste flows in the U.S. remanufacturing industry.

Real time condition assessment uses sensors to discern the condition of modules without requiring thorough disassemble and assess each component. This information can then be relayed to the user, offering insight into module condition that affect the overall system health and reuse potential. This data can also be used in predictive analytics, which can identify when systems are not working correctly or are about to break, enabling corrective measures to be performed prior to unplanned system failure.

Predictive sensors, data analysis, and software algorithms act as critical companion technologies to condition monitoring systems. In some sectors, for example, on-condition prognostics use design information to identify potential failures and comply with maintenance interval requirements. Effective remanufacturing thus requires access to and understanding of design and performance data to ensure not

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only that remanufactured parts meet performance requirements, but also that they function properly with monitoring and prognostic systems in subsequent life cycles.

The remanufacturing industry may also have requirements for condition assessment technologies that go beyond the current uses. While contemporary systems may attempt to predict complete failure, remanufacturers may wish to identify components for removal at defined service periods so components do not fail completely and are still able to be restored. This may require novel sensors and reliability models unique to the remanufacturing industry. According to the survey, 55% of large companies see a significant opportunity to develop advanced prognostics and predictive data analytics technologies. (Figure 10)

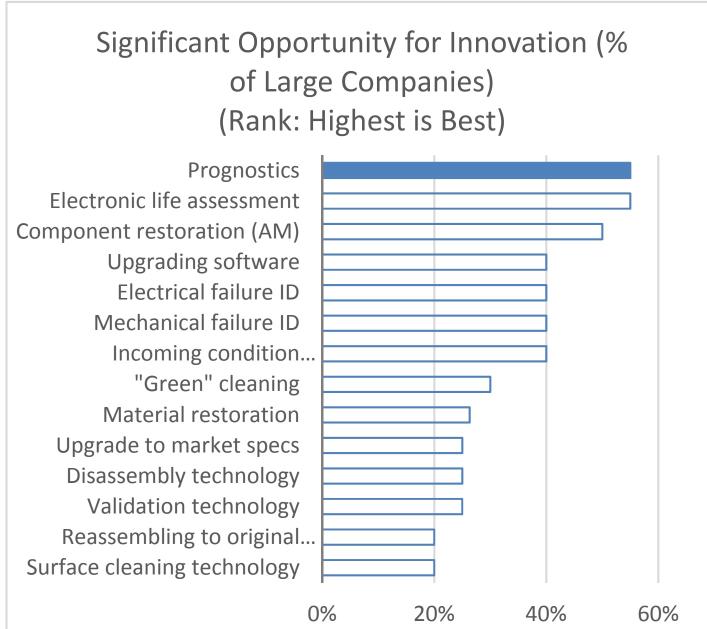

Figure 10: Opportunities for innovation: Prognostics

Condition assessment is especially challenging in electronics-rich systems. However, there has been limited success and there is, at this time, no roadmap for guiding R&D activities for advancing the quality and capabilities of prognostics and health management in electronics-rich systems. There is therefore significant opportunity for foundational research in this area.

This notion is supported by survey data, which suggests that 55% of large companies see a significant opportunity to develop technologies to assess the remaining life of electronic components. (Figure 11) Interestingly, however, nearly a third of SME respondents say this topic does not even apply to them.

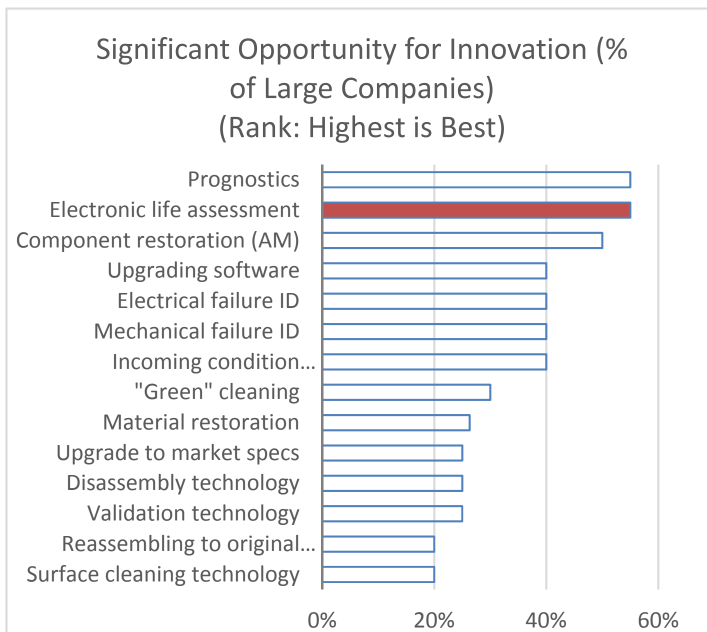

Figure 11: Opportunities for innovation: electronic life assessment

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Business and Market Issues

Remanufacturing faces a diversity of systemic market challenges that limit both the predictability and profitability of operation. One conclusion drawn from the survey responses was that efforts need to be made to improve the public awareness of both the sustainability and financial benefits of remanufactured products.

While remanufacturing is fundamentally different from recycling, it is oftentimes referred to as the 'ultimate form of recycling' because it is able to preserve not only material, but also the embodied energy used to make a product. This direct reuse of components mitigates depletion of global nonrenewable resources and reduces environmental impact of material entering the landfill.

Yet only 22% of respondents stated that the public is aware of the sustainability benefits of remanufacturing with this awareness helping their business. (Figure 12) Additionally, only about a third of respondents suggest that the public values remanufactured products enough to help their business. (Figure 13)

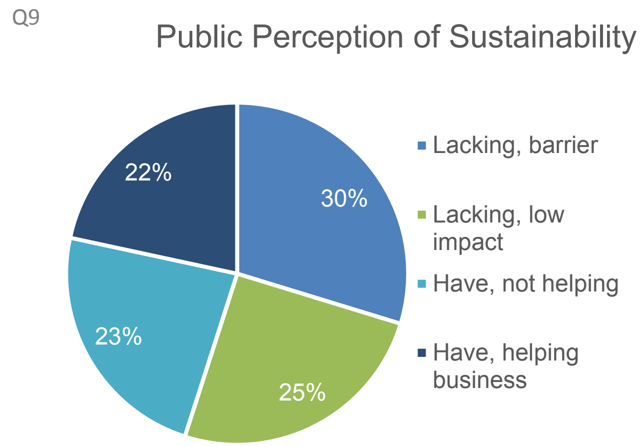

Figure 12: Public perception of sustainability

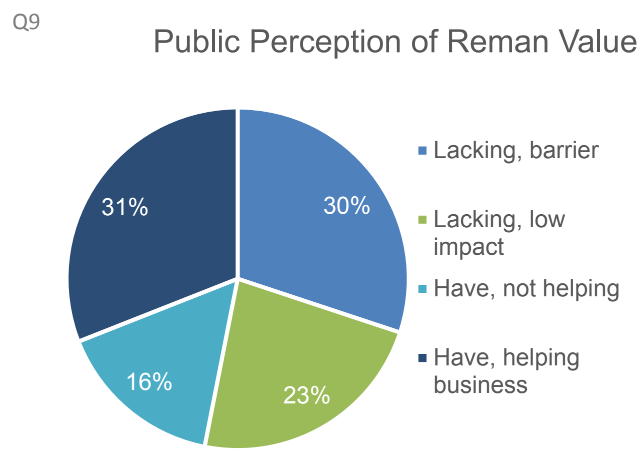

Figure 13: Public perception of the value of remanufactured products

This lack of public support for remanufacturing is surprising since 94% of respondents suggest that their remanufactured products will have the same life and performance as a new alternative. In addition, the environmental impacts avoided through remanufacturing present a benefit to the product that may appropriately considered value-added, and would thus be reasonably reflected in product pricing.

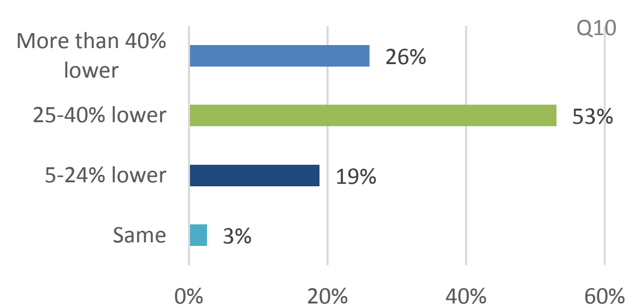

Figure 14: Sale price of reman vs new

However, mechanisms to increase the economic valuation of the environmental benefits of remanufacturing must be explored and subsequently reflected in product pricing. Over half of all respondents say that their remanufactured products are discounted 25-40% below the purchase price of comparable new products, and 26% of

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respondents discount their products for more than 40% below new (Figure 14). As a result, over 40% of respondents state that they do not currently meet target margins on remanufactured products.

The cause of this deficit is twofold. First, there is a lack of general consumer understanding that the performance of remanufactured products is equivalent to new. Second, even though the survey respondents have high confidence in their ability to remanufacture their products to the high quality standards of the original specifications, many of the comments provided by the same respondents suggest that much of the negative public perception of remanufactured product is due to other products on the market that call themselves remanufactured, but have not gone through the full rigor required to bring the product back to a like-new condition. This greenwashing done by inferior products presenting themselves as fully remanufactured is damaging the image of the entire industry. In this, the industry needs better control and standardization of what can be called a remanufactured product to improve both broad market acceptance of truly remanufactured products and enhance penetration into existing markets.

Legal Relations, Regulations, and Restrictions

According to nearly two-thirds of all survey respondents, government investment incentive policies restrict domestic business to some degree. Additionally, the industry is concerned over what it perceives as unfair foreign competition. For example, the terms of the Trans-Pacific Partnership create import restrictions on general used goods imposed by several foreign countries. While this is intended to mitigate the international flow of potentially harmful electronic waste, many countries inappropriately apply these policies to remanufactured goods, disproportionately restricting global market access for U.S. exporters.

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4. SITE VISITS

Introduction

In conjunction with the remanufacturing industry survey and extensive background research, the early stages of this roadmapping process included onsite visits with remanufacturers in each industry sector as a means of setting the context in which this roadmap would be developed. Through these site visits, RIT researchers were able to gain valuable insight into operational practices, remanufacturing culture, and technology challenges that cannot be effectively communicated through any other media than direct observation. In this, site visits proved indispensable to RIT in understanding deeply the perspectives of the industry stakeholders it endeavored to engage in the roadmapping process.

In all, personnel from RIT made visits to 20 remanufacturing companies to assess their technical needs firsthand and corroborate the findings of the *Remanufacturing Industry Survey*. These visits represented all industry sectors except for restaurant equipment, from which no remanufacturing companies actively sought to participate. The insights revealed from these sight visits are summarized in this Appendix.

Site Visit Overview

Prior to conducting the site visits, potential candidates were asked to complete a set of questions developed by RIT centered on core logistics, workforce, training, and the remanufacturing process. Site visits typically consisted of a short plant tour to observe the remanufacturing operations, followed by question-and-answer sessions with company management, and, when possible, interviews with remanufacturing floor personnel to gain base-level insights. Table 1 (right) outlines the companies with whom site interviews were conducted from each industry sector.

Industry Sector	Companies Visited	Location
Aerospace	Lufthansa Technik	Tulsa, OK
Locomotive	National Railway Equipment (NRE)	Mount Vernon, IL
	Alstom Transport	Mare Island, CA
Heavy Duty	Caterpillar	Peoria, IL
	Detroit Diesel	Detroit, MI
	CNH Industrial Remanufacturing	Springfield, MO
	OEM Remanufacturing	Edmonton, Canada
Machinery	Gleason	Rochester, NY
Medical Equipment	Phillips Medical Refurbished Systems	Cleveland, OH
	Ambassador Medical (GE Healthcare)	Indianapolis, IN
Electrical Apparatus	SRC Electrical	Springfield, MO
	Circuit Breaker Sales	Plainville, TX
IT- Consumables	Xerox	Rochester, NY
Auto Parts	LKQ Corporation	Springfield, MO
	Bendix	Huntington IN
	Jasper Engines and Transmissions	Jasper, IN
	Delphi	Detroit, MI
Consumer Products	CoreCentric	Carol Stream, IL
Office Furniture	Davies Office, Inc.	Albany, NY
Retread Tires	Goodyear Tire and Rubber Company	Akron, OH

Table 1: Site visit companies

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In general, there site visit observation revealed significant variation in the type and execution of remanufacturing processes across different industry sectors. In medical equipment remanufacturing, for example, the bill of materials (BOM) was retained after disassembly because if any component was changed or upgraded from the original BOM, the remanufactured product had to be recertified. This recertification step meant that final product testing was especially rigorous, and that adequate information flow was accordingly critical to proper remanufacturing regardless of circumstances. This was also observed in locomotive remanufacturing, where individual assemblies such as wheel trucks or components engine could be remanufactured *only* if they were guaranteed to be returned to the locomotive from whence they came.

Site visits also revealed that high-volume remanufacturing companies—such as those in automotive or heavy duty component remanufacturing—have automated a number of their remanufacturing processes, including both initial cleaning and final assembly. In contrast, lower-volume companies very little process automation, if any at all. In fact, every observation in the medical remanufacturing sector revealed the ubiquity of hand-cleaning processes for all components. However, lower-volume companies—because of the more relaxed turnaround constraints associated with lower throughput—were able to compensate for the higher proportion of manual cleaning processes by reducing the actual manual labor dedicated to cleaning through soaking parts for longer periods of time.

Key Site Visit Insights

From these site visits and subsequent analysis of their results, RIT personnel identified several technical challenges that seemed pervasive across multiple industry sectors. These key insights are outlined below:

Cleaning

Irrespective of the remanufacturing sector, cleaning was identified as a challenge. For the heavy-duty and automotive sectors, parts can be cleaned up to five times during a remanufacturing process, creating uncertainty about both value and efficiency. With the high chemical and disposal costs, this level of repetition can make cleaning an excessively expensive process. In general, remanufacturers perceive that the best way to reduce these costs is to reduce the number of cleaning steps used in the process.

As an example of one simple solution, many companies in the automotive and heavy-duty sectors use baking soda for cleaning components. While this solution works reasonably well for cleaning and is relatively benign in disposal, it is not a perfect process; baking soda can only be used one time, thus creating both a high volume of waste and significant recurring costs. Remanufacturing companies thus need alternative technologies that are cost-effective, environmentally-benign, *and* effective cleaners.

Prognostics

Remanufacturing companies in all sectors except for medical have apparently no sound method to determine in which life cycle stage a component might be. Components nearing the end of their lifecycle need to be replaced, while components at the beginning or middle can be reused, but the uncertainty of component stages makes optimizing material flow effectively impossible. Companies with extensive remanufacturing experience can use this knowledge to determine when to replace a component, but those without this experience are prone to both premature and delayed replacement decreasing efficiency dramatically. Prognostic methods for tracking components and their history must be developed to ensure that components are used for their entire lifetime and replaced at an optimal time to minimize both part damage and system disruption. Increasing component reuse rather than replacement will also reduce the costs of remanufacturing, but more advanced technologies are required to assess when this is appropriate.

Inspection

Most remanufacturers use manual or visual methods for inspection, whether for crack detection or dimensional verification. Companies relayed that they would like to reduce the amount of labor spent on these inspections by increasing automation. Many also suggested that there was need for improved inspection methods in order to subsequently improve the quality determination of an incoming core.

Additive Manufacturing

Most of the larger remanufacturing companies are using additive manufacturing technologies such as welding, laser cladding, and thermal spray. In addition, some of these remanufacturing companies are investigating cold spray and Laser Engineered Net Shape (LENS) remanufacturing processes. However, most of the medium- or smaller sized remanufacturing companies are not using additive manufacturing at all; they believe that these processes are not cost-effective due to the high initial capital costs and/or the amount of finishing (machining) required after additive manufacturing. Instead, they are either machining new components or machining surfaces off of old components, and subsequently using either oversized or undersized components during reassembly. Lower-cost AM processes must be a priority.

Electric / Electronic Component Remanufacturing

Remanufacturing of electrical components consists of cleaning internal boards and verifying proper functionality. If products function correctly, they simply are reused. Some companies will repair broken connectors within circuit boards and replace some failed components such as capacitors and resistors. Others will replace 100% of some components, such as relays and capacitors, regardless of their remaining functionality. This is reflective of the difficulty in assessing remaining life in electrical components, especially in instances where a previously all-mechanical product has been integrated with electromechanical components in newer generations.

A number of remanufacturing companies stated a need for better electrical test equipment to determine if a circuit board can be reused or to verify the efficacy of the remanufacturing process. The desired electrical test equipment should be able to simulate the actual electrical inputs and test the electrical output from each electrical input signal.

Another challenge expressed for electronics remanufacturing is removing the potting material without damaging the electronic component. Numerous methods have been developed over years of research, but all to date have been unsuccessful. Repotting the electronic component after repair is also a challenge.

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Training

Most remanufacturing companies find it difficult to hire qualified employees because much of the manufacturing workforce pool holds a negative opinion of the remanufacturing industry. In addition, training new employees is a challenge due to apparent skills gaps.

Conclusion

The insights revealed through these site visits provided valuable information to RIT researchers who then used these understandings to inform their approach to multi-sector collaborative roadmapping. Beyond this support, however, these site visits confirmed with firsthand empirical evidence the notion that the range of technological capability throughout the remanufacturing industry is highly stratified both within and between industry sectors. This variation—and the disequilibrium of industrial aptitude that results—is perhaps the most fundamental barrier to growth in the remanufacturing industry, and the obstacle this roadmapping process aims at its base to conquer.

These site visits thus proved invaluable in identifying the underlying outcome that the fruits of this roadmap seek to achieve—developing, creating, and deploying platform technologies that may become commonly and equally accessible across all sectors and specializations of remanufacturing industry players. It is only by advancing the fundamental toolset to manage the unique products, demands, and technologies of the 21st century that remanufacturing may transform its role within the industrial economy in pursuit of a more sustainable future.

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5. Background Research

To provide a baseline foundation from which to build the roadmap, RIT engaged in industry-wide investigations of both current and future technology needs. This section highlights some of the emerging technologies that have the potential to impact the remanufacturing industry. This includes technologies that are both available and in development, gathered from a substantial review of academic literature, industry publications, and current technology research trends. In addition, material flow analyses based on statistical data published by several U.S. federal agencies—including the Department of Energy (DOE), Department of Commerce (DOC), and Environmental Protection Agency (EPA)—provide insight into the current impacts of the U.S. remanufacturing sector in terms of market share, material use, energy consumption, waste, and trade. This research was used to frame the perspectives from which RIT would approach the roadmapping workshop activities, and ultimately provided the backbone of the roadmap itself.

Overview of Pre-Competitive Research

There are diverse technical roadblocks that currently inhibit the broader penetration of remanufacturing in individual industrial sectors. Rather than seek advancement in each of these individual sectors, however, many experts involved in policy, research, and industry alike recognize the need to identify opportunities for cross-cutting advancement that will benefit the remanufacturing industry more broadly. In order to identify the best of these opportunities, GIS grouped multiple industry sectors according to the commonalities in their products and the manufacturing and remanufacturing processes required to make and maintain them.

Technologies	Aerospace	Locomotives	HDOR	Machinery	Medical equip.	Electrical App.	Restaurant equip.	IT equipment	Automotive parts	Consumer prod.	Office Furniture	Retread Tires
Product Design and Information Flow												
1) Design for Remanufacturing					√	√	√	√		√	√	√
2) Electro-Mechanical Integration	√	√	√	√					√			
3) Information Flow	√	√	√	√								
4) Augmented Reality	√	√	√	√								
Condition Assessment and Reliability Engineering												
5) Prognostic & Health Management	√	√	√	√	√	√		√				
6) Electrical component condition assessment	√	√	√	√	√	√	√	√	√	√		
Remanufacturing Process Technology												
7) Additive Manufacturing	√	√	√	√					√			
8) Green Cleaning									√	√	√	
Business / Market Issues												
9) Life Cycle Assessment					√	√	√	√	√	√	√	√

Table 2: Areas of cross-cutting research

Background research on the products, processes, and technologies used in these groups then revealed a range of common obstacles preventing further growth and advancement. From these obstacles, RIT analysis distilled nine (9) areas of cross-cutting technology in which development and deployment in a pre-competitive environment would likely serve to defeat these obstacles by transforming the way industry is able to approach them. Table 2 summarizes the aggregation of research opportunities for each industry sector. Each area of cross-cutting technology research need is defined on the next page.

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Cross-Cutting Technology Needs

Product Design and Information Flow

1. **Design for Remanufacturing:** Develop purposeful remanufacturing design practices, standards, and skills that enable products to be cost effective and easier to remanufacture. This includes promoting the ability to upgrade to meet graduated energy standards, as well as hardware and software upgrades to ensure that remanufactured products can compete with contemporary market performance.

2. **Mechatronics Integration:** Many products are moving towards the marriage of mechanical and electronic systems. Remanufacturing processes that enable the integration of advanced electronic controls, electric generators, and energy storage systems with products that were traditionally mechanically based are required to extend the valuable life of durable products.

3. **Information Flow:** Develop data technologies that enable the tracking and assessment of critical components and remanufacturing characteristics. Examples in the aerospace sector show that technologies such as RFID have been successfully deployed in numerous applications, including pure logistics, stock management, configuration management, and maintenance operations. The potential for implementation and broad functionality is clear, presenting a significant opportunity to the remanufacturing industry.

4. **Augmented Reality:** Includes advancements in wearable technology and information access and display technologies that can automatically identify components, retrieve lifecycle information, and facilitate remanufacturing processes through visual aids.

Condition Assessment and Reliability Engineering

5. **Prognostic & Health Management (PHM):** Develop metrics, technology, standards, and processes to track condition in real-time and assure the proper operation of a remanufactured system. In addition, develop metrics, technology, and processes to quantify and document that remanufactured parts both perform and have the same life and wear characteristics as new products. This will lend market viability to remanufactured products and enable seamless adoption of remanufactured parts into systems that require predictive maintenance. This includes connectivity technologies that foster component-, product-, and system-level communication through the Internet of Things.

6. **Electrical / electronic component condition assessment:** Develop technologies that enable advanced condition assessment, failure analysis, and prognostics techniques for electronic components and products to reduce the rate of no-fault-found failures.

Remanufacturing Process Technology

7. **Additive manufacturing:** Develop technologies to test and restore materials that have been degraded through wear or environmental conditions to original dimensions and physical

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properties. Needs in this area include cost-effective solutions in spray welding, laser cladding, and 3D printing with reduction in work-envelope constraints to enable greater adaptability.

8. **Green cleaning:** Develop environmentally-friendly cleaning chemistries and processes that reduce costs and the number of processing steps, enable the use of non-hazardous materials, reduce overall energy-intensity and solution volumes, and produce less user-exposure, while assuring that the cleaning systems meets required standards.

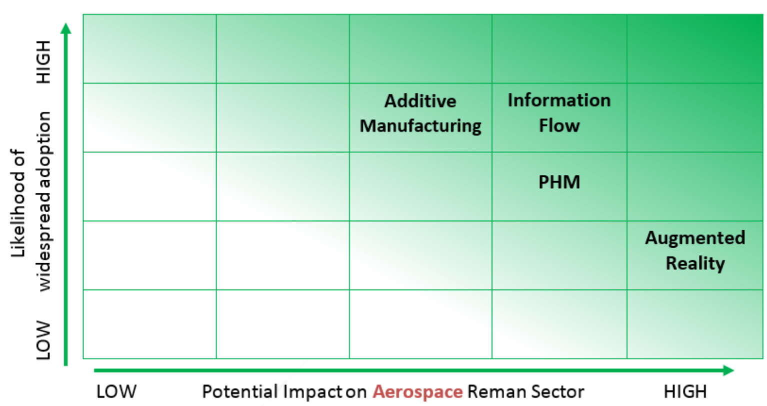
Business and Market Issues

9. **Life Cycle Assessment:** Develop accurate and consistent modeling techniques to identify environmental hot spots and enable process improvements, as well as to demonstrate environmental benefits of remanufactured products to enhance market appeal. Includes the development of meaningful lifecycle data systems.

Summary of Key Technologies by Industry Sector

Beyond the cross-cutting technologies identified above, extensive background research and analysis conducted by GIS highlighted key technologies in each industry sector that are worth exploring further within the context of the broader challenges facing the remanufacturing industry. As a summary, GIS developed a matrix for each sector in which the potential impact of a given technology on industry advancement is compared with the likelihood that the technology will be thoroughly adopted. All of these technologies already exist; therefore the likelihood of adoption assesses cost, benefit, regulation, and industry willingness to change. The research need in each industry sector is summarized below.

Aerospace



Remanufacturing is highly prevalent in the aerospace industry sector as *maintenance, repair, and overhaul* (MRO), but several barriers are preventing growth in a sector where the potential impact of remanufacturing is immense. Particularly, because aerospace products are highly regulated through the Federal Aviation Administration (FAA), remanufacturers must be able to ensure parts meet specific performance requirements and are able to continue meeting them for the duration of a specified time-to-replacement. Currently, remanufacturers in this space are challenged by a lack of specific core design and performance parameters that inhibits their ability to make absolutely sure remanufactured parts are able to perform as required. In this, new policies and technologies supporting the cross-cutting technical areas of ***information flow*** and ***prognostics & health management*** are required to not only enable remanufacturers to bring parts into alignment with specifications, but also to ensure that their life cycle

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performance is likewise on par with virgin components. In a similar vein, because the end products in this sector—aircraft—are immensely complex, and each component system is regulated within a unique threshold for performance, remanufacturers would likely benefit greatly from advanced logistics management, and process optimization strategies enabled through ***augmented reality*** technologies. The following are further highlights of research in this sector.

- **Information Flow:** RFID and other forms of individual part tracking offer excellent opportunity to facilitate expedited, economic, and energy efficient regulatory compliance MRO activities. While traditional part tracking systems rely on general part numbers and extensive manual documentation, RFID will allow the aerospace industry to define key minimum part data requirements in effort to streamline and fortify monitoring, inspection, remanufacturing, and replacement techniques. RFID also allows for data uniformity that functions well in the standardized and regulated market environment of aerospace MRO.

  Aerospace RFID leader MAINtag has delivered over 1 million flyable RFID tags to more than 60 tier-one suppliers in the aerospace industry to date. Its new FLYtag® skin hybrid technology uses a high-memory silicon chip designed to perform on curved flyable metal and non-metal surfaces in both cabin and non-pressurized areas. It can be used in numerous applications, including pure logistics, stock management, configuration management and maintenance operations.

  Airbus has also been using RFID for over a decade in a number of areas, including tracking parts and assemblies from incoming logistics through to final assembly, and has experienced clearly positive returns on its investment. Airbus introduced the A350XWB in 2013 with approximately 2,000 parts tagged with RFID. The International Air Transport Association released its *Guide on Introducing Radio Frequency Identification into Airline Maintenance Operations* in 2013, citing immense industry-wide cost and efficiency benefits. From this, a number of manufacturers have begun integrating RFID into operations in both flyable and non-flyable parts, including common rotables and life-limited components and chemicals, down to life vests and seat covers.[8] The proliferation of RFID throughout the aerospace remanufacturing sector exhibits great promise to lean out and optimize MRO activities. This will allow providers to know exactly what parts are on what planes, how long they have been there, how much life they have left, and what their condition will be when they come back.

- **Prognostic and Health Management:** Equipment will continue to become smarter and more self-aware, moving maintenance to be more on-condition and predictive. Predictive maintenance enabled by sensors and telematics will initially drive the user to purchase new OEM replacement parts to assure that the predictive system performs as designed. The remanufacturing industry will be burdened to demonstrate that the remanufactured parts perform the same functionally, but

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[8] IATA (2013). *Guidance on Introducing Radio Frequency Identification into Airline Maintenance Operations*. IATA Safety, Operations, and Infrastructure. Web.

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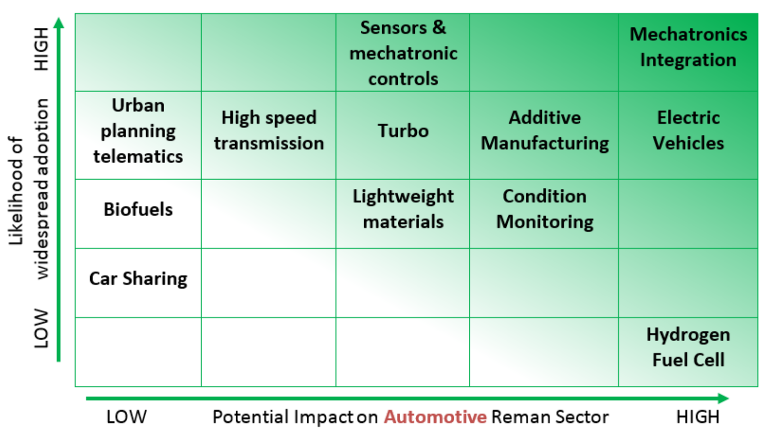
also have the same life and wear-out characteristics as new, and can fit seamlessly into cutting-edge predictive systems.

- **Augmented Reality:** Although aircraft are not, by definition, stationary or permanent equipment fixtures, their size, complexity, and geographically transient nature render them relatively difficult and costly to take offline or transport for remanufacturing purposes. These system properties therefore necessitate field service, creating a unique set of costs and challenges. An emerging technology well-positioned to have a huge impact on field maintenance and the aviation MRO (maintenance, repair and operations) is augmented reality and wearable assessment equipment. Maintenance "at-the-asset" is expected to be the norm and augmented reality technologies connect operators, engineers, and technicians to vital information quickly and easily. Thus, there is significant potential for wearables to function as a disruptive technology that changes the way the MRO services are performed and delivered.

- **Additive Manufacturing:** The aerospace industry is one of the leading manufacturing sectors that is actively developing additive manufacturing, which is referred to by GE Aviation as "the next industrial revolution". Nearly all major aerospace and defense companies have major additive manufacturing programs, including: Boeing, BAE Systems, Lockheed Martin, Northrop Grumman and Honeywell.[9] The last decade has seen significant advances in additive manufacturing (AM) technologies which have led to exciting new remanufacturing applications. For example, many new technologies have been developed that add materials to existing parts enabling the restoration of many previously unrestorable parts.

Automotive



With the continuous rise of hybrid and electric drive systems, drive-by-wire technologies, and digital control platforms, the prevalence of electronic systems in the automotive sector will necessitate a great migration in the automotive sector's remanufacturing approach. As technologies in this space continue to advance at an unprecedented rate, remanufacturers are in great need of ***electromechanical integration*** strategies that allow them to assess, process, diagnose, disassemble, and repair automotive systems in which electronic and mechanical systems are linked. Further, as this trend of automotive electrification

[9] https://serviceinindustry.com/2015/03/03/3d-printing-will-disrupt-the-spare-parts-markets/

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continues, remanufacturers require new technologies that enable them to bring older, more strictly mechanical systems up to speed with newer technologies, regulations, and performance requirements.

In terms of specific process technology, ***additive manufacturing*** holds great potential to transform the automotive remanufacturing sector. Advancement in AM technologies for surface restoration will allow remanufacturers to address surface wear (one of the most common failure modes of automotive products) rather than resort to replacement. In addition, 3D printing technologies can enable remanufacturers to quickly and cost-effectively create specific parts for which replacements may no longer be in production, not cost-effective to stock, or exceedingly difficult to acquire—ultimately broadening the approachable market for automotive remanufacturing.

- **Mechatronics Integration:** New national and global environmental regulations are dramatically changing the future of the auto industry. The U.S. has developed a national program for greenhouse gas emissions and fuel economy standards through joint collaboration of the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA). The final standards are projected to result in an average fleetwide level of 163 grams/mile of carbon dioxide (CO2) in model year 2025, which is equivalent to 54.5 miles per gallon (mpg) if achieved exclusively through fuel economy improvements. Significant changes to the automobile design are required to meet these new standards. Our analysis shows that currently, only electrified vehicles meet the 2025 EPA emissions requirements meaning that there will be a significant shift to hybrid and electric drivetrains. This is also recognized by the European auto industry and CLEPA expects that by 2025, around 50% of new vehicles sold in Europe will by hybrid or electric.

- **Sensors & Mechatronic Controls:** By 2020, over 22 billion sensors will be used in the automotive industry per year. With Advanced Driver Assistance Systems, vehicle electrification, traffic control and communication systems, vehicles are becoming a blend of electronic sensors and electro-mechanical controls, sophisticated software, and mechanical systems.

- **Lightweight Materials:** Vehicle weight reduction activities being implemented for conventional fuel vehicles should also apply to electric and hybrid vehicles. Weight reduction is being achieved through the use of stronger, lighter materials, such as: plastics, carbon fiber-reinforced polymers, and lighter metals such as aluminum or magnesium. Without advances in design practices to enable part removal, new material restoration practices, or new recycling technology, much of this new lightweight non-metal material will end up as automotive shredder residue.

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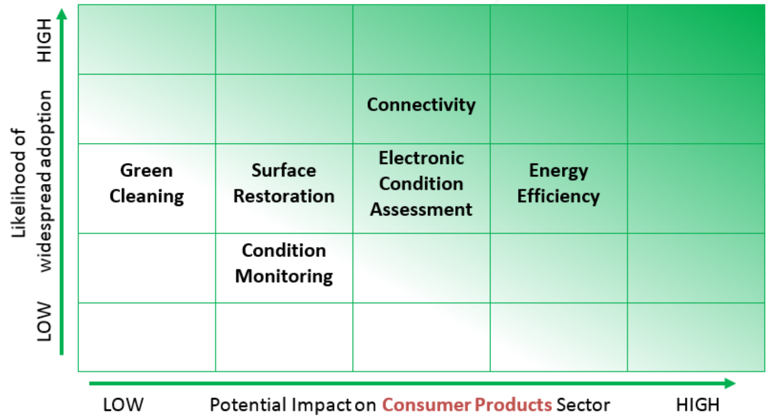
Consumer Products



Perhaps the greatest barrier to remanufacturing in the consumer product sector is the supply stream. Because products in this sector are rapidly advancing in technology and of relatively lower individual value, they are often disposed and replaced at the end of life. To address this, significant advancements in the supply chain of consumer products are necessary. Key to this are technologies in ***connectivity*** and ***condition monitoring***, so remanufacturers may better understand and manage both where products are in the supply chain and what kind of remanufacturing processes they might require. In addition, the technical ability to integrate connectivity technologies into past-generation remanufactured products will be central to both making them competitive in a market where Internet of Things (IoT) capability is increasingly prevalent, and facilitating future remanufacturing through improved information flow.

- **Sustainable Design:** The bulk of the life cycle environmental impact of consumer products occurs during the use phase of the product due to high operating energy use. Technological advances in energy-efficiency in equipment improve performance at such a rate that equipment replaced after years of operation will have a short payback period due to energy savings alone. Opportunity thus exists to extract more value from these products by enabling upgradability through remanufacturing. This opportunity may be best enabled when the equipment is designed to be upgraded from the outset.

- **Connectivity and Condition Monitoring:** Consumer products currently and are increasingly using technologies to create an "internet of things" (IoT) wherein products relay use and performance data to each other and, ultimately, through a central interface or Smart Grid. These systems may benefit from expanded connectivity technologies that enable the transfer selected asset health information to remanufacturers.

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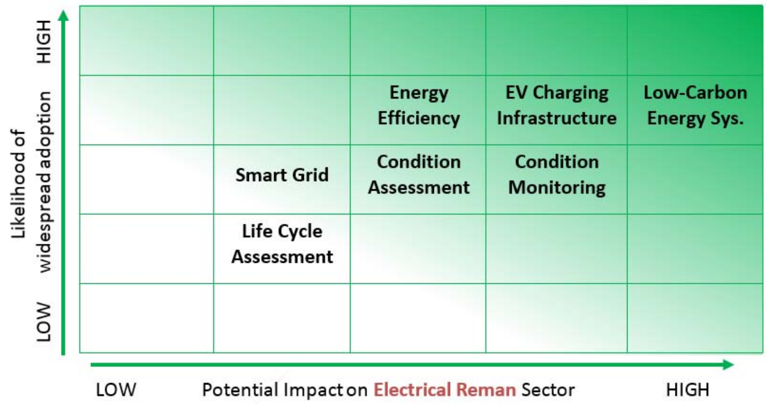
Electrical Apparatus



Renewable energy technologies are some of the fastest growing technology sectors in today's economy. As a global transition to ***low-carbon energy systems*** gradually takes hold, remanufacturers in the electrical apparatus sector require technologies that enable them to upgrade existing systems to perform optimally in dynamic and transformative energy environments. Parallel to this is the emerging concept of ***smart grids***. Apparatus remanufacturers thus also have a need to ensure that remanufactured systems are able to perform advanced functions in energy management and distribution—from recognizing the most beneficial parameters for generation to optimizing distribution based on complex tradeoffs in cost, carbon, and supply uncertainty. Compounding these challenges is a rapidly growing ***electric vehicle (EV) charging infrastructure*** that will create new complexities in grid management and a need to remanufacture existing infrastructures for compatibility with EV systems.

- **Energy Efficiency:** The IEA World Energy Outlook suggests that between 40-50% of the desired global emissions reductions over the next 20 years will come from increased energy efficiency, forcing equipment manufacturers to develop energy-efficient and high-performance products. The remanufacturing industry will therefore be challenged to not only bring the old equipment back to a "like new" condition, to upgrade equipment to meet the new efficiency requirements. Movement toward renewable energy systems will require remanufacturers to develop technologies by which to adapt incumbent energy infrastructure for compatibility.

- **EV Charging Infrastructure:** The electrification of the U.S. automobile sector has simultaneously driven an explosion on charging infrastructure across the nation. Despite increases in charging stations by an order of magnitude, significant gaps remain in some parts of the country. Remanufacturers may be challenged to adaptively remanufacture existing apparatus for compatibility with EV infrastructure, and must develop a working knowledge of products in this space to ensure viable business models when these systems reach EOL in the future.

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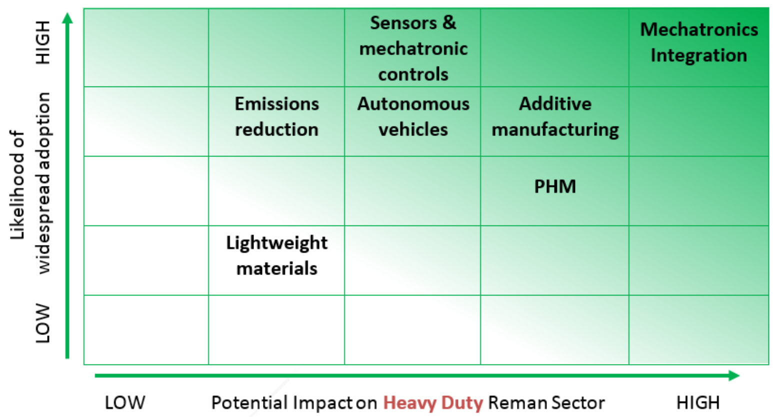
Heavy-Duty Equipment



Similarly to the automotive sector, the heavy-duty equipment sector is increasingly relying on technologies in which mechanical systems are deeply integrated with electrical control. Remanufacturers' ability to both assess, process, and repair modern systems *and* enable ***electromechanical integration*** of new technologies for existing past-generation platforms has the potential to increase the growth of remanufacturing in this industry sector. Parallel to this electrification is the rise of ***autonomous vehicle systems***, the use of which has already taken hold in the industries that depend on heavy-duty equipment, such as mining and agriculture. Ensuring that remanufacturers know how to handle these technologies and develop strategies to integrate autonomous technologies into existing products is thus a priority.

- **Emissions Reduction:** New global HD off-road emissions requirements phased-in by 2015 are driving the development of new technologies such as exhaust gas recirculation (EGR), selective catalytic reduction (SCR), and diesel particulate filters (DPF).

- **Mechatronics Integration:** The world has committed to reduce greenhouse gas emissions and future emissions targets are below what can be achieved with traditional power generated by fossil fuels. To save fuel and address future carbon emission standards, the industry is moving towards hybridization. This will move the remanufacturing industry toward more electronic controls, electric generators, electrical storage devices, and smaller engines than traditionally serviced by this industry.

- **Autonomous Vehicles:** Autonomous vehicles are currently in use in this sector and their market share will likely continue grow as they show improved productivity and safety, and as a tool to address current labor shortages in the construction, mining, and agriculture sectors. Similar to hybrid systems, autonomous vehicles have more electronic control components and systems to enable remote control.

- **Sensors & Mechatronic Controls:** Driven by vehicle hybridization and autonomous control, vehicles are becoming a blend of electronic sensors and electro-mechanical controls, sophisticated software, and mechanical systems.

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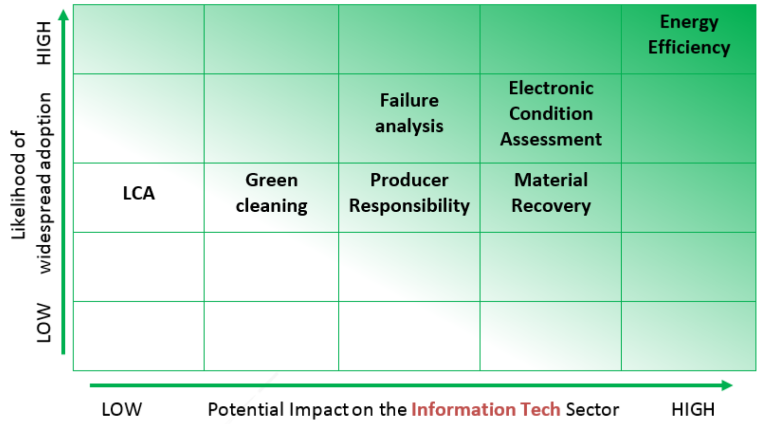
Information Technology



Large-scale server systems are some of the largest consumers of energy in the United States. Even at smaller scales, the embodied energy of personal IT products is one of the most significant sinks around the world. As awareness of these impacts grows, the criticality of ***energy efficiency*** in IT products will continue to increase. Remanufacturers must thus be equipped to upgrade existing products to be more energy efficient so they may compete with the rapidly advancing technologies in new product markets.

Beyond energy efficiency, remanufacturers also require new technologies and methodologies for assessing IT products at the end of their lives. Due to their highly-electrical and minimally-mechanical nature, it is notoriously difficult to perform ***failure analysis and condition assessments*** on electronics and IT products in a cost- or time-effective manner. New strategies to understand how and why these products fail will improve the business case for remanufacturing in this sector.

In a similar vein, new paradigms of ***producer responsibility*** for IT and electronics products are emerging as consumer consciousness regarding the impacts of new product manufacturing, and particularly end-of-life management, continues to increase. Understanding where remanufacturers might fit into these paradigms from a policy, business, and environmental perspective requires significant research.

- **Energy Efficiency and Emissions Reduction:** EPA estimates suggest that recycling one million laptops may save the amount of energy equivalent to the total annual consumption of 3,500 U.S. homes. Advanced technologies in low-impact IT product manufacturing, as well as use-phase energy efficiency upgrading methodologies, are a priority. These advancements may achieve up to 50% of necessary emissions reductions.

- **Electronic Prognostics and Failure Analysis:** Current technologies rely predominantly on mathematical models and performance predictions, but often product returns fail without advanced indication or fault identification. Barriers to onboard prognostic and analysis equipment created by critical failures increases the requirement for manual inspection and testing, which reduces the cost-effectiveness of remanufacturing. Continuous, real-time, and automated technologies are needed.

- **Material Recovery:** Significant potential to recover valuable precious metals from current and future waste streams is currently underrealized. Advanced collection, sorting, isolation, and purification technologies are required in order to realize thousands of tons and millions of dollars in viable material. These materials may be used in subsequent manufacturing and remanufacturing processes to offset the costs and impacts of primary material production.

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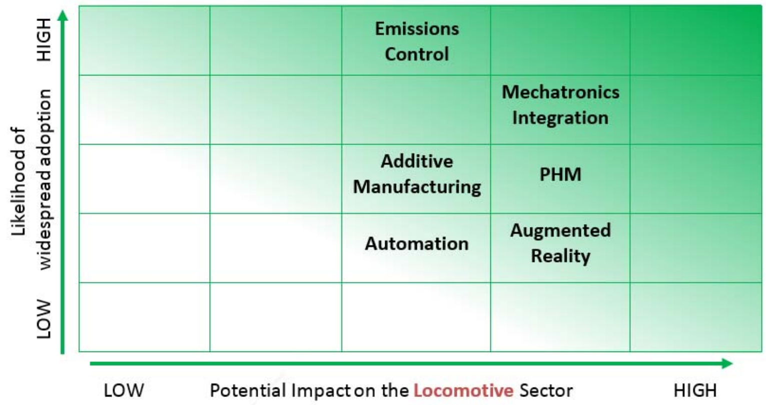
Locomotive



Similar to both the automotive and heavy-duty sectors, the locomotive sector is also increasingly relying on both electromechanical systems and ***autonomous operation & control***. Remanufacturers' in this space thus also require strategies for ***electromechanical integration*** of new technologies into existing past-generation platforms. In addition, both the size and complexity of locomotive systems create challenges for remanufacturers in the current industrial climate. In this sense, ***augmented reality*** technologies for advanced information flow, logistics management, and process optimization create significant potential to positively impact the quality and efficiency of locomotive remanufacturing.

- **Emissions Control:** The U.S. EPA tightened existing emissions standards for diesel locomotives in 2008 in support of the agency's National Clean Diesel Campaign (NCDC). New emissions regulations—Tiers 3 and 4—under the Code of Federal Regulations (CFR) Title 40, Part 92 aim for reductions of 90 percent in particulate matter (PM) and 80 percent in NOx emissions by 2030.

- **Mechatronics Integration:** To save fuel and address future carbon emission standards, the industry is moving towards hybridization. In addition, regenerative braking is employed to a limited extent, providing notable savings in both energy/fuel consumption and resultant GHG emissions. This will move the remanufacturing industry toward more electronic controls, electric generators, electrical storage devices, and smaller engines than traditionally serviced by this industry.

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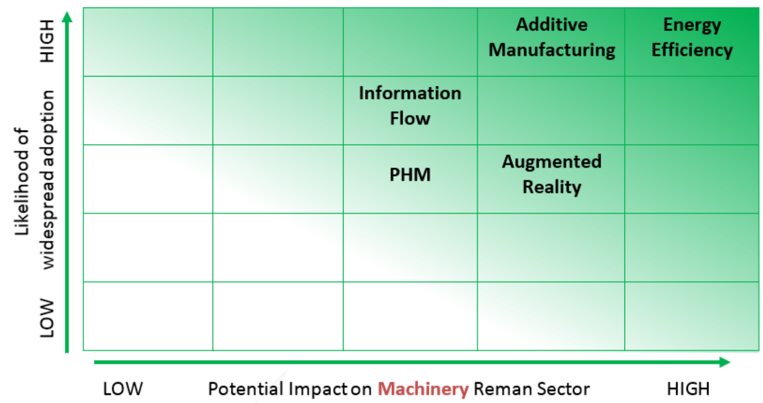
Machinery



Like IT products, machinery is a significant user of energy, and savings from energy efficiency are perhaps the greatest driver of technological advancement in this sector. Remanufacturers in this space must therefore develop new strategies and technologies to improve ***energy efficiency*** in legacy products if remanufacturing is to remain competitive with new production. Directly related to energy efficiency is the concept of system optimization, in which the operation of entire networks of machinery can be collectively optimized to minimize energy consumption and waste. In addition, like many other heavy-industry type products, surface wear is a common failure mode for products in this sector that may be well addressed through advancements in ***additive manufacturing.***

- **Augmented Reality:** Equipment in the machinery sector can have semi-permanent installation and be immobile and costly to remove from the site. Additionally, installations can be remote or difficult to access. This combination makes field service necessary, but challenging and expensive. One technology positioned to improve field maintenance is wearable technology. Wearable technologies connect people to vital information quickly and easily. Industrial wearable glasses allow for unprecedented access to data with nearly hands-free operation. With wearables, field technicians can use supportive functionality such as step by step instructions, interactive checklists, inventory management, or augmented reality such as overlaying schematics onto the machine while they are servicing it. Additionally, cameras can immediately identify the parts and devices at which the technician is looking, and read serial numbers and bar codes or access RFID functionality. Other features can allow the technician to stream video back to a remote subject matter expert for real-time troubleshooting. Ultimately, wearable technology and augmented reality enable field technicians to solve problems faster.

- **Additive Manufacturing and Material Restoration:** The last decade has seen significant advances in additive manufacturing (AM) technologies which have led to exciting new remanufacturing applications. For example, many new technologies have been developed that add materials to existing parts enabling the restoration of many previously non-restorable parts.

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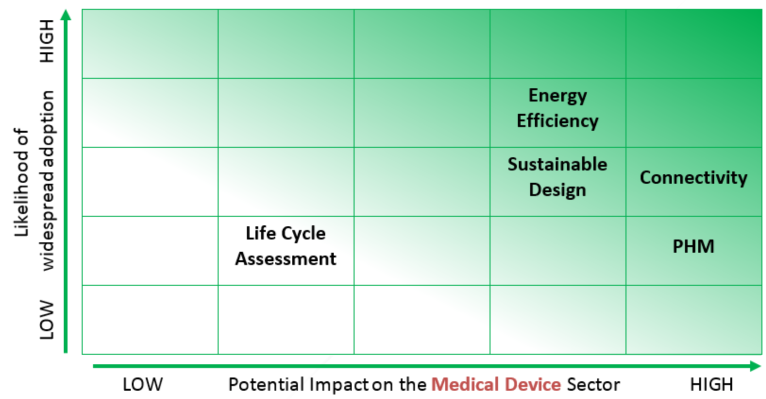
Medical Equipment

Because downtime due to product failure can be both costly to users and create significant impacts on human health, the potential for ***prognostics & health management*** to stimulate significant savings is immense. Remanufacturers have a unique opportunity to be the leaders in this space, as most installed durable medical equipment in the United States is approaching legacy status but is rarely replaced with new systems due to capital cost.



- **Energy Efficiency:** The need for energy efficiency is not lost on the medical equipment industry as estimates suggest that U.S. healthcare facilities spend more than $8 billion per year on energy alone. The remanufacturing industry will therefore be challenged to not only bring the old equipment back to a "like new" condition, but will need to upgrade the equipment to meet the current energy efficiency requirements.

- **Prognostics and Health Monitoring:** Medical equipment is increasingly using technologies to tap into the "internet of things" (IoT) wherein products relay use and performance data to each other and, ultimately, through a central interface. These systems may benefit from expanded connectivity technologies that enable the transfer selected asset health information to remanufacturers.

- **Life Cycle Assessment:** LCA is used to identify lifecycle "hotspots" of energy use, material waste, or resource inefficiency, allowing stakeholders to make decisions that can dramatically reduce environmental impact and LCA results are used to help support marketing claims.

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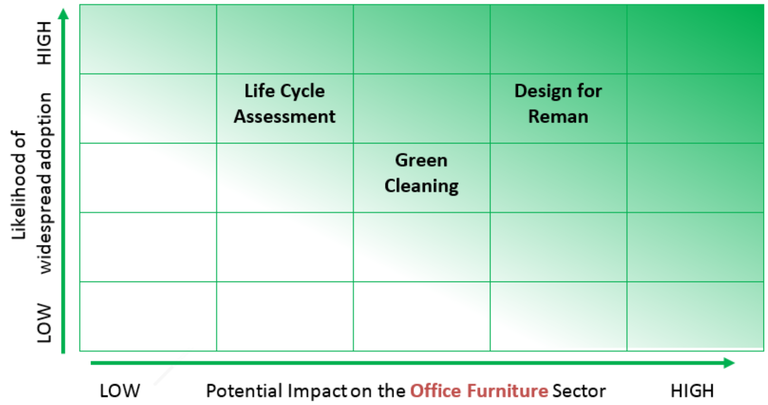
Office Furniture



Office furniture products are unique in that the technologies facilitating their use rarely, if ever, change or evolve. As static and passive systems, their most significant complexities—and thus, economic and environmental impacts—come from their materials, construction, and end-of-life-management. Despite these impacts, products in this sector are immensely durable, even through multiple remanufacturing cycles; in this sense, the potential for growth of remanufacturing in this sector is great, but must be supported through improvements in ***Design for Remanufacturing*** (DfR). New technologies that support innovative DfR strategies at both OEM and remanufacturer stages are critical to enabling this growth.

In addition, environmental benefits are often a key characteristic used to market remanufactured office furnitute products. There is thus significant potential for environmentally-benign process technologies—such as ***green cleaning***—to increase the environmental benefits of remanufacturing and thereby improve the competitive advantage of remanufactured products over new markets. Identifying other opportunities for improvement in remanufacturing process technology may also be accomplished with more widespread adaptation of ***Life Cycle Assessment*** (LCA) strategies throughout this sector.

- **Green Cleaning:** Cleaning activities focus predominantly on light surface cleaning, as the majority of physical contamination in office furniture results from surface contact with human skin oils as well as the penetration of dirt and dust into small areas. Chemistries and physical processes are thus not required to overcome significant resistance, and are therefore sound candidates for biodegradable, low-waste, low-VOC, or VOC-free cleaning technologies.

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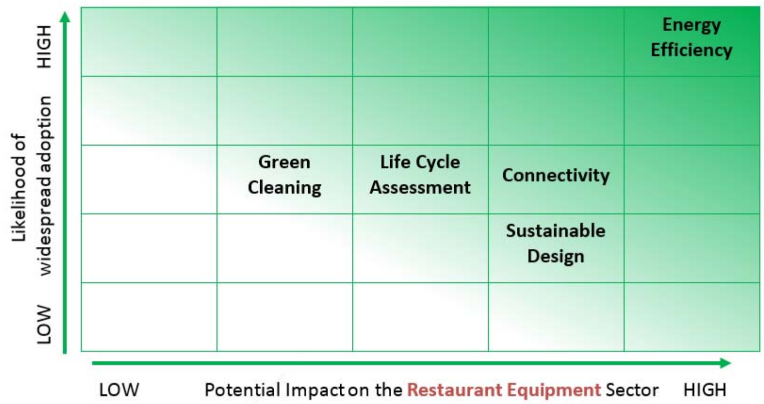
Restaurant Equipment



Similar to the broader machinery sector, restaurant equipment products are significant users of energy. As some targeted global greenhouse gas emissions reductions will come from improved energy efficiency in everyday products both small and large, it is inevitable that products in this sector will continue to be designed and redesigned for increased energy efficiency. Remanufacturers in this space must—like those in others—develop strategies to incorporate ***energy efficiency*** technologies into the existing product infrastructure through remanufacturing. Part of this will likely include advanced ***connectivity*** technologies that enable system optimization.

Another, somewhat unique, opportunity in this sector is ***green cleaning***. As restaurant equipment that is directed for remanufacturing inherently serves a life of food preparation and/or management, the need for thorough cleaning is both obvious and relatively specialized with respect to industrial products in other sectors. Meeting cleaning requirements while still creating remanufactured products that are safe for subsequent food preparation and management is critical to maintaining and advancing competitiveness in this sector, making green cleaning an important technology need.

- **Energy Efficiency:** Restaurant equipment energy efficiency is increasingly regulated by the ENERGY STAR program. The remanufacturing industry will therefore be challenged to not only bring old equipment back to a "like new" condition, but also to upgrade equipment to meet the new efficiency requirements.

- **Connectivity and Condition Monitoring:** Restaurant equipment is increasingly being connected through energy management systems as an "internet of things" (IoT). These systems may benefit from expanded connectivity technologies that enable the transfer selected asset health information to remanufacturers.

- **Green Cleaning:** In the restaurant sector, cleaning may include degreasing, or removing burnt on carbon, as well as conforming to sanitation requirements. Chemistries and physical processes are thus required to overcome significant removal resistance; however, these aggressive cleaning processes can have a significant impact on the environment.

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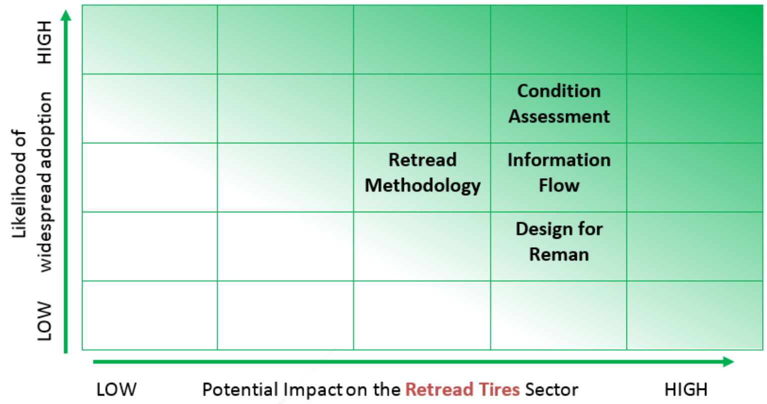
Retread Tires



The tire remanufacturing sector may benefit especially from integration of advanced part marking and tracking technologies that enable improved ***information flow***. Some tire OEMs currently use RFID to assist in the identification of tires that may be subject to safety recalls. However, advancements in this technology and the mechanisms of its integration may enable remanufacturers to quickly and easily understand the use context and failure modes of products, subsequently making it easier to identify the appropriate remanufacturing technologies. In a similar vein, there is also significant opportunity to make ***remanufacturing technologies*** themselves—which have remained essentially the same for decades—more effective, more efficient, and less costly. Such improvements will ultimately advance the competitive advantage of retreaded tires against new product markets.

There is also opportunity to make remanufacturing in this sector more cost effective by more accurately and more easily tracking product health and performance during the use phase. By developing condition assessment as well as prognostics & health management technologies specifically for tire products, remanufacturers may benefit from increased knowledge about and improved quality of the incoming core stream, making retreading a simpler, lower-waste, and more cost-effective process.

Conclusion

Ultimately, while the exact benefits of different technology development needs are in many cases context- and application-specific, it is clear that at a broader-level, establishing a common platform of capability in these areas will be beneficial to the remanufacturing industry as a whole. In order to ensure equitable benefit, however, such cross-cutting technology development requires the cooperation of diverse stakeholders in a pre-competitive environment. While the unique arrangements of that environment may be best determined through other academic-industry-government partnerships, the fundamental concepts revealed through this background research provided a powerful lens through which to view the subsequent roadmapping processes, and have thus contributed meaningfully to the underlying objective of this endeavor.

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6. WORKSHOP OVERVIEW

With the support of the previously discussed research efforts, GIS then sought to bring together remanufacturing leaders from across the industry sectors in an open forum to understand how these technologies and perspectives could be applied in the real-world. GIS conducted a workshop, facilitated by Energetics Incorporated to assist in the planning and execution of a 2-day, in-depth concluding workshop held in Troy, Michigan on September 29–30, 2016. The workshop brought together a select and diverse group of subject-matter experts and industry representatives (see Appendix A for participants) to hone in on cross-cutting challenges, identify and reach consensus around the remanufacturing industry advanced technology objectives, and set research priorities. The workshop process steps are illustrated in the figure below. See Appendix B for workshop process details.

Figure 15: Workshop process flow

Participants first determined the specific characteristics of a desired future that could be achieved near and long-term. First, they were asked to consider the current state and then specify what that desired future would look like, i.e., the specific changes that will have been achieved. In doing so, the participants developed a definition of success and identified potential indicators for tracking progress. After generating a list of characteristics, participants grouped the individual ideas into categories. Grouping the ideas helped the participants to identify the major changes or avenues of change that need to occur to achieve the desired future state.

After establishing the desired future state, participants identified the key technical challenges, barriers, or problems inhibiting meaningful progress toward the desired future state. Participants were encouraged to focus on defining the problem rather than specifying a solution. In addition, participants considered the nature of the challenge, e.g., whether it is a gap, limitation, or problem and whether it is a technical, operational, process, or knowledge-related issue. The participants also scrutinized the impact, i.e., how the challenge specifically hinders or prevents the industry from achieving the desired future state. These considerations helped participants identify the most pressing challenges and uncover synergies, which were then used to group the challenges into meaningful and distinct areas of opportunity and need within each topic area.

Participants then shifted from defining problems to specifying pathways toward a solution. Participants identified and prioritized research projects that address the challenges identified in the previous session. For each project idea, participants were asked to specify the activities involved and the type of research

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to be conducted and the anticipated output (e.g., a new tool, device, capability, or database). Participants were also asked to think in terms of "projects," with a project defined as a set of connected, focused, and aligned activities, actions, or tasks that produce a defined result or output.

After brainstorming, participants organized the ideas into a set of distinct projects and grouped those projects into meaningful categories. To identify the highest-priority projects, the participants voted on the projects based on their potential impact and likelihood of achieving the desired future state.

Finally, participants assembled into small groups, and each small group worked on a high-priority project, mapping out a detailed project plan. The participants reconvened with their whole breakout group, and each small group presented its project to the rest of the breakout group to obtain feedback and broader input. This feedback helped enhance the plans and fill in any gaps.

Workshop Output

The workshop participants identifies eleven high-priority projects intended to focus and direct research, development, and demonstration (RD&D) work toward addressing the most critical technical, market, and business challenges facing the industry. The projects are designed to lead to transformational pre-competitive solutions that can be implemented near and long-term. The 11 high-priority projects that compose the RD&D plan are as follows:

- Develop and Integrate Design for Remanufacturing Concepts within Engineering Tools
- Standards Development and Remanufacturing Certification
- Inspection Process Development and Optimization
- Low-Cost Additive Manufacturing Process
- Advanced Surface Cleaning Technologies
- Nondestructive Evaluation
- Electronic Systems Condition Assessment
- Overcome Data Silos
- Provide Validated Information to Inform Policy and Decision Makers
- Methodology and Tools to Model Global Lifecycle Value/Impacts of Remanufacturing
- Multi-Level Remanufacturing Marketing Campaign

The following report section provides details for each proposed roadmap project.

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7. REMANUFACTURING ROADMAP

This chapter presents the high-priority research, development, and demonstration (RD&D) projects as a comprehensive research program for the remanufacturing industry. Figure 16 provides a graphic representation of the integrated remanufacturing research program and its eleven projects, organized by the output toward which each project is working. The program is driving toward three main categories of outputs: (1) new standards and certifications for remanufacturing and an increased knowledge base; (2) new technologies and process improvements to increase remanufacturing capabilities and efficiency; and (3) improved perception and understanding of remanufacturing and new governmental policies that are supportive of remanufacturing and, in particular, facilitate the trade of cores and remanufactured goods.

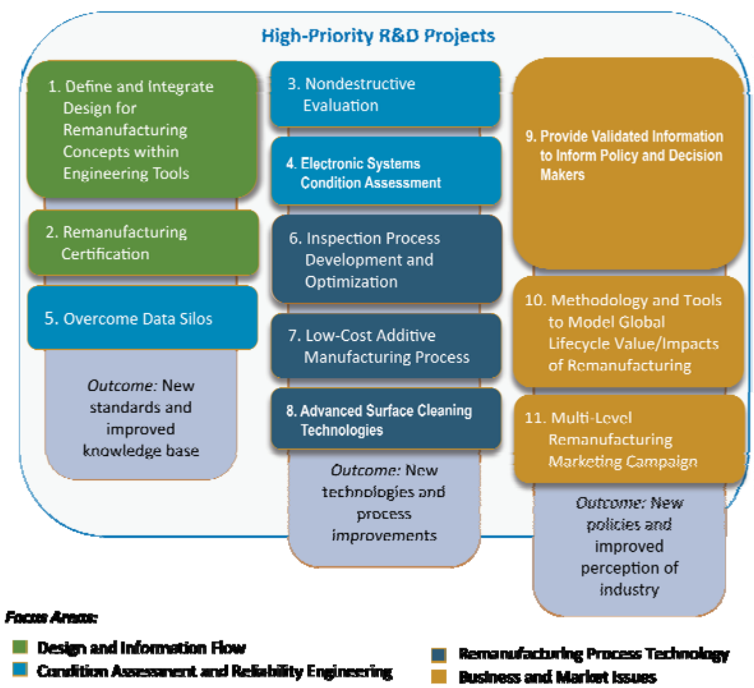

Figure 16. Integrated Remanufacturing Research Program

Summary of Actionable Projects

The priority projects identified collectively represent the core of the research program. The eleven projects are highly interconnected and integrate into a comprehensive initiative for generating the information and knowledge required to overcome the diverse challenges facing the U.S. remanufacturing industry. The need for these projects is highlighted and supported in the background research, industry survey results, site visit data, and developed further by the workshop participants. The 11 high-priority projects that compose the RD&D plan are as follows:

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1. **Develop and Integrate Design for Remanufacturing Concepts within Engineering Tools**: Currently, Design for Remanufacturing (DfR) is based on individual company experience with no definitive DfR reference work in the literature. Additionally, traditional engineering and design tools (enterprise resource planning, product lifecycle management, computer-aided design, etc.) have no remanufacturing specific content. The background literature, industry survey, and workshop participants have all identified Design for Remanufacturing as an area of cross-cutting technology need. This project proposes forming an industry-wide workgroup to create, standardize, and publish reference materials to establish DfR best practices by sector. Once the foundational material has been established, suppliers of engineering tools can be engaged to discuss integration.
2. **Standards Development and Remanufacturing Certification:** At this time, there is no established remanufacturing standard process definition to drive uniformity across the industry. Varying definitions of remanufacturing currently contributes to brand dilution, inconsistent levels of quality, and a lack of both business and consumer acceptance. This project proposes to form a team with representation from each of the 12 key industry segments to develop an "ISO 9001-equivalent" standard for the remanufacturing industry with third party certification that aligns with one common definition of remanufacturing and ensures a minimum set of quality standards and practices are met.
3. **Inspection Process Development and Optimization:** Key insights from site visits and survey feedback indicate that most remanufacturers use manual methods for incoming inspection, and participants relayed that they would like to reduce the amount of labor spent on these inspections. Many also suggested that there was need for improved inspection methods and automation in order to subsequently improve the quality determination of an incoming core. This project proposes to develop inspection techniques that create efficiencies in determining overall condition of parts and reduce over-processing costs through conducting benchmarking and application studies targeting the major cross-cutting challenges.
4. **Low-Cost Additive Manufacturing Process:** Site visit data revealed that larger remanufacturing companies are using additive manufacturing technologies such as welding, laser cladding, and thermal spray in their component recovery process. Literature also showed significant integration of additive manufacturing processes across industry sectors that deal with high value components such as aerospace, heavy equipment, locomotive, and machinery. However, most of the visited medium- or smaller sized remanufacturing companies are not using additive manufacturing at all; and they believe that these processes are not cost-effective due to the high initial capital costs and/or the amount of finishing required after additive manufacturing. This project would therefore focus on developing additive manufacturing processes that could be more cost effective to use on targeted repairs for a broader range of industry sectors and components.
5. **Advanced Surface Cleaning Technologies:** Site visits and background research also revealed that irrespective of the remanufacturing sector, cleaning was identified as a technical challenge. For the heavy-duty and automotive sectors, parts can be cleaned up to five times during a remanufacturing process, creating uncertainty about both efficacy and efficiency. With the high chemical and disposal costs, this level of repetition can make cleaning an excessively expensive

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process. This project proposes to develop environmentally-friendly cleaning chemistries and processes that enable the use of non-hazardous materials, reduce overall energy-intensity and solution volumes, and produce less user-exposure, while assuring that the cleaning system meets required standards.

6. **Nondestructive Evaluation:** The background literature for multiple sectors and the industry survey have highlighted the research need for technologies that improve the assessment of the condition of returning cores. This need was echoed by the workshop participants which expressed that all industry sectors have requirements for nondestructive evaluation (NDE) which currently does not exist. The participants proposed to develop methods or protocols for evaluating inbound cores for each remanufacturing segment. This project would engage a broad array of SMEs in sensors and data recording technologies to develop cost effective solutions.
7. **Electronic Systems Condition Assessment:** Research has shown that the proliferation of hybridization, prognostics, and the connection of products to the internet-of-things has led to significant integration of electronics across multiple sectors. There is currently only limited electronic systems cores tested, and failure modes of electronic systems are not as well understood as their mechanical system counterparts. This project proposes to develop methods and protocols for the assessment of cores containing electronic circuits.
8. **Overcome Data Silos:** Background literature and the industry survey have highlighted the research need for better information on the returning cores. The technology need includes data management and information network technologies such as RFID and database standardization. Aerospace industry leaders Airbus and Boeing have already mandated that some supply chain activities use RFID to enable better system parts tracking. Airbus, for example, introduced the A350XWB in 2013 with approximately 2,000 parts tagged with RFID, and plans on expanding the use of RFID to other aircraft series. The value proposition for RFID part marking lies in the visibility and record keeping of each critical part. Pre-competitive research in this area thus demonstrates potential to reach across the entire remanufacturing industry.
9. **Provide Validated Information to Inform Policy and Decision Makers:** Often remanufactured goods are treated as "used goods," and new restrictions continue to evolve without industry/government input regarding the consequences. Free movement of cores is restricted because cores are often confused or classified as waste material, impeding the remanufacturing business models. This project will develop the data, models, and information necessary to represent remanufacturing to trading partners worldwide. Remanufacturing "model regulations" will be developed that will be used in negotiations with trading partners to facilitate increased remanufacturing trade.
10. **Methodology and Tools to Model Global Lifecycle Value/Impacts of Remanufacturing:** Life cycle assessment (LCA) is a technique used to assess environmental impacts associated with all the stages of a product's life from raw material extraction through end-of-life. Feedback from site visits and from the survey highlighted significant potential to improve the visibility of remanufacturing by using tools such as LCA which could show the environmental preference of remanufacturing processes. However, there are currently limited available tools and methodologies that have the ability to address the uniqueness of remanufacturing. This project proposes to develop a standard, accepted methodology to assess the value of remanufacturing

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across all sectors. This methodology could then be utilized to support and inform policy and decision makers on the environmental (emissions, waste, materials, and energy), economic, and labor impacts of remanufacturing.

11. **Multi-Level Remanufacturing Marketing Campaign:** Less than a quarter of all survey respondents stated that the public has enough awareness of the sustainability benefits of remanufacturing to help their business. Additionally, only about a third of respondents suggest that the public values remanufactured products enough to help their business. This project proposes to create a consumer, business, and government-focused national campaign to improve the brand awareness and preference for remanufacturing. This work will include identifying key metrics and gathering the baseline data.

Individually, each project will help drive toward the vision of improving the advanced manufacturing capabilities of U.S.-based remanufacturing firms. While the eleven projects were identified as high priority projects, it still remains to determine the ordering of projects – which projects are started in the near-term, which are postponed until the mid or long-term. This determination is an important first step of the implementation, but can be aided by recognizing the opportunities for synergy across various projects. To further aid in the ordering of the projects, Figure 17 on the next page displays the 11 projects along a common assuming all eleven projects were started concurrently.

It is assumed that once a master schedule is developed, individual project teams within the industry-led Remanufacturing Research Consortium structure will implement these projects. Different teams may execute the individual projects within the program; however, the knowledge and information developed under one project will feed into the other projects, even if it is in a different focus areas or working toward a different outcome.

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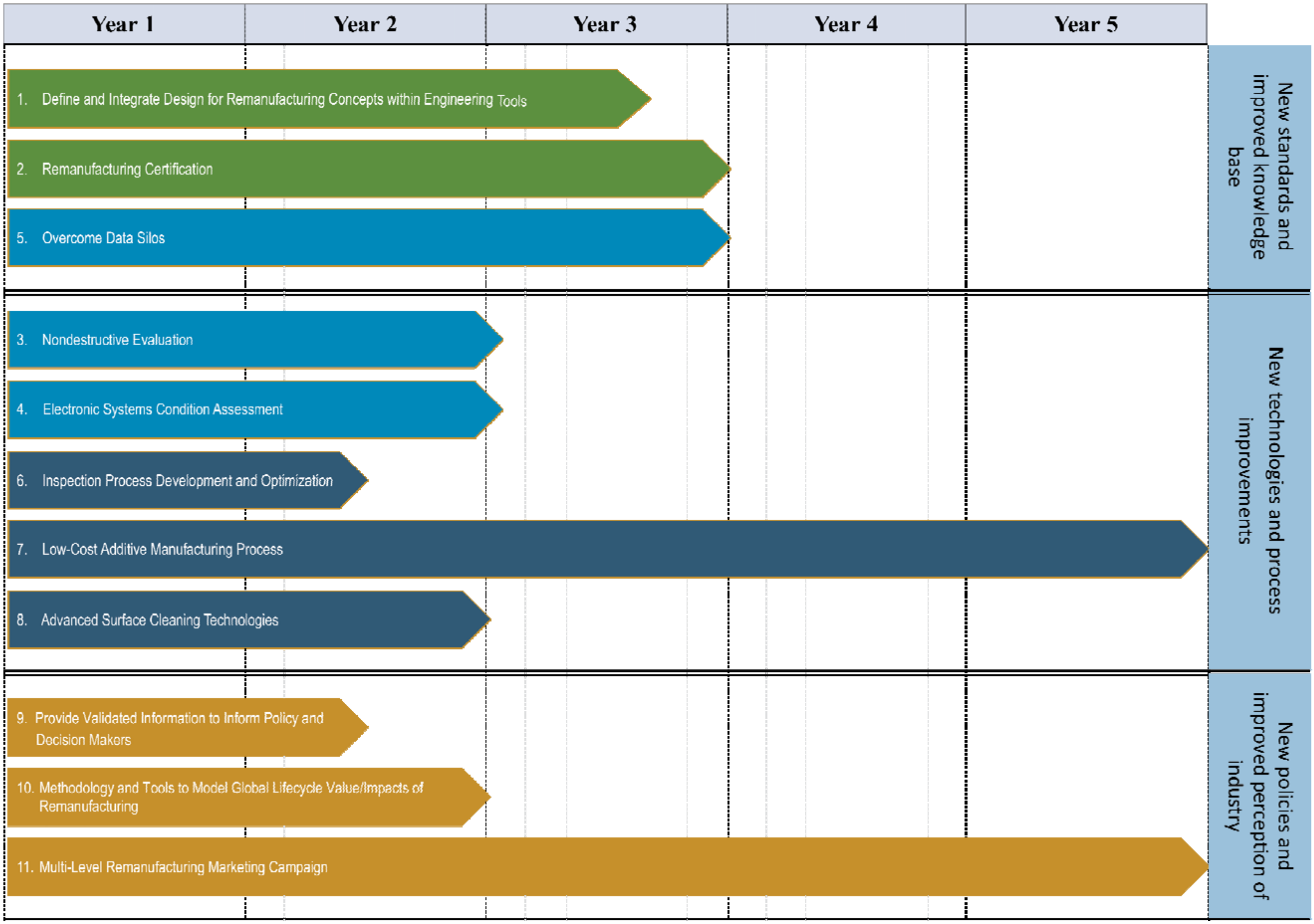

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8. SUSTAINABILITY PLAN

Introduction

The research program and the eleven high-priority research, development, and deployment (RD&D) projects have the potential to overcome critical pre-competitive challenges and dramatically advance the industry. However, to have this impact, effective project implementation is essential.

In particular, commercialization is critical for these innovations to benefit the industry. Commercialization brings technology innovations to the market and makes them widely available, enabling them to compete with and/or replace existing technologies. However, commercialization is challenging and comes with high risks. Many innovative prototypes never make it to the market. Lack of policy support, collaborators, and funding are all significant barriers to commercialization. Therefore, a plan that promotes collaboration and identifies funding sources is essential to ensure effective implementation and commercialization.

The following section presents an overview of the Remanufacturing Research Consortium Sustainment Plan, which will support the implementation of this roadmap.

Sustainment Plan

The Sustainment Plan identifies the critical path forward for the roadmap. It considers what, how, when, where, why, and who will be charged with taking action on the identified RD&D pathways and projects. The plan envisions how the roadmap will be disseminated, implemented, sustained, reviewed, and updated—with a heavy focus on fostering the collaborations critical for success.

Roadmap Dissemination

The roadmap will be widely disseminated and posted online (http://remanroadmap.rit.edu/). The Rochester Institute of Technology (RIT) will present the roadmap at targeted events and trade organization meetings to broadly publicize and continue to build support for its implementation.

Project Implementation and Sustainment

Technical working groups and project-focused research teams consisting of interested companies, researchers, and suppliers will ultimately implement the RD&D projects. These teams will identify funding sources, measure project outcomes, and continually track progress and metrics. The Remanufacturing Research Consortium will oversee this effort and will monitor, guide, and enable collaboration for the projects. This industry-led consortium has strong representation from key stakeholders in U.S. industry (e.g., original equipment manufacturers and independent remanufacturers), not-for-profit groups (e.g., trade organizations), research institutions, and government organizations.

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Together, Consortium member companies and research teams will pursue the resources needed to assist the suppliers and researchers in implementing the RD&D projects.

Industry Engagement

Industry engagement will be critical for effective implementation. To ensure industry-wide engagement, the RIT will facilitate the organization of partnerships and collaborations with the whole value chain, including small and medium enterprises. The Remanufacturing Industries Council, an alliance of businesses and academic institutions that supports the entire remanufacturing industry, will also serve a prominent role and help to ensure an industry-wide emphasis in the collaborations.

Although U.S. remanufacturers compete within the industry, they all have a vested interest in the success of the execution of this roadmap; the health and growth of their businesses are at stake. Therefore, it is expected that a number of companies, suppliers, and researchers will be involved in implementing the roadmap and carrying out the Sustainment Plan. The active involvement of industry companies will encourage rapid progress toward implementation and commercialization.

Funding Sources

Funding represents another critical resource for the success of these projects. The research teams will continue working on the RD&D projects through the Consortium after the Advanced Manufacturing Technology Consortia (AMTech) planning funding ends. Funding support for the Consortium will come from a variety of sources. The remanufacturing industry itself will provide the primary share of research funding. In addition, the Consortium will seek out funding through federal programs such as the U.S. Department of Energy, Environmental Protection Agency, Economic Development Administration, and the Department of Defense. The Consortium will pursue state and local economic development programs as appropriate and explore opportunities to collaborate with other researchers and consortia working on sustainable manufacturing.

The Consortium will also develop outreach materials describing the priority RD&D projects and will actively seek potential sponsors for specific projects.

Roadmap Review and Update

To sustain progress in addressing technology challenges facing the remanufacturing industry, the Consortium will review the roadmap annually. Specifically, the Consortium will organize the annual review to solicit feedback on accomplishments and to identify any emerging challenges. The roadmap will be updated accordingly, and these updates will be made available to all members via http://remanroadmap.rit.edu/.

Role and Structure of the Consortium

The Sustainment Plan began prior to development of this roadmap with the establishment of the Remanufacturing Research Consortium in late 2015. The Consortium is an industry-sustained collaborative, and it serves as the coordinating and oversight body for roadmap implementation.

To provide effective oversight of all eleven projects, the Consortium will utilize a centralized web-based infrastructure. The website will facilitate communication between the research teams, various funding

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sources (e.g., the remanufacturing industry, federal programs, and state and local economic development programs), industry stakeholders, and various other stakeholders. In this capacity, it will serve as a clearinghouse of critical information, providing each entity with access to the information that is relevant to it. The website will also assist with tracking project progress and coordinating technology transfer.

Because lack of collaboration and communication has been identified as a critical challenge for the industry, this web-based implementation infrastructure will be critical for promoting increased communication and ensuring that information is appropriately disseminated. Together, the Consortium and the implementation infrastructure will help the research teams stay informed, funded, and on track.

Conclusion

Implementing the eleven high-priority RD&D projects presented in this roadmap will be challenging. It will require considerable collaboration and funding. However, the Sustainment Plan, Consortium, and implementation infrastructure presented here will help overcome these challenges. As new or unforeseen challenges arise, the annual roadmap review process will serve to update the roadmap accordingly to address those challenges and take advantage of new opportunities.

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9. CONCLUSION

This roadmap presents an integrated research program to facilitate the development of broadly deployable technologies and market solutions that can bolster the advanced manufacturing capabilities of U.S.-based firms along the entire value chain. This program will help increase understanding and awareness of remanufacturing, increase process efficiencies, expand access to cores, promote supportive policies and standards, and increase knowledge sharing and availability of critical information. These changes will result in the increased purchase and use of remanufactured goods both domestically and abroad—an important step toward a circular economy.

Analysis of the key challenges has demonstrated the need and opportunities for innovation in remanufacturing. Moreover, the potential research, development, and deployment (RD&D) projects identified demonstrate the potential to overcome these challenges and yield substantial benefits to the entire remanufacturing industry. Addressing the challenges discussed in this roadmap will have substantive national impacts, such as supporting the health and growth of small and medium enterprises, retaining jobs and creating new jobs, increasing U.S. exports, providing solutions to extend the life of military vehicles, decreasing U.S. reliance on materials sourced in foreign countries, and addressing environmental challenges.

This roadmap identifies eleven high-priority projects intended to focus and direct RD&D work toward addressing the most critical technical, market, and business challenges facing the industry. The projects are designed to lead to breakthroughs and pre-competitive solutions that can be implemented near and long-term. To support this implementation, this roadmap presents a sustainment plan and robust implementation infrastructure.

However, even with these resources, implementing these pre-competitive research projects is beyond the scope of a single organization. It is imperative for the diverse remanufacturing industry to join this effort and collaborate to carry out these RD&D projects and realize the resulting benefits. Therefore—in addition to providing critical guidance for future RD&D efforts—this roadmap serves as a call to action for industry-wide collaboration.

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Appendix A: Workshop Participants

The Remanufacturing Roadmapping Workshop held on September 29–30, 2016, in Troy, Michigan, brought together a diverse and distinguished group of industry representatives. These representatives, presented below, provided critical insight to inform the content of this report.

Participant	Organization
Paul Adamson	Spinnaker Management Group
Albert Arce	Airgroup Dynamics, Inc.
Jennifer Brake	Remanufacturing Industries Council
Stephen Crandall	Crandall Office Furniture
Edward Daniels	Argonne National Laboratory
John Disharoon	Caterpillar, Inc.
Robert German	Flight Systems Automotive Group
Gregory Hammes	Goodyear
Marty Hannig	John Deere
Michael Haselkorn	Golisano Institute for Sustainability
Vaughn Henson	SRC Logistics
Brian Hilton	Golisano Institute for Sustainability
Todd Hooper	JLG Industries
Jeff Jorgensen	Spinnaker Management Group
Kevin Kelley	Xerox Corporation
Kathy Kosciolek	Golisano Institute for Sustainability
Dennis Krawczak	Detroit Diesel Reman
Joe Kripli	APRA
Patrick Layman	WABCO Reman Solutions
Dave McGuire	MERA
Robert Mungillo	Airgroup Dynamics, Inc.
Nabil Nasr	Golisano Institute for Sustainability
Ken Oda	CoreCentric Solutions
James Porter	Kentwood Office Furniture
Angie Rosenfield	ROMAC Supply Company, Inc.

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Participant	Organization
David Rosenfield	ROMAC Supply Company, Inc.
Michael Schmit	GE Healthcare
William Schofield	Circuit Breaker Sales Co., Inc.
Jeff Stukenborg	WABCO Reman Solutions
Jeffrey Sutherland	Caterpillar, Inc.
Bob Von Kaenel	Kentwood Office Furniture
Monish Wadiwala	CoreCentric Solutions
Todd Wieland	Cummins, Inc.

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APPENDIX B: WORKSHOP PROCESS

Remanufacturing Workshop Agenda

September 29–30, 2016, Troy, Michigan

Day 1: Thursday, September 29, 2016

Time	Activity
7:15-8:00am	**Breakfast & Networking**
8:00-8:30am	**Welcome and Introduction** *The purpose of this session is to provide important background information on the roadmapping project, the progress of work to this point, and the purpose of the current workshop.*
8:30-10:00am	**Plenary Presentations:** *A series of plenary presentations will provide information that equips participants to participate in the breakout discussions. In general, the presentations are used to put everyone on the same page regarding the current state. They may also serve to bound the technical issues or challenges and put constraints on the solution set.*
10:00-10:30am	**Break – Participants move to breakouts**
10:30-11:30am	**Breakout Session 1: *Characteristics of the Future State*** *In this first breakout session, participants will determine the specific characteristics of a desired future that could be achieved within the next 5–10 years in the breakout topic area. They will be asked to specify what that future would look like—the specific changes that will have been achieved. In essence, participants will be developing a definition of success and identifying potential indicators that could be used to track progress.*
11:30am-12:30pm	**Lunch**
12:30-2:00pm	**Breakout Session 2: *Identify Key Technical Challenges*** *In this second breakout session, participants will continue the process of analyzing the breakout topic area by identifying key technical challenges. In particular, they will specify the key technical challenges, barriers, or problems that are inhibiting meaningful progress toward the desired future state. The focus of the discussion is on "problem definition" rather than "solution specification."*
2:00-2:30pm	**Break**
2:30-4:00pm	**Breakout Session 3: *Generate Projects*** *In this session, participants will shift in focus from defining problems to specifying a pathway toward a solution. Participants will identify and prioritize research projects that address the challenges identified in Breakout Session 2. For each project idea, participants will specify the nature of the research to be conducted and the*

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	anticipated RD&D output. At the end of the session, participants will prioritize/down select the projects that have the highest potential of making a difference toward achieving the desired future state.
4:00-4:15pm	**Break and return to Plenary Room**
4:15-5:00pm	**Plenary Session: *Report Out*** *A representative from each breakout group will give a <5 minute presentation of the top-priority projects identified by the breakout group. The purpose is to have each group understand the progress being made by the other breakout groups.*
5:00pm	**Adjourn**

Day 2: Friday, September 30, 2016

Time	Activity
7:15-8:00am	**Breakfast & Networking**
8:00-8:15am	**Plenary Session: *Introduction to Day 2*** *Participants will convene as a large group before moving to the breakouts. The purpose of this brief opening session for Day 2 is to answer any questions that may have come up about Day 1 and to re-engage and inspire participants for the Day 2 work.*
	Participants move to breakout rooms
8:15-9:45am	**Breakout Session 4: *Planning Research Projects*** *For this session, participants within each breakout group will subdivide into small groups of 2–3 people. Each small group will work on a high-priority project and complete an 11 x 17 planning worksheet to map out a project plan. The templates are intended to both guide researchers and influence funding sources.*
9:45-10:15am	**Break**
10:15-11:30am	**Breakout Session 4: *continued***
11:30am-12:00pm	**Closing Plenary Session** *To close the workshop, participants will reconvene as a large group. Participants will be given a chance for a final word. The organizers will review next steps and thank participants.*
12:00-1:00pm	**Lunch**

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Workshop Process

The Remanufacturing Workshop brought together a diverse group of subject-matter experts and industry representatives to hone in on cross-cutting challenges, identify and reach consensus around the remanufacturing industry advanced technology objectives, and set research priorities to overcome the technological barriers inhibiting the growth of advanced manufacturing capabilities in the remanufacturing industry. (See Section 6 for details.) At the workshop, participants were divided into four breakout groups, with each group focusing on one of four critical topic areas: (1) Design and Information Flow, (2) Condition Assessment and Reliability Engineering, (3) Remanufacturing Process Technology, and (4) Business Market Issues. Each breakout group considered the specific topic and determined the characteristics of the desired future state, identified key technical challenges, generated specific projects toward a solution, and planned specific research projects.

Workshop Process Example: Remanufacturing Process Technology

The following section demonstrates the workshop workflow using data from the Remanufacturing Process Technology breakout group.

Current State of Remanufacturing Process Technology

Remanufacturing process optimization is critical for sustainable manufacturing. In fact, 31 percent of all respondents of the GIS survey identified remanufacturing process optimization as the most potentially beneficial topic in sustainable manufacturing. Remanufacturing processes rely on many unique steps that are not performed during original product manufacturing, and accordingly, many of these processes have not undergone the same extensive refinement, standardization, and technological optimization enjoyed by new product manufacturing. Process steps such as disassembly; cleaning; condition assessment; physical, mechanical, and electrical parts restoration; components replacement; reassembly; and validation are fundamental to remanufacturing but have infrequently been the focus of efforts in technological innovation and optimization. Therefore, this topic area considers common challenges faced during the remanufacturing process and the crosscutting platform technologies that may enable significant improvement throughout the industry.

Future State of Remanufacturing Process Technology

In the area of remanufacturing process technology, the desired future state for a 5- to 10-year timeframe is one in which a number of diverse changes have occurred across the industry to increase knowledge about incoming cores and improve remanufacturing techniques. These changes, organized into two broad categories, are explained below:

Increased Knowledge

There is currently a lack of standard simulations models and a deficit of knowledge about the history of incoming cores. Therefore, in the desired future state, this will be addressed, and remanufacturers will have access to standardized specifications and other relevant market information. In addition, lifecycle cost models will increase knowledge about products' lifespans.

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Improved Manufacturing

In the desired future, a number of technology and process improvements will have increased the efficiency and effectiveness of remanufacturing. Additive manufacturing will have become cost effective and enable efficient component restoration. There will be new methods to improve the remanufacturing processes and reduce costs by enabling targeted cleaning, characterizing and reversing fatigue, and repairing cores without disassembly. Presently, fatigue damage cannot be determined, and the costs of cleaning and restoration—both labor-intensive processes—are high and represent a major challenge to the industry. Hence, these new processes will be a considerable step forward for the industry.

Key Technical Challenges of Remanufacturing Process Technology

The key challenges, barriers, and problems inhibiting meaningful progress toward the desired future state are numerous and varied, ranging from technical to regulatory issues. The four major themes are discussed below:

Knowledge Barriers

As discussed in the Design and Information Flow subgroup, there is a lack of data collection, communication, and feedback response technology systems that connect primary and remanufacturing systems. Beyond design and intended performance parameters, actual use data is lacking and would provide remanufacturers insight into both how the product failed and the baseline new performance standard to which remanufactured products must be returned. The current lack of known product specifications forces remanufacturers to reverse engineer products to learn how to effectively remanufacturer them. This practice is not efficient. Furthermore, the shortage of information hinders the development of complete system solutions.

Workforce

Remanufacturing involves many labor-intensive steps and requires a skilled workforce; however, locating workers with a suitable background for skilled and semi-skilled remanufacturing labor is difficult. For example, reverse engineering goods for the remanufacturing process requires skills that most workers lack. This skill deficiency results in high rates of process scrap and slowed innovation. The current lack of skilled process engineers also elevates the cost of remanufacturing, hindering market entry and profitability. One reason for the workforce shortage is the current education system, which typically does not teach remanufacturing as part of product lifecycles. Furthermore, manufacturing path and lifecycle definitions often overlook remanufacturing. Therefore, the lack of training and educational programs specifically focused on remanufacturing hinders the growth of the workforce and thus the industry.

Technical

A number of technical issues hinder progress in the remanufacturing industry. The short product lifecycles of many components—especially electronic components—hinders their use for remanufacturing. Another technical challenge is the lack of NDE techniques for crack detection and similar issues. NDE enables the examination of parts and products without impairing their future

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usefulness—saving time and money. The lack of these techniques reduces the amount of materials that can be effectively remanufactured. In addition, the materials in many current products are designed in a way that prevents remanufacturing.

Cleaning and Other Remanufacturing Processes

Cleaning is a critical step and a significant economic challenge for the industry. The current cleaning process is labor intensive, requires costly chemicals, and suffers from hazardous waste disposal issues. Components often need to be cleaned multiple times, and inconsistency in the process can result in over-cleaning, further driving up costs. Inspecting components is also expensive, because it, like cleaning, is labor-intensive. Automated processes that could reduce labor intensity are often not cost effective. Other remanufacturing processes, including three-dimensional printing, and certain materials, such as additive metals, are also not cost effective.

Research Concepts for Remanufacturing Process Technology

To address the numerous and significant challenges explored above, a number of research projects are needed. These projects focus on overcoming critical knowledge gaps, improving process technologies, and enabling cost-effective automation. These projects, grouped into three categories, are explored below:

Knowledge

A variety of projects are needed to overcome the knowledge gaps surrounding remanufacturing. Understanding products' complete lifecycles is critical to determining the cost effectiveness of remanufacturing. Therefore, a project is needed to conduct lifecycle analyses on a variety of products. These analyses would provide data to demonstrate whether the benefits of remanufacturing outweigh the costs. In particular, research is needed to investigate the cost versus performance of plating and abrasive blasting—an important remanufacturing step to remove rust, paint, and other materials to restore surfaces to like-new conditions. Knowledge of the costs and benefits will provide greater remanufacturing opportunities.

Research is also needed on advanced coatings, bonding agents, solvents, and additive materials. More data on these materials could improve their use in remanufacturing. Research should also investigate remanufacturing new materials, including carbon fiber advanced castings and metal matrix composites. These research efforts could lead to new, advanced remanufacturing techniques, processes, products, and opportunities.

In addition to the knowledge gaps discussed above, a critical knowledge gap exists in the current workforce. To address this gap, a project should provide training for the remanufacturing workforce. This project would cover multiple process technologies, focusing on common and new technologies. The training could take the form of standard online seminars that would be easily accessible to the entire U.S. workforce.

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Process Technology

A number of projects are needed to improve remanufacturing specific process technologies. One such project would develop a low-cost additive manufacturing process. Improved additive processes would eliminate or reduce machining, drilling, grinding, or similar methods. In doing so, additive processes could improve efficiency and reduce waste. A project is also needed to develop a targeted cleaning process. This process would require fewer steps and would result in improved and lower-cost cleaning. Early inspection techniques should also be developed to reduce processing costs. These techniques could be used prior to or just after disassembly. Another project should develop a condition assessment of systems using sensors and data analysis algorithms. This assessment would estimate the remaining life in a core to help determine its usability in remanufacturing. Further research should explore surface restoration processes and techniques for plastics. The output of this research would be low-cost process solutions that make remanufactured goods more competitive with new products.

Automation

Research is needed to explore the potential of automation for the remanufacturing industry. Most current remanufacturing processes are not automated, although automation offers potential for improved efficiencies. For example, current visual inspections yield inconsistent results. Automatic inspection or gauging could reduce labor costs and increase accuracy; however, the current automated processes are not cost effective, so a concerted research effort on automation is required. A project should specifically investigate automated metal cladding, which could scan a part, compare it to a model, and then automatically add metal. This type of cladding could reduce costs and minimize machining.

High-Priority Research Projects for Remanufacturing Process Technology

From the research projects discussed above, three projects emerged from this breakout group as having the highest potential toward achieving the desired future state. These three high-priority projects are described below.

Inspection Process Development and Optimization

This project will develop inspection techniques that improve the efficiency of determining the overall condition of parts and reduce over-processing costs. Current visual inspection techniques are inconsistent and often reliant on the competence of a few workers. Dirty parts pose a significant challenge for these inspections, and pre-cleaning can be costly and wasteful if component is later determined to be non-recoverable. To help address these issues, the project will conduct a benchmarking and application study targeting the major, crosscutting challenges. It will also create a database documenting current capabilities and technologies. Ultimately, the project will develop a new technology or process that can be utilized by the entire industry. Adoption of this new technology or process will reduce costs and time spent on inspections.

Low-Cost Additive Manufacturing Process

This project will develop a low-cost additive manufacturing technology. This technology will focus on targeted repairs for adding material on various components (e.g. engine components). Current additive process are expensive and primarily used for high-production manufacturing. An improved process

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would reduce machining cost, lower heat and distortion, and enable the recovery of previously non-recoverable components.

Advanced Surface Cleaning Technologies

This project will develop a unique green cleaning process that will be more efficient and cost effective than current processes. To develop this improved cleaner, the project will conduct an expansive literature search as well as other research and experimentation. In addition, the project will research automation and incorporate automated processes into the targeted cleaning process. The project will need to balance cleaning efficiency with cost considerations and sustainability requirements. Ultimately, the project will develop an automated targeted cleaner that can reduce processing costs and improve product quality.

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APPENDIX C: ADVISORY GROUP

An initial meeting with the Advisory Group was held in Michigan on September 29th, 2015. Attendees are listed in the table below.

Name	Organization
Joe Kripli	Automotive Parts Remanufacturers Association (APRA)
John Disharoon	Caterpillar
Robert Paternoga	Caterpillar
William Schofield	Circuit Breaker Sales Co., Inc.
David Dyer	CNH Remanufacturing
Todd Wieland	Cummins
William Davies	Davies Office
Anita Barlow	Delphi
Sanjiv Khurana	Detroit Diesel Remanufacturing
Michael Schmit	GE Medical
Nabil Nasr	Golisano Institute for Sustainability
Gerry Hurley	Golisano Institute for Sustainability
Tricia Judge	International Imaging Technology Council (I-ITC)
Martin Hannig	John Deere Reman Operations
John Chalifoux	Motor and Equipment Remanufacturers Association (MERA)
Doug Powell	Professional Electrical Apparatus Recyclers League (PEARL)
Paul Stiebitz	Remanufacturing Industries Council (RIC)
David Rosenfield	ROMAC
Angie Rosenfield	ROMAC
Jack Stack	SRC Holdings
Don Chenevert	SRC Holdings
Jeff Stukenborg	WABCO Reman Solutions
Thomas Eastham	Woodland Fluid Power, Inc.
Greg Cagle	Woodland Fluid Power, Inc.
Kevin Kelley	Xerox Corp.

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