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Research on Remanufacturing Process and Its impact on the Environment

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Abstract: ***With sustainable industrial development, Remanufacturing has gained immense popularity. Attempts are made to rebuild new products while maintaining the quality equivalent to that of newly manufactured products. The need to study and apply the concept of Remanufacturing on a large scale arises due to the limited availability of resources on the planet Earth. Remanufacturing is a process of restoring a non-functional, discarded, or traded-in product like-new condition. It results in 68-83% reduced energy, material use, and production costs. Environmentally, remanufacturing facilitates a decrease in 73-87% fewer carbon dioxide emissions. Remanufacturing has become a critical element of the circular economy wherein products are developed, manufactured, used, and recovered to prevent any sort of waste and reduce the extraction of raw materials. Despite successful growth in Remanufacturing industry, it continues to face numerous challenges but holds the potential to become a multi-billion-dollar industry. The paper discusses the process of Remanufacturing, its design aspects, and the environmental impact. It also provides case studies for explaining the Remanufacturing of Engines.***
Keywords: Remanufacturing, Circular Economy, Sustainable development, Global Warming Potential, Design Engineering

I. INTRODUCTION

The earliest definition of Remanufacturing was dated in 1987 which stated – "Remanufacturing is an industrial process in which worn-out products are restored to like-new condition. Through a series of industrial processes in a factory environment, a discarded product is completely disassembled. Usable parts are cleaned, refurbished, and put into inventory. Then the new product is reassembled from both old and, where necessary, new parts to produce a unit fully equivalent-and sometimes superior-in performance and expected lifetime to the original new product. In contrast, a repaired or rebuilt product normally retains its identity, and only those parts that have failed or are badly worm are replaced or serviced" While a product is being Remanufactured it undergoes various phases of transformation i.e. core acquisition, disassembly, condition assessment of core, cleaning, repair, assembly, testing, service life, and core return.[1]

Remanufacturing as a business concept is advantageous because it is based on the concept – resources utilized in manufacturing are reused. Material recovery is very high in Remanufacturing process as compared to other processes such as recycling, repair, or reuse. Reduced costs for material, energy, and labor along with short time spans required while remanufacturing a product. This makes remanufacturing a superior process with a high level of material recovery, especially metals.[2] Remanufacturing, unlike any other material recovery process, is a standardized industrial process wherein the cores are restored to their original condition. This may allow the core to perform even better or equivalent to new conditions. Remanufacturing is a unique process that allows restoration of the core to full new service life for each usage cycle. On the contrary, the process of repair, reuse, and refurbishment ensures that the product fulfills its single life cycle. These processes are employed in order to maintain, fix and modify the product and do not establish the product to new condition to provide a new service life. In terms of sustainability and circular economy, remanufacturing is the most efficient way to moderately use resources.[3]

II. CONCEPTUAL APPROACH FOR REMANUFACTURING

In the present world, Remanufacturing should be approached under two economic circumstances:

1) Remanufacturing of technological equipment whose design is not conceived for remanufacturing. For example – gearboxes.
2) Remanufacturing requirements are taken into consideration for product conception and design stage. For example – engine.

Important characteristics necessary for remanufacturing of products:

a) Equipment that does not dissipate while remanufacturing.
b) Existing technology for bringing the product to its original shape, condition, and operability.
c) Documentation, and use of standard operational processes.

Remanufacturing is advantageous as it offers a high-quality level with lower costs, as compared to a newly manufactured component. While various study cases prove that remanufacturing significantly reduces the use of nascent materials and resources, with an increase in skilled staff and opens up a new horizon of the market with loyal customers. A remanufactured product should maintain its performance just like a new product; which requires thorough assurance in quality and technological enhancements to the product. The functioning components which can be reused are removed from a used core/product and transformed into a new product.

With drastic climate change, exhausting natural resources, and environmental threats we need to shift our user mentality from – use and dump to reuse, refurbish and remanufacture. Table 1 Differentiates various material recovery techniques. The customer and the producer should share equal responsibility for the overall pollution that is being created due to industrial activities and consumerism business because government alone is not able to deal with vast amounts of waste that are being generated and disposed of without regulatory treatment. In the end, the waste ends up in our biodiversity – oceans, lakes, rivers, and nature. Pollution can be controlled if we can set up material banks in every town and city to deal with the used resources and revert them into the economy on a local scale. This will ensure the implementation of a circular economy with infinite use of natural resources.

Table 1 - Differentiating between material recovery techniques

Technique	Disassembly	Quantity Recovered	Quality	Technological Upgradation	Service Life	Warranty	Value Retention
Reuse	Limited	Fully/ Partially	Low	No	Low	No	Yes
Repair	Limited	Fully/ Partially	Inferior	No	Low	Yes	Yes
Refurbish	Limited	Fully/ Partially	Low	Yes	Extended	Yes	Yes
Recycle	Selective	Selective	-	No	-	-	Lost
Reconditioning	Selective	Selective	Inferior	No	Extended	No	Yes
Remanufacture	Complete	Very High	Very High	Yes	High	Yes	Yes

Circular economy refers to waste being used as an input to make new products equal in standard while minimizing the usage of natural resources. Value creation from waste is the main objective of the circular economy. The 9R's form the basic pillars of the circular economy.[4] The above-mentioned product techniques differ vastly from one another on the basis of the following factors: Disassembly, Quantity recovered, Quality, technological up-gradation, service life, warranty, and Embodied value retention. The above factors differentiate the 9Rs from each other and Figure 1 helps us to understand them in-depth and then apply them accordingly to save our resources in the process.[4] The 9Rs can be grouped into three main categories:

(i)Useful application of resources – Recycle and Recovery

(ii)Extend the lifespan of the product and its parts – Reuse, Repair, Refurbish,Remanufacture and Repurpose

(iii)Smarter product use and manufacture – Refuse, Rethink, Reduce

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Figure 1 – 9Rs of Circular Economy[9]

III. METHODS

A. *Remanufacturing Life Cycle*

Various steps are involved while remanufacturing a core and it undergoes a life cycle. Figure 2 represents the remanufacturing steps and they are defined below:

1) *Core Acquisition:* Core is collected at the remanufacturing site for processing.
2) *Disassembly:* Failed components of the core are removed from the main body and complete dismantling of the core is performed.
3) *Condition Assessment:* Every component of the core is inspected after dismantling. The working condition of every component is checked, and parts are segregated according to workability. A component may be in good condition and can be used, or it may require a certain degree of repairing or might not suffice the working requirement and shall be discarded or scraped off.
4) *Cleaning:* The components that can be used or repaired are cleaned extensively so remove any debris or dirt on them.
5) Repair: Repairing any damaged component is an essential step of remanufacturing. The latest technology used for repairing makes it less labor- intensive.
6) *Assembly:* Assembly of new core is carried out using the components acquired which undergo cleaning and repair before being assembled together. If a damaged component cannot be reused, then a new component replaces it.
7) *Testing:* Quality testing of the remanufactured core is carried out. According to standards, the core's performance should be better or equivalent to a new core.
8) *Service Life:* The new core begins its service life which is expected to be equal to that of a newly manufactured core, if not higher.
9) *Core Return:* After the core completes its life cycle and reaches its end, it is again sent to the remanufacturing facility wherein evaluation of remanufacturingability takes place.

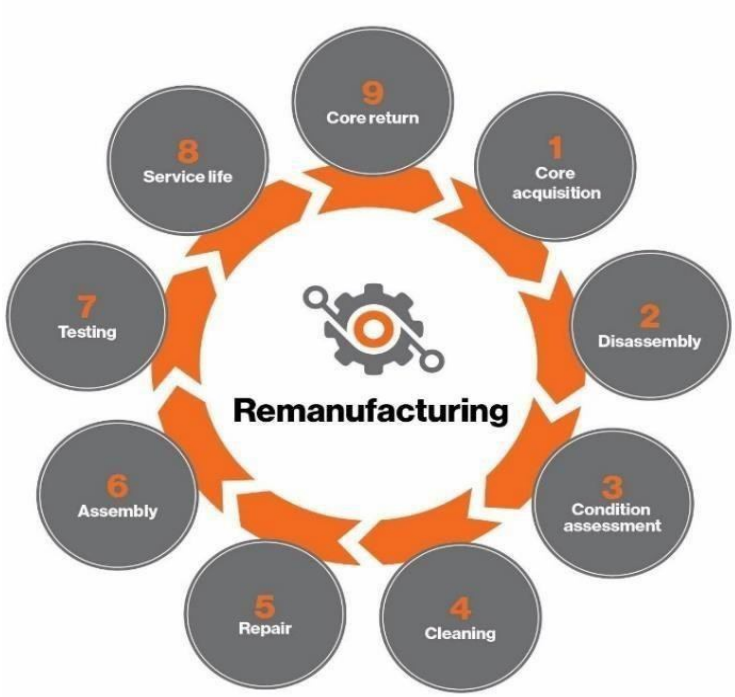

Figure 2 - Steps Involved in Remanufacturing[4]

B. Economics of Remanufacturing

Remanufacturing is feasible when the production cost of the remanufactured product is less than that of a new product. Also, the product should have marketable value with sufficient demand. The buyers should be convinced to purchase the remanufactured product. The product cost should be low enough to attract buyers, yet it should recoverall the restoration, logistics, and labor costs.[7]

Remanufacturing is considered a multi-billion-dollar industry worldwide. In 1987, the Automobile remanufacturing sector earned a revenue of $100 million to an American company. In 2021, the European Automobile remanufacturing industry was worth around 11.9 billion EUR, while it was worth around 9 billion EUR in 2015. This helps countries with GDP as well. Also, it leads to increased demand for skilled jobs and adds to the creation of jobs, and increases the local employment ratio. Table 2 describes the Remanufacturing market size across various Industries.

Table 2 - Remanufacturing Market Size across various Industries [8]

SECTOR	THE MARKET SIZE OF REMANUFACTURING	
Aerospace Industry	EUR 15.2 billion (3 %)	EUR 16.3 billion (4 %*)
Automotive Industry	EUR 9.1 billion (3 %)	EUR 11.9 billion (7 %*)
Heavy duty and off-roadequipment	EUR 4.2 billion (0.5 %)	-
Electrical and electronic equipment	EUR 4.4 billion (5 %*)	-
Medical Equipment industry	EUR 1.32 billion (4 %*)	EUR 1.4 billion (5 %)
Machinery	EUR 1.04 billion (0.5 %)	EUR 1.4 billion (5 %*)
Railway Infrastructure	EUR 430.4 million (3 %)	EUR 562.1 million (7 %*)
Furnishing Industry	EUR 422.1 million (5 %)	-
Marine Industry	EUR 78.7 million (0.5 %)	EUR 157.6 million (11 %*)

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C. Societal And Environmental Impacts Of Remanufacturing

An exponentially increasing industry such as remanufacturing will offer greater opportunities to the local labor markets throughout the world. We might comprehend that if components do not wear quickly and do not require regular replacement, remanufacturing sector's market share won't be lucrative enough to offer a great opportunity for employment. But this might not be the scenario as the employees working in metal extraction and similar industries would lose their jobs. So, the void will be compensated by Remanufacturing industry. Remanufacturing reaps deep rewards for strengthening the societal fabric. The benefits range from higher employability, lesser use of resources and energy, and greater flow of materials within the economy (which helps in achieving self-reliance for various nations). Studies suggest that remanufacturing needs less than 15% of the energy required to produce a completely new item. This equals to the petrol requirements of 6 million cars every year or 15,000,000 barrels of crude oil. Various climate factors like – the emission of greenhouse gases, extensive use of natural resources, and waste disposal issues. It is estimated that remanufacturing alone reduces 28 million kgs of carbon dioxide from being generated yearly. This is equivalent to the emission level of 5000-megawatt coal-powered stations. The material saved in remanufacturing would fill 2.3 lakh railway carriages of a train with length 2600 km long.

D. Challenges

Even though Remanufacturing sector offers environmental and societal benefits, there are significant challenges that are ahead while implementing it on a large scale. Majorly the challenges are dealt with by organizations and are stated as below:

1) *Design Engineering:* Component designing is a crucial criterion to achieve scalable and affordable remanufacturing processes. Product design should provide ease of dismantling. Every product should ideally be designed in a way that it becomes easy to dispose it or remanufacture or reuse it.
2) *Executive Commitment:* Various organizations like GE, Renault and Caterpillar have implemented the concept of remanufacturing at a large scale. The execution requires commitment towards a sustainable goal which is not possible without the futuristic vision of higher authorities present in an organization.
3) *Marketing, Sales, and Advertising:* For remanufactured products to be sold in the market, people should first accept and try to inculcate a sustainable lifestyle.A loyal base of customers will give the necessary boost to the remanufacturingindustry.
4) *Supply and Demand Challenges:* Product returns and forecasting techniques are many times stochastic and are usually a failure as they do not consider knowledge related to customer behavior, life expectancy of product, sales and product usage. Isolated locations for remanufacturing might pose barriers for supply chain and reverse logistics. To counter this material banks shall be created in every town and city.
5) *Sustainable Approach Challenges:* Various aspects of sustainability aren't practiced by the standards in the remanufacturing industries. Environmental policies should be regulated and effectively followed in order to ensure sustainability. Regulatory laws, waste disposal, wastewater treatment, and greenhouse gas emission should be practiced and monitored.

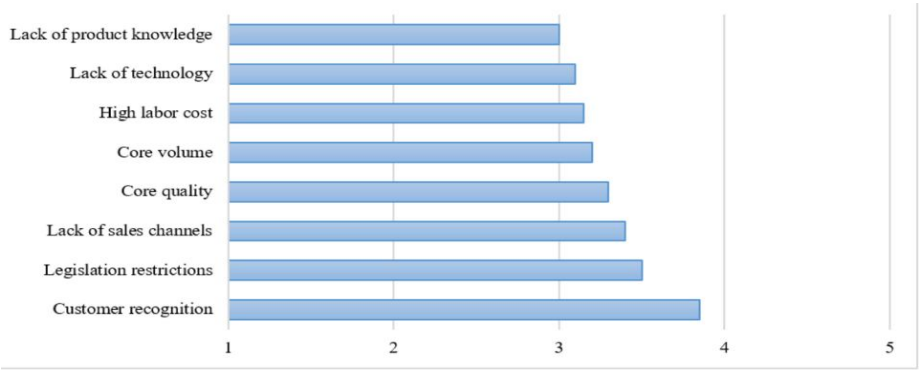

Figure 3 - Overall barriers to Remanufacturing[5]

The above figure shows major barriers against Remanufacturing and its extensive use. Figure 3 represents important factors involved in remanufacturing such as – Lack of product knowledge, Lack of technology, high labor cost, core volume, core quality, lack of sales channels etc. These factors are ranked based on seriousness, while5 being very serious and 1 being least serious. [9]

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IV. CASE STUDY: REMANUFACTURING OF ENGINES

FARAL is a French company, founded in the 1930s and is an independent supplier of cylinder heads, engines, turbos, and standard gearboxes. FARAL had annual revenue of €9M in 2014 and employed 75 people. FARAL is situated in a small county, located in Figure 6 of Laval in France wherein all the products are remanufactured in Laval's manufacturing facility, and introduced remanufacturing at their facility in 1965.

