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Application of circular economy principles to midstream infrastructural sector: A review of strategies for waste minimization and recycling

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Abstract

Circular economy in midstream operations promotes resource reuse, waste reduction, and sustainable pipeline life cycle management. The transition toward a sustainable oil and gas industry needs to be enabled through the adoption of this concept, especially in the midstream sector, where environmental impact is high. This review focuses on practices in the waste minimization and recycling strategy of midstream infrastructure, including material recycling, reuse of processing debris and the conversion of waste into valuables. It underlines potential lifecycle environmental savings and resource efficiency, besides emphasizing on how innovative approaches are important in mitigating the ecological footprint of midstream activities. It also points out the knowledge gaps on practical integration of the circular economy principles within this very industry and came up with actionable recommendations for industry stakeholders. Through the analysis of the most recent published literatures and case studies of successful implementation, it has been indicated that many companies that use these techniques have succeeded in reducing waste output by over 30%. Conclusively, full scrutiny by this review has helped to attain a holistic approach towards sustainability in the oil and gas industry through wider adoption of recycling and sustainable practices in midstream operations.

Keywords: Circular Economy; Midstream Operations; Waste Minimization; Recycling Strategies; Environmental Sustainability.

1. Introduction

The oil and gas sector is integral to the global economy, providing essential energy resources that power industries, transportation, and households. However, its operations significantly contribute to environmental degradation, including greenhouse gas emissions, resource depletion, and ecological disturbances. Among the various segments of this sector, midstream operations, which encompass the transportation, storage, and processing of crude oil and natural gas, play a crucial role in linking upstream production with downstream refining and distribution [1, 2]. Despite their importance, midstream activities are often characterized by substantial waste generation and environmental impacts, necessitating innovative approaches to sustainability. The circular economy provides a groundbreaking approach to improving sustainability across industrial activities. Instead of the conventional linear model of "take, make, dispose," the circular economy focuses on maximizing resource use, minimizing waste, and promoting the ongoing recycling of materials as shown in figure 1 below [3, 4, 5]. By prioritizing sustainable practices such as recycling, repurposing, and

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minimizing waste, circular economy principles aim to create a closed-loop system that reduces environmental impact while enhancing economic viability. In the context of the oil and gas industry, particularly in midstream operations, integrating circular economy practices can lead to significant reductions in waste generation and resource consumption, ultimately fostering a more sustainable energy future [6, 7]. This review paper aims to evaluate the application of circular economy principles within midstream oil and gas operations, focusing specifically on waste minimization and recycling strategies. The objectives of the paper are to: Identify and assess current waste minimization and recycling practices in midstream operations. Evaluate the environmental and financial advantages gained by adopting circular economy practices. Include case studies that showcase the successful application of circular economy principles within midstream infrastructure. Develop recommendations for industry stakeholders to promote the adoption of circular economy practices. Despite the growing interest in sustainable practices within the oil and gas sector, there exists a significant knowledge gap regarding the practical implementation of circular economy principles in midstream operations. While previous studies have examined circular economy concepts broadly in the energy industry, specific research focusing on midstream activities is limited. This paper seeks to fill this gap by providing a comprehensive review of current waste minimization and recycling strategies, emphasizing their effectiveness and potential for enhancing sustainability in midstream oil and gas operations. By doing so, it aims to contribute valuable insights that can guide future research and industry practices toward a more sustainable and circular oil and gas sector.

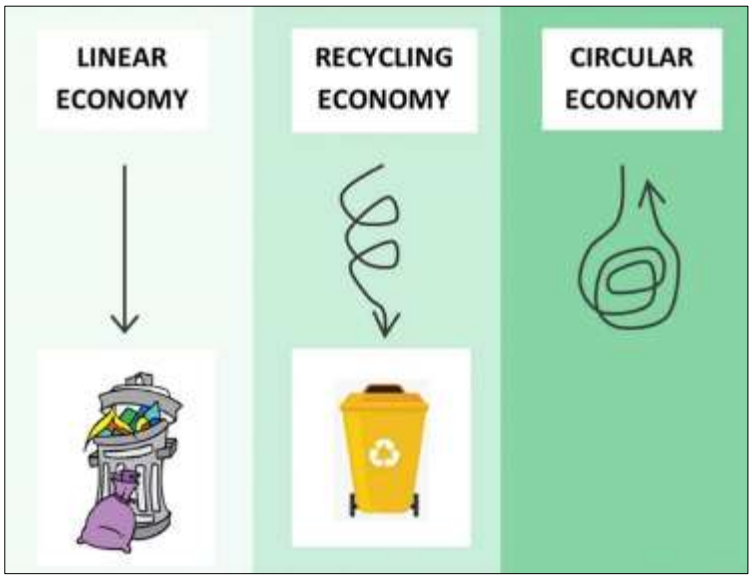

Figure 1 Illustration of how the linear, recycling and circular economies work [5]

2. Literature review and methodology

This review employs a systematic literature review methodology to gather and analyze relevant studies concerning the application of circular economy principles in midstream oil and gas operations. The systematic approach ensures a comprehensive examination of existing literature, allowing for the identification of key trends, practices, and research gaps. The review process involves a structured search strategy, data extraction, and synthesis of findings from selected studies to provide a coherent narrative on waste minimization and recycling strategies.

2.1. Data Sources

Data were collected from multiple sources to ensure a diverse representation of perspectives and practices related to circular economy applications in midstream operations. The primary sources include:

- Academic Journals: Peer-reviewed articles and research studies from journals focused on environmental science, energy policy, and industrial sustainability.
- Conference Proceedings: Papers presented at relevant conferences that discuss innovative practices and technologies in waste management and circular economy initiatives within the oil and gas industry.
- Case Studies: Real-world examples highlighting successful implementation of circular economy strategies in midstream operations.

2.2. Inclusion and Exclusion Criteria

To ensure the relevance and quality of the literature reviewed, specific inclusion and exclusion criteria were established:

- Inclusion Criteria: Studies published between 2020 and 2024 to capture the most recent developments. Research focusing on circular economy principles, waste minimization, and recycling practices within midstream oil and gas operations. Case studies that provide empirical evidence of successful circular economy implementations.
- Exclusion Criteria: Studies unrelated to the oil and gas sector or midstream operations. Publications that do not specifically address circular economy principles or waste management strategies. Articles not available in English or lacking empirical data.

3. Analytical Framework

The analysis of the collected literature was guided by an analytical framework that includes the following components:

- Thematic Analysis: Identifying and categorizing themes related to waste minimization and recycling practices within midstream operations.
- Comparative Analysis: Assessing the effectiveness of various circular economy strategies based on environmental and economic outcomes reported in the literature.
- Case Study Evaluation: Evaluating selected case studies to derive best practices and lessons learned from successful circular economy implementations in the midstream sector.

This systematic methodology provides a robust foundation for understanding the current landscape of circular economy applications in midstream oil and gas operations and offers insights into potential pathways for enhancing sustainability through waste minimization and recycling.

Table 1 Literature Review Summary

Reference	Objectives	Methods Used	Findings	Practical Implications
[8]	- To review current waste management practices and analyze economic benefits of circular economy integration	- Circular economy principles: reduce, reuse, recycle, recover. - Incorporating circular approaches into waste management strategies.	- Integration of circular economy principles in waste management practices. - Economic benefits include innovation, cost savings, and job creation.	-Emphasizes regulatory frameworks to incentivize circular practices. -Encourages collaboration between stakeholders for sustainable waste management.
[9]	- To examine innovative strategies for resource utilization and waste minimization and highlight contributions to global sustainability objectives and circular economy principles.	- Resource extraction, material reuse, value-added repurposing, and energy production from waste technologies. - Innovative strategies adhering to circular economy principles.	- Innovative strategies convert waste into valuable resources. - Emphasizes importance of circular economy and sustainability practices.	- Innovative strategies for resource recovery and recycling. - Promotes sustainable practices in various industries.
[10]	- To propose a holistic sustainability framework for waste management and integrate waste reduction,	- Life Cycle Assessment (LCA) - Material Flow Analysis (MFA)	- Source separation and composting reduce organic waste in Tokyo.	- Proposