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RESEARCH ARTICLE

LEVERAGING CIRCULAR ECONOMY PRACTICES TO CREATE RESILIENT SUPPLY CHAIN OPERATIONS

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Abstract

The concept of the Circular Economy (CE) is driving a paradigm shift in Supply Chain Management (SCM), moving away from the traditional linear model of "take-make-dispose" toward a more sustainable, resource-efficient framework.

This paper investigates how the integration of CE principles and practices transforms each stage of the supply chain, enhancing operational resilience, reducing costs, and addressing environmental impacts. Through a review of existing principles and practical applications, the study examines key strategies, enablers, and barriers for embedding circularity within SCM processes. Furthermore, it explores emerging opportunities for businesses to deepen their adoption of CE practices through different innovations. The findings underscore that circular supply chains are not only critical for environmental sustainability but also offer substantial economic value, positioning them as a strategic pillar in modern supply chains.

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Introduction:-

In recent years, industries have experienced significant transformation, prompting increased research efforts and strategic investments across key domains that are deemed vital for operational efficiency and sustainability. Among the emerging focal areas are supply chain management and circular economy, both of which are increasingly recognized for their synergistic potential in enhancing industrial performance. Consequently, significant research papers are being published here exploring the intersection and mutual reinforcement of these two fields. Concurrently, academic institutions and research organizations worldwide are responding to this industrial evolution by developing specialized programs and curricula aimed at cultivating expertise, advancing theoretical understanding, and transferring innovative practices and technologies to the industry.

Overview of Supply Chain Management Processes:-

Supply Chain Management (SCM) is a concept that has evolved significantly over the decades. Although the term was first introduced in the 1980s, it was initially perceived primarily from a logistics perspective defined as the movement of goods from the point of origin to the point of consumption (Lambert, 2014). However, by the early twenty-first century, a clear distinction emerged between logistics and SCM, with logistics being recognized as only one component of the broader SCM framework (Lambert, 2014). Since then, SCM has expanded to encompass all activities associated with the flow of products and services, from raw material sourcing through to end-of-life

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management, including reverse logistics. According to the 2024 edition of the Association for Supply Chain Management (ASCM) Supply Chain Dictionary (the eighteenth edition), SCM is defined as “the design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand, and measuring performance globally." This definition emphasizes the integrated nature of modern supply chain practices. The body of academic research on supply chain management (SCM) is extensive, encompassing a wide range of quantitative and qualitative modeling approaches aimed at evaluating key supply chain performance metrics. A fundamental characteristic of SCM is its inherently sequential and interdependent structure, in which the execution of all activities is often based on the timely completion of preceding processes. This introduces potential disruptions in which delays or inefficiencies in one stage of the supply chain can propagate through subsequent stages, generating a cascading effect on the operation requirements.

This highlights the importance of coordinated planning and risk mitigation strategies to prevent minor disturbances from escalating into significant operational disruptions. To improve oversight and responsiveness, certain companies divide their supply chain operations into upstream activities, like production and sourcing, and downstream activities, such as distribution and delivery. This separation enables more targeted and efficient management of the entire supply chain. Importantly, supply chain management is not a stand-alone discipline; rather, it serves as a supporting function that enables operational continuity across various sectors. As such, its conceptualization and practical application vary significantly depending on the industry. For instance, the supply chain strategies and tools applicable to the construction industry differ substantially from those relevant to an oil and gas industry. This necessitates industry-specific adaptations of SCM frameworks to ensure operational effectiveness. Over time, the scope of supply chain management (SCM) has expanded beyond operational efficiency. As Richey et al. (2021) point out, modern SCM increasingly incorporates environmental, stakeholder, and consumer considerations, introducing a shift toward more sustainable and socially responsible practices. In recent years, two key concepts that help evaluate how well supply chain systems perform are responsiveness and resilience. Responsiveness refers to how quickly and effectively a supply chain can adjust to changing and unexpected situations.

Many researchers have explored this concept, offering different viewpoints on how it can be understood and applied. For instance, Gunasekaran et al. (2008) define supply chain responsiveness as the ability to create cost-effective and timely solutions that meet customer needs. At the same time, resilience focuses on a supply chain’s ability to manage unforeseen disruptions, recover smoothly, and improveafter such events. Caniato and Rice (2003) highlight this recovery aspect as essential to resilient supply chains. Gilmore (2010) adds that supply chains flexibility plays a crucial role, both in handling short-term disturbances and in driving long-term strategic enhancements to strengthen the system's overall resilience. Several factors influence the responsiveness and resilience of supply chains, including fluctuations in customer demand, the intensity of market competition, and the structural complexity of supply chain processes (Reichhart & Holweg, 2007). An effective evaluation of supply chain systems must consider the inherent variability in demand and lead times, as these factors significantly impact a company’s operational performance and strategic decision-making. From an operational standpoint, Hopp and Spearman (2004) emphasize the importance of incorporating safety stocks and safety lead times into planning processes to buffer against uncertainties in inventory, capacity, and timing.

This underscores the importance of designing adaptive systems that can quickly adapt to industry changes as required. Ultimately, enhancing responsiveness and resilience directly contributes to customer satisfaction by improving supply chain reliability and overall operational performance. However, it is crucial to recognize that maintaining high inventory levels does not always lead to operational efficiency. In some cases, consolidating material usage and optimizing inventory flows can offer more sustainable and cost-effective alternatives, preventing excess stock accumulation. These considerations are particularly relevant in shaping Material Requirements Planning (MRP) decisions. Overall, researchers have proposed various conceptual and empirical frameworks to assess supply chain management (SCM) performance. For instance, Handfield and Bechtel (2002) developed qualitative models to explore how trust and the strength of buyer–supplier relationships impact the overall effectiveness of SCM. Other studies have highlighted important elements such as recipient satisfaction (Chehbi-Gamoura et al., 2019) and the influence of quality management practices in driving supply chain efficiency and success.

Overview of Circular Economy Principles:-

Circular economy (CE) has been conceptualized in various ways depending on the context, but it is generally viewed as an economic model that seeks to minimize waste and optimize resource utilization by promoting a regenerative system (Joensuu et al., 2020). It is defined as "an economic system intended to minimize waste and maximize the use of resources through a regenerative process achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, recycling, and upcycling. This is the opposite of the linear economy" (ASCM, 2024). Therefore, this concept stands in contrast to the conventional linear economy, which follows a "take, make, dispose" pattern of resource consumption. The circular economy (CE) has emerged as a transformative framework aimed at decoupling economic growth from resource consumption while minimizing environmental impacts. Central to this approach is the concept of closing material loops by maintaining the value of products, components, and materials for as long as possible (Ellen MacArthur Foundation, 2019). Among the tools used to operationalize CE principles are the 10R strategies, which represent a hierarchy of actions to retain product and material value. These strategies range from preventive actions such as refusing and rethinking to restorative activities such as recycling and energy recovery (Potting et al., 2017). Additionally, and at the international level, the International Organization for Standardization (ISO) has introduced ISO 59004:2024, a standard that provides a structured terminology and implementation guidance for CE practices. According to ISO 59004 (2024), the traditional linear economic modelcharacterized by resource extraction, production, use, and eventual disposal contributes to resource depletion and environmental degradation, compromising the ability of future generations to meet their needs. In response, there is a global shift toward a more circular economic model, which emphasizes the sustainable use, renewal, and regeneration of resources to meet present and future societal demands.

ISO 59004 (2024) outlines six interrelated and complementary principles that organizations should consider when transitioning to a circular economy:

1. **Systems Thinking:** Organizations should adopt a lifecycle perspective and long-term planning to understand and mitigate their environmental, social, and economic impacts across all stages of a product or service.
2. **Value Creation:** This principle emphasizes the recovery, retention, or enhancement of value through efficient resource use and the provision of solutions that contribute to both socio-economic and environmental well-being.
3. **Value Sharing:** Organizations are encouraged to equitably distribute the value created along the value chain or network, ensuring inclusive benefits that contribute to societal well-being.
4. **Resource Stewardship:** This involves the sustainable management of resource stocks and flows, including strategies to close, slow, and narrow loops to ensure continued resource availability and reduce dependency on virgin materials.
5. **Resource Traceability:** Organizations must collect and maintain data to track resources throughout their value chains, ensuring transparency and accountability in sharing relevant information with stakeholders.
6. **Ecosystem Resilience:** This principle calls for the development and implementation of strategies that protect and enhance the resilience and biodiversity of ecosystems, including measures to prevent harmful losses and emissions, and to operate within planetary boundaries.

Together, these principles provide a comprehensive roadmap for organizations seeking to transition toward a more sustainable and regenerative economic model, aligning business practices with broader environmental and societal goals.

Paper Objectives and Significance:-

Companies consistently seek to build supply chains that efficiently balance operational demand with warehousing and logistics capacities. A well-structured and resilient supply chain is essential for business success and continuity, making it one of the most crucial components of operational efficiency. Similarly, circular economy has a vital role in shaping key areas in the procurement and supply chain management. Integrating circular economy principles into supply chain operations ensures long-term value creation while minimizing environmental impact. This paper equips supply chain managers with a deeper understanding of this integration with practical strategies for improvement. Additionally, it aims to encourage the development of circular economy models to help mitigate supply chain risks which are essential for effective operations. The paper outlines key intersections here that influence the responsiveness and resilience of the supply chains. It shows how the circular economy influence the various stages of procurement and supply chain management. In addition to that, it highlights the key enablers and obstacles for this implementation. By addressing these questions, the paper contributes to both academic knowledge and practical application in creating more sustainable and responsive supply chains.

Mapping Circular Economy Practices Into Supply Chain Stages:-

Circular Supply Chain is defined as "a type of supply chain that involves the reuse, recycling, refurbishment, and repurposing of used products and/or materials to allow companies to maximize their investments in materials and labor, extend the product life cycle, and reduce their carbon footprint. A circular supply chain differs from a forward supply chain in that it considers two-way movement of materials and products" (ASCM, 2024). Unlike traditional forward supply chains, which follow a linear model of production and consumption, circular supply chains are characterized by a bidirectional flow of materials and products, thereby integrating reverse logistics into the core operational framework. This paper adopts a qualitative methodology to explore the alignment between fundamental circular economy principles and the various stages of the supply chain in order to identify actionable strategies that facilitate the practical implementation, thereby transitioning from theoretical understanding to operational application (Durdyev et al., 2023).

Circular Supply Chain focuses on converting the linear chain of sequential activities of supply chain to circular loops with different ways and mechanisms to help reduce waste and unlock multiple financial, operational, and environmental opportunities. This is presented through five different techniques, namely closing resources loops, slowing resources loops, narrowing resources loops, dematerializing resources loops and intensifying resources loops (Hazen et al., 2021). The concept of those loops lies in giving productsa circular lifecycle with low or no waste at production for all stages in the supply chain. The importance of creating the loops in supply chain systems was proven clearly during supply chain disruption in the Covid-19 pandemic when supply was disrupted for longer periods with no supply.

Closing loop in supply chain is the practice to reuse the materials at the end of product life through recycling, remanufacturing, reusing. In order not jeopardize the operations, products that are returned and looped back to the supply chain should be inspected and examined in a way that will fit into the end user needs.

Slowing loops in supply chain is the practice of prolonging the use of products through lifecycle extensions. This is about shifting procurement mindset from new product sales to post-sales services such as maintaining and repairing products. Accordingly, consumers tend to purchase durable goods with extended life span.

Narrowing loops in supply chain is the practice of increasing resources efficiency via using fewer resources. This is conducted by reducing resource usage and improving efficiency in the production process. Just in Time (JIT) supply chain process is used to increase the efficiency of the supply chain. Digitalization has the potential to significantly narrow loops by giving managers unprecedented ability to respond to customer demand without maintaining excess inventory. Additive manufacturing is another innovation way to narrow loops in the supply chain. However, there is still some uncertainty or lack of clarity for SC managers about the optimum way and timing to implement those technologies.

Dematerializing loops refers to substituting product utility with services and digital solutions. It is a practice of using less to do more effectively and efficiently. It is clearly shown in the packaging industry, offering solutions that are smaller, lighter and thinner but just as effective. Another example of this technique is renting instead of product ownership. Unfortunately, dematerialization is perhaps the most under-researched of the five CE loops discussed here. However, it is in the area of dematerialization that researchers and practitioners can have the biggest impact in realizing a SC designed for CE.

Intensifying loops in supply chain motivates a more intensive product use phase that creates more efficient value. It is applied by conserving and increasing the shared resources usage through operations. In this technique, resources access (who can utilize it) is prioritized over resources ownership (who owns a resource). In turn, this helps to open the underutilized resources to be consumed by others (Hazen et al., 2021).

In both academic research and practical literature, the concept of circular economy material loops is fundamentally associated with systems in which materials are retained at their highest value through reuse, recycling, and other recovery processes, thereby deviating from the traditional linear model of "take-make-waste". A key framework used to operationalize this concept is the 10R'sframework, which outlines a hierarchical set of strategies aimed at maximizing resource efficiency and minimizing waste generation (Morseletto, 2020). As illustrated in Table.1, these strategies include: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and

Recover (Potting et al., 2017; Kirchherr et al., 2017). Those R's are ordered based on their environmental and economic desirability from the most preferred (highest impact in terms of resource conservation) to the least preferred. This hierarchy reflects the idea that preventing resource use and waste generation at the source is more sustainable than dealing with waste after it has been created. Those strategies are numbered in an ascending order from 0 to 9, typically organized into short loops, medium loops, and long loops, depending on how far a product moves from its original value chain (Potting et al., 2017). Short loops keep products close to their original use and they act early in the lifecycle. Medium loops are those strategies for extending the useful life of products and components while longer loops involve deeper processing or even returning materials back to the biological cycle recovering value from waste streams. Together, these strategies facilitate the creation of closed-loop systems, where materials are continuously cycled back into the economy, supporting sustainability and resilience in production and consumption systems.

Table 1: 10 Circular Economy R-Strategies

Loops	R-Strategy		Definition
Short	R0	Refuse	Choosing not to buy, use, or accept unnecessary or environmentally harmful products, packaging, and services to prevent waste and reduce resource consumption at the very beginning of the product lifecycle.
	R1	Rethink	Rethinking how we view products and consumption by focusing on durability, sharing, and service-oriented models instead of ownership. It challenges conventional ways of producing and consuming goods, encouraging designs that support long life, repairability, and reuse.
	R2	Reduce	Minimizing the consumption of resources, the creation of waste, and the use of materials by using less overall. This can involve reducing demand for new products by rethinking our needs, reducing material usage in product design, and lowering the consumption of energy, water, and raw materials throughout the entire life cycle of products.
Medium	R3	Reuse	Using products, components, or materials more than once, either for their original purpose or for a new one, without significant reprocessing or transformation.
	R4	Repair	Fixing broken or damaged products to restore their original function and extend their useful life, rather than discarding them and generating waste.
	R5	Refurbish	Restoring a product to its full functionality and good condition, often by repairing and replacing parts, to extend its life and allow for reuse.
	R6	Remanufacture	Disassembling used products, cleans and inspects them, replaces defective parts, and then reassembles and tests them to meet or exceed the quality and performance standards of a new product, often with a warranty.
	R7	Repurpose	Using a discarded product or its components for a new, different function than the one it was originally designed for, thereby giving it a new life cycle and extending its usefulness.
Long	R8	Recycle	Breaking down products or materials to their basic component level and then remaking them into new products, thereby keeping materials in use and reducing waste.
	R9	Recover	Obtaining energy or other useful materials from waste products that cannot be directly recycled, thus giving them a new purpose and reintroducing them into the economic cycle.

To contextualize the application of the 10Rs, they can be mapped against the five value chains stages, namely: (1) design, (2) material acquisition, (3) production, (4) use and consumption, and (5) end-of-life recovery. This mapping (Table.2) enables organizations to strategically integrate circular practices throughout a product's lifecycle.

Table 2: Mapping R-Strategies to Value Chains

Value Chain	Mapping of 10R Strategies	Example Practices
Design	Refuse (R0), Rethink (R1), Reduce (R2)	Design out waste and pollution through material minimization, product simplification, and innovative business models
Material Acquisition	Reduce (R2), Refuse (R0), Rethink (R1)	Selection of renewable, recycled, or secondary materials to minimize virgin resource extraction.
Production/Manufacturing	Reduce (R2), Repair (R4), Refurbish (R5), Remanufacture (R6)	Process optimization, manufacturing of components for repairability, and incorporation of remanufactured parts.
Use and Consumption	Reuse (R3), Repair (R4), Refurbish (R5), Remanufacture (R6), Repurpose (R7)	Extending product lifetime through repair, refurbishment, repurposing, and reuse in shared economy models
End-of-Life Recovery	Repurpose (R7), Recycle (R8), Recover (R9)	Capturing material and energy value from products at the end of their functional life.

According to NIST (2022), the five stages within a product's lifecycle where circular actions can be applied are:

1. **Design:** Conceptualizing products with circularity in mind, including eco-design principles and business model innovation.
2. **Material Acquisition:** Sourcing and selecting sustainable or secondary materials.
3. **Production/Manufacturing:** Transforming materials into products while minimizing waste and ensuring ease of disassembly.
4. **Use and Consumption:** Utilizing products in ways that maximize lifespan, functionality, and shared value.
5. **End-of-Life Recovery:** Capturing value from products that are no longer usable through recycling or energy recovery.

This mapping demonstrates that the initial phases of a product's lifecycle, particularly design and material sourcing, are primarily governed by preventive strategies such as Refuse, Rethink, and Reduce. These interventions are considered the most effective in circular economy practices, as they aim to eliminate waste at its origin (Ellen MacArthur Foundation, 2019). Intermediate loops emphasize value retention through product life extension techniques, such as Repair and Refurbish, which necessitate coordinated efforts among consumers, manufacturers, and service providers (Potting et al., 2017). In contrast, extended loops, including Recycling and Recover, are typically employed as final-stage solutions when higher-priority strategies are no longer viable. By aligning the 10R hierarchy with distinct stages of the product lifecycle, this framework offers a structured and actionable pathway for industries seeking to adopt circular economy principles. Companies can incorporate modular design principles (Rethink), utilize secondary materials in production (Recycle), and establish regulatory frameworks that support end-of-life material recovery and energy extraction (Recover). Such integration facilitates a systemic shift toward sustainability by embedding circular strategies into both operational and strategic decision-making processes.

For instance, several circular practices that are recommended to be embedded into the design of the firm's supply chain and this helps to mitigate the supply chain disruption such as:

1. Product life extension
2. Remanufacturing
3. Refurbishing
4. Reuse
5. Reverse logistics
6. Waste recycling
7. Take-back programs
8. Modularity design programs
9. Circular procurement
10. Shared use
11. Digital twins for circular design
12. Optimum transportation solutions
13. Innovative solutions to supply spare parts
14. Innovative solution to manage waste

15. Circular economy awareness programs for supply chain employees

Various performance metrics are employed to assess the effectiveness of circular supply chains (Almelhem et al., 2025), providing insights into resource efficiency, environmental impact, and sustainability outcomes. These indicators help organizations track progress toward circular economy goals and identify areas for improvement.

Key metrics include:

1. **Material Circularity Indicator (MCI):** This metric evaluates the extent to which a material remains within a closed-loop system throughout its lifecycle, including its recovery and reintroduction into the supply chain after end-of-life use.
2. **Recycling Rate:** This measures the proportion of materials that are successfully recovered and reprocessed into new products, reflecting the efficiency and effectiveness of recycling systems within the supply chain.
3. **Product Lifetime Indicator**: This assesses the average duration a product remains functional before becoming obsolete. Factors such as durability, reparability, and potential for upgrades are considered, as they contribute to minimizing the frequency of replacements (Kühl et al., 2020).
4. **Lifecycle Greenhouse Gas (GHG) Emissions:** This metric quantifies the total emissions of greenhouse gases associated with a product throughout its entire lifecycle from raw material extraction and manufacturing to transportation, use, and end-of-life disposal.
5. **Energy Use Intensity:** This measures the amount of energy consumed per unit of output or per unit of economic value generated. It helps identify opportunities to improve energy efficiency and reduce environmental impacts across the supply chain.

These metrics collectively support the transition toward a more sustainable and resource-efficient supply chain model by enabling data-driven decision-making and performance tracking.

Enablers And Barriers To Circular Economy Integration With Supply Chain:-

The transition toward a circular economy (CE) within supply chain systems is influenced by a variety of enablers and barriers. One key enabler is the development of strong supplier relationships, which can enhance reverse logistics and support circular practices such as recycling, refurbishment, and remanufacturing. In addition to that, the successful implementation of circular supply chain processes also depends on consumer acceptance and demand. End consumers play a critical role in ensuring that circular products meet operational standards related to quality, availability, and responsiveness to urgent needs. Public awareness campaigns and educational initiatives are necessary to build understanding and acceptance of CE principles among end users. In parallel, the modern supply chain environment increasingly relies on data-driven decision-making (supply chain digital twins) to enhance efficiency and sustainability. As highlighted by Awaysheh (2020), supply chain analytics can be categorized into three main types: **Descriptive Analytics** which provides insights into past performance, **Predictive Analytics** which leverages historical data to forecast future trends, and **Prescriptive Analytics** which utilizes advanced technologies such as Machine Learning (ML) and Artificial Intelligence (AI) to recommend optimal decisions. These analytical tools are instrumental in supporting strategic and operational decisions across all stages of the supply chain, from product design and sourcing to usage and end-of-life management. By integrating data analytics with circular economy strategies, organizations can better navigate the complexities of sustainable supply chain transformation.

Research indicates that a big-data-driven supply chain serves as a moderating factor in the relationship between circular economy and overall firm performance within a circular supply chain context (Del Giudice et al., 2021). In other words, the integration of big data analytics enhances the impact of business practices aligned with circular economy principles. By enabling more informed decision-making, optimizing resource use, and improving coordination across circular processes, big data analytics strengthens the operational effectiveness. This highlights the importance of aligning digital capabilities with supply chain management to support sustainable operations. On the other hand, this integration is facing multiple barriers to implement in the actual operations. Those barriers include consumer behavior and perceptions (Hazen et al., 2021.). Moreover, the concept of a "green premium" where consumers should pay more for sustainable options. Financial constraints play a role here as transitioning to a circular economy often requires upfront investments in new technologies, processes, or infrastructure. Therefore, fostering a change in consumer perception and behavior is essential to drive the adoption of circular supply chains. In most cases, consumers tend to purchase new materials instead of thinking about restoring the used ones. This is due to the lack of awareness and understanding of circular economy principles among stakeholders.

Conclusions:-

The integration of circular economy (CE) principles into supply chain management presents a transformative opportunity for industries, particularly in sectors such as oil and gas, where sustainability and operational efficiency are increasingly critical. This paper has explored the alignment between CE strategies and supply chain stages, highlighting how circular practices such as product life extension, remanufacturing, reuse, and reverse logistics can enhance resource efficiency, reduce environmental impact, and build resilience in supply chain systems. A key insight from this analysis is that CE integration does not merely represent an environmental imperative but also delivers substantial economic and operational benefits. By adopting strategies such as closing, slowing, and narrowing resource loops, organizations can minimize waste, optimize material use, and reduce dependency on virgin resources. The application of the 10R framework across the product lifecycle provides a structured approach to embedding circularity at every stage from design to end-of-life recovery. Moreover, the study has demonstrated that digital technologies, particularly data analytics including supply chain digital twins, serve as critical enablers in implementing and scaling CE practices. These tools facilitate predictive and prescriptive decision-making, allowing organizations to manage complex circular flows and improve transparency across the supply chain. Additionally, strong supplier relationships and consumer engagement play a pivotal role in ensuring the success of circular initiatives, as collaborative ecosystems and informed demand are essential for sustaining circular value chains. However, the paper also reveals that the path to full CE integration is not without challenges. Barriers such as consumer behavior, financial constraints, lack of awareness, and misaligned regulatory frameworks hinder the adoption and scalability of circular practices. Addressing these challenges requires a multi-stakeholder approach involving industry leaders and policymakers, and consumers. Ultimately, this paper highlights the importance of strategic alignment between supply chain management and circular economy principles to drive long-term sustainability and resilience.

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