Remanufacturing requires strong technical knowledge and is an attractive sector due to its environmental, economic, and societal benefits. Every year FARAL remanufacturing facility works on 2000-cylinder heads and engines, 6000 turbos, and 1300 gearboxes. With the development of their own patented process for remanufacturing of cylinder heads, the company can successfully remanufacture various kinds of components – over 300 types of cylinder heads, turbos, and engines.

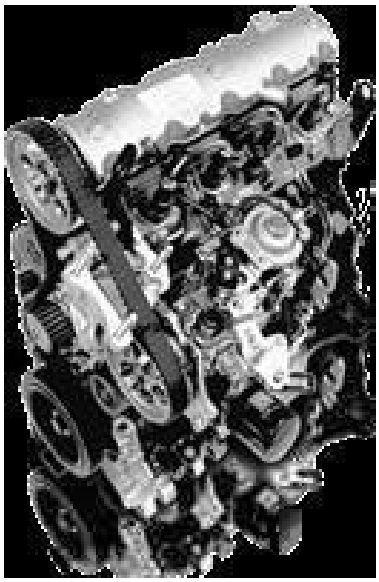

Figure 4 - Remanufactured Engines[9]

Figure 5 – Ecolabel[9]

FARAL remanufactures cores, originally developed by companies – Ford, Renault, Opel, and so on. Engines are primarily designed to be remanufactured, but this isn't so for turbos, and gearboxes. Parts and components of engines as shown in Figure 4, are specifically designed for machining operations like milling, drilling and so on which makes it easier for refurbishment. Engines are also durable which facilitates their remanufacturing. [9]FARAL with their environmental studies has calculated the benefits of remanufacturing to our environment. By developing their own ecolabel as shown in Figure 5, FARAL ensures its customers that any purchase of remanufactured cores from them decreases carbon dioxide emissions, use of raw material is reduced along with reduced energy consumption.

FARAL claims to have recovered 20,000 tons of steel into remanufactured engines and various automotive components. The company ensures maximum material recovery for components that cannot be remanufactured by a waste sorting and collaborating with recyclers.

As compared to new engines, remanufactured engines are 20 to 40% cheaper and avail an economic edge. While remanufactured gearboxes and turbos do not offer any economic edge and lie within the same order of magnitude. The production cost of new parts is significantly higher than the production costs of remanufactured components. The company aims to extract maximum feasible economic value from used parts and materials.

Every component manufactured or remanufactured by FARAL is associated with the label - "Made in Mayenne". Figure 7 shows that FARAL promotes the economic activities in Mayenne province and creates demand for skilled employees. It suggests the company's ability to train the young population from the region and recruit them. FARAL's high assurance of quality and collaboration with recyclers and partners makes it an ideal company for the circular economy.

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Figure 6 - Location of Faral in France[9]

Figure 7 - Made in Mayenne Logo[9]

Effective communication, knowledge transparency, and awareness can the change perception of remanufacturing sector. Other major challenges faced by the company areas follows –

1) Access to new cores which is controlled by OEMs
2) Laws and tax regulations that could impact the remanufacturing industry.
3) Incorporation of advanced manufacturing technologies.

The emissions from the automotive industry are regulated strictly in the European Union. The exhausts from engines include hydrocarbons, CO_2, carbon monoxide, nitrogen oxides, and particulate matter under 2.5 µm. Figure 8 gives us the difference between emissions for a newly manufactured and a remanufactured engine. It can be evaluated from the figure that a remanufactured engine has 20-50% fewer emissions for all the gases.[9]

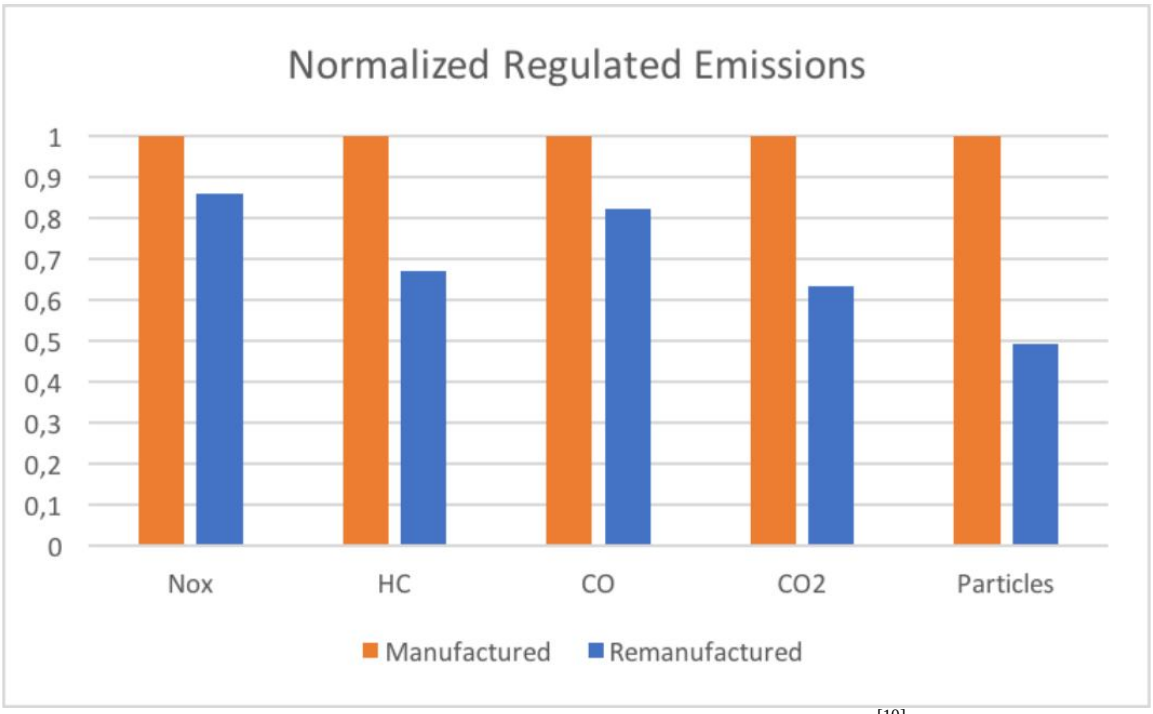

Figure 8 - Emissions of Remanufactured and newly manufactured product [10]

Aromatic hydrocarbons are the major emissions from the hydrocarbons which surface to the water. The main reason for hydrocarbon emission is aluminum production, which accounts for 80%, wherein the carbon monoxide is emitted during the use phase at around 95%. The remaining emissions occur from the manufacturing processes of milling and drilling.

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Metals are becoming scarce due to over-extraction and rapid consumption. Remanufacturing offers less raw material to be extracted from the ground. Figure 9 shows the use of raw materials in remanufactured products and remanufactured ones. Thus, it can be clearly seen remanufactured engines draw less raw material. For all the raw metals, we can see around 50-80% of raw material is being saved if the engine is remanufactured. Hot rolled steel and aluminum are majorly used in production of engine.

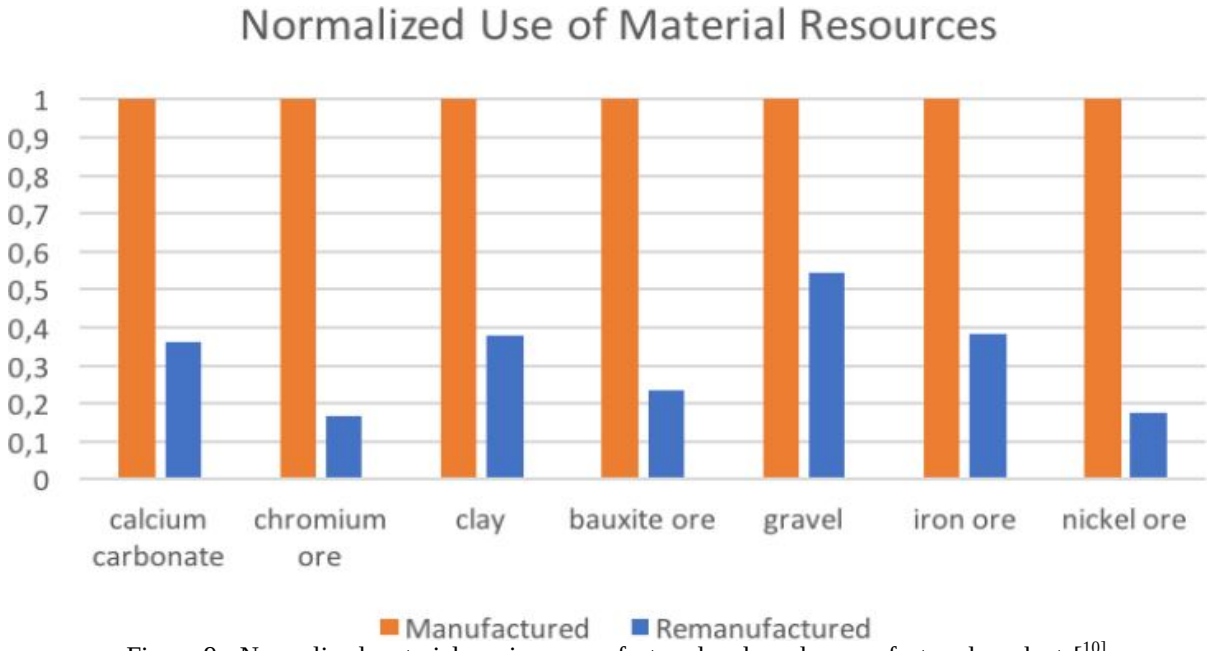


Figure 9 - Normalized material use in remanufactured and newly manufactured products[10]

After material resources, we will look into the energy resources used in remanufacturing. From Figure 10, we can see conclude only 50% of coal is required to remanufacture an engine as compared to a newly manufactured engine. This saves our planet from various million tons of carbon dioxide being emitted in our environment. Similarly, 40% less natural gas is required for remanufacturing and 8% less crude oil is used.

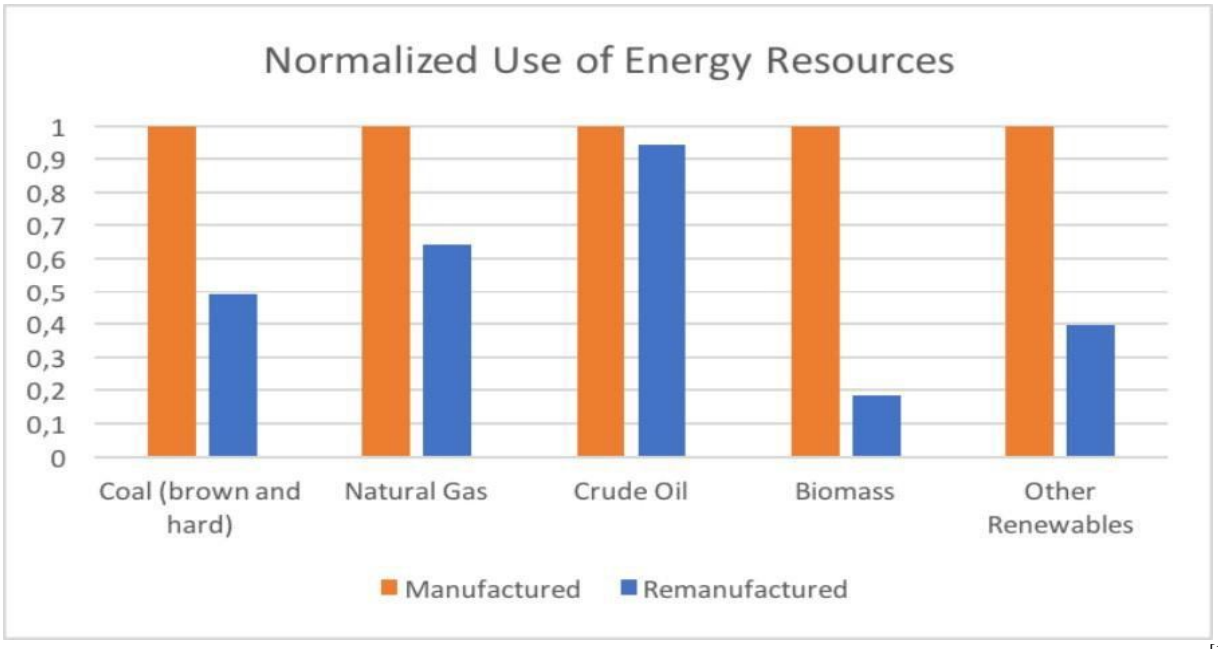


Figure 10 - Use of various energy resources in manufactured and remanufactured over acomplete product life cycle[10]

Lastly, we will study Figure 11 which analyzes the carbon dioxide emissions during the lifetime of the engine, thus illustrating the carbon footprint of the engine. The Global Warming Potential (GWP) is presented in the form of kg CO2- equivalence for 100 years. Use phase in both – remanufactured products and newly manufactured engines contributes to the highest share of emissions. Overall remanufacturing reduces carbon dioxide emissions by 37%.[10]

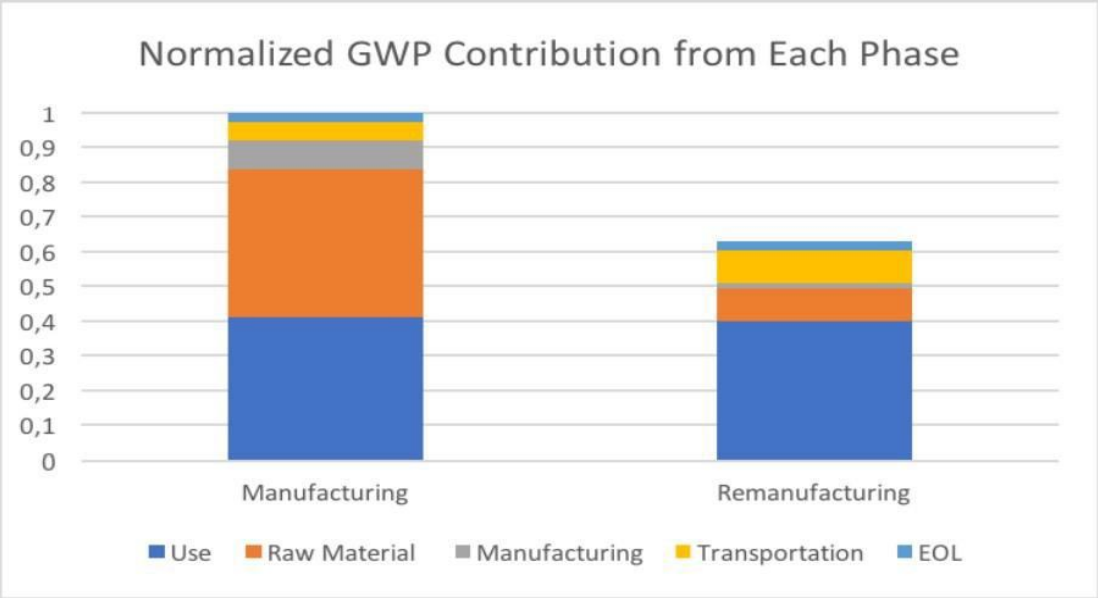


Figure 11 - Normalized Global Warming Potential (GWP) contribution

V. CONCLUSION

The above study was conducted by extensive research on Remanufacturing process and its impact on the environment. As we are aware that an impact can be positive or negative, depending on the process. The study bought attention to the recent developments in the field of Remanufacturing and how it stands as a major foundational pillar for the advancement of Circular Economy and Sustainable development across all the commercial sectors. In this study, it was found that across the globe all the nations are devising the required policy frameworks for the growth of Remanufacturing, wherein European Nations were leading the way. It is estimated by Researchers that around 85% or more of the original energy, material resources, and labor is conserved in remanufacturing. The Aerospace industry offers the highest market size value for Remanufacturing which is estimated to be EUR 15-16 billion in 2021, followed by the Automotive industry with a market size of EUR 9-11.9 billion in 2021.

The case study conducted in the report revealed that Remanufacturing can be practiced with profitable returns on a commercial basis. Remanufacturing industry has the potential to change our economy from linear to circular with the ability to save our depleting resources from exhaustion. It has various positive impacts on societal, economic and environmental levels.

VI. FUTURE SCOPE

With the continuous advancement in the field of Remanufacturing and extensive support from Government policies, Remanufacturing is leading the way in to fight against various major world issues – Global warming, Climate change, and Linear economy.

Remanufacturing can be used in every sector and can be applied to every product be it – plastics, paper, utensils, clothes, furniture etc. Imbibing the concept in every sector needs skilled employees and rigorous Research in various subjects. Prolonging the material life needs extensive research on Life Cycle Analysis (LCA) to ensure that product will work in good condition after Remanufacturing. An extensive supply chain network is essential for Remanufacturing. This establishment can make remanufacturing feasible and viable forming a closed loop between manufacturers and the customer. In a global scenario, Remanufacturing is being extensively studied and implemented across Europe, U.S.A, Japan, and China while India still lacks behind in implementing it. There is an exponential growth in the number of Research papers being published in this domain over the past decade. Organizations are switching toward a sustainable future and eradicating the – use and dump approach. With the shared responsibility of consumers and producers toward the environmental issues, it becomes easier to tackle Global warming and climate change.

REFERENCES

[1] E.R.Venta, A.M. Wolsky – Energy and Labour cost of gasoline engine Remanufacturing (September 1978), U.S Department of Energy and Environmental Systems Division, Vol-I, Argonne National Laboratory, ANL/CNSV-1, pp. 3-8https://doi.org/10.2172/6263358

[2] H.C. Haynesworth, R. Tim Lyons – Remanufacturing by design, the missing link (1987). Production and Inventory Management Journal, pp. 1-14 https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.404.9614&rep=rep1

[3] Zhengyang Zhang, Kazuyo Matsubae, Kenichi Nakajima – Impact of remanufacturing on the reduction of metal loss through life cycles of vehicle engines (July 2021), Journal –Resource, Conservation and Recycling, Volume 170, 105614, Elsevier, pp.4-7 https://doi.org/10.1016/j.resconrec.2021.105614

[4] Julian Kirchher, Denise Reike, Marko Hekkert – Conceptualizing the circular economy: An analysis of 114 definitions (September 2017), Resources, Conservation and Recycling, Vol127, SSRN Electronic Journal, Elsevier, pp. 221-232 https://doi.org/10.1016/j.resconrec.2017.09.005

[5] Winifred L. Ijomah - Addressing decision making for remanufacturing operations and design-for-remanufacture (28 July, 2009), International Journal of Sustainable Engineering,Vol No.2, 2:2, 91-102, pp. 1-5 https://doi.org/10.1080/19397030902953080

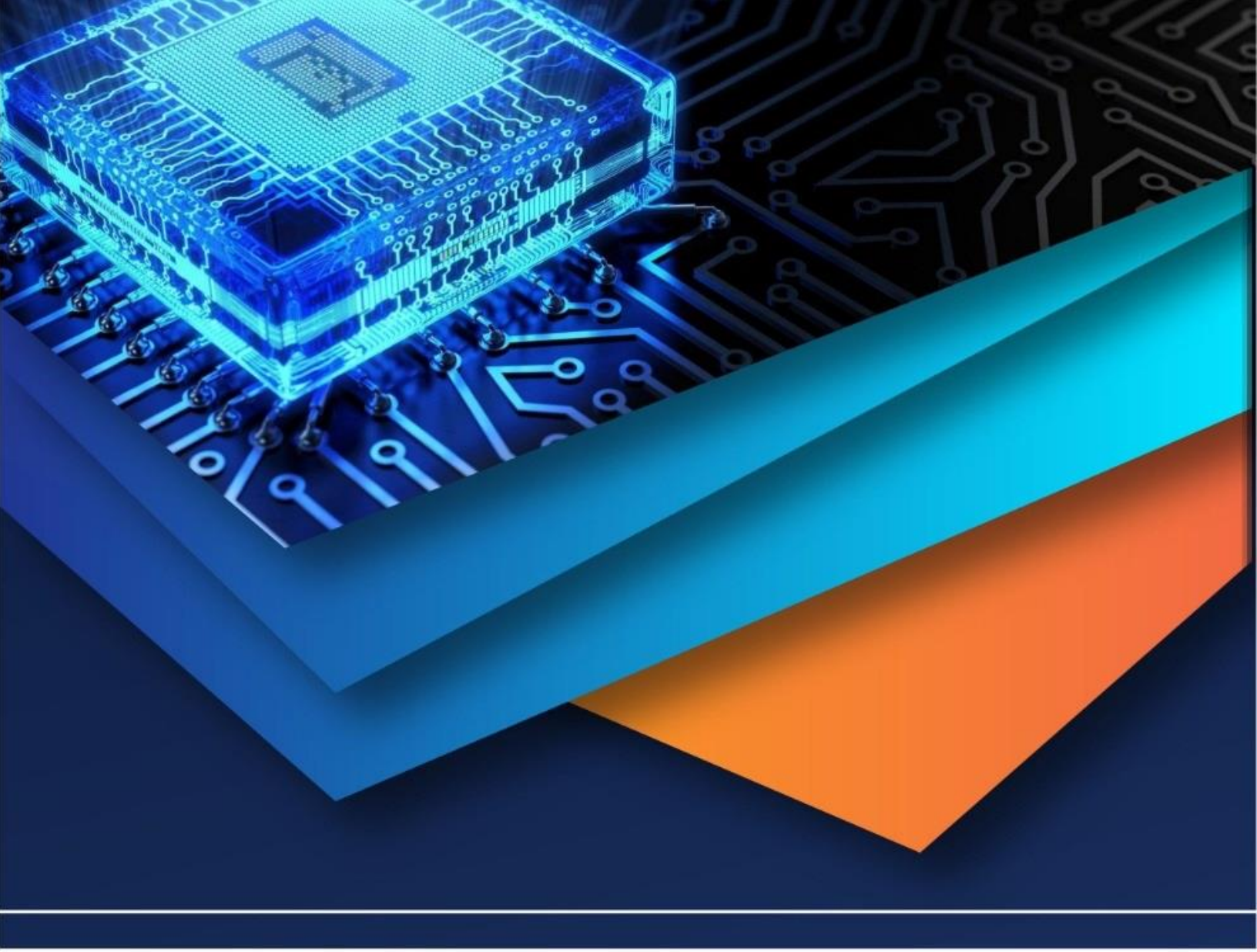
[6] Xueliang Yuana, Mengyue Liua, Qian Yuanb, Xiaohan Fana, Yuqiang Tenga, Junhua Fuc, Qiao Maa, Qingsong Wanga, Jian Zuod – Transitioning China to a circular economy throughremanufacturing: A comprehensive review of the management institutions and policy system(3 May 2020), Resources, Conservation & Recycling, Vol. 161 104920, Elsevier, pp. 1-12 https://doi.org/10.1016/j.resconrec.2020.104920

[7] Steve Statham – Remanufacturing towards a more Sustainable Future(2006), Published in Technology watch by Electronics-enabled Products Knowledge-transfer Network Wolfson School of Mechanical and Manufacturing Engineering, pp. 7-18 https://www.lboro.ac.uk/microsites/mechman/research/ipmktn/pdf/Technology_review/remanufacturing-towards-a-more-sustainable-future.pdf

[8] Mona Arnold, Katariina Palomäki, Kévin Le Blévennec, Carina Koop, Theo Geerken - Contribution of remanufacturing to Circular Economy (December 2021), European Environment Agency: European Topic Centre on Waste and Materials in Green Economy, pp. 7-39

[9] Sharon Prendeville (TU Delft), David Peck (TU Delft), Ruud Balkenende (TU Delft), Emmanuelle Cor (G-SCOP), Kim Jansson (VTT), Iris Karvonen (VTT) – Map of Remanufacturing Product Design Landscape (January 2016), European Union's Horizon, pp.20-25

[10] Pranav Gabhane, Muhamad Kaddoura: Remanufacturing in Circular Economy: A Gearbox Example. A Comparative Life Cycle and Cost Assessment (2017), Department of Technology Management and Economics, Division of environmental System Analysis, Chalmers University of Technology, Report No. 2017:7, pp. 3-35



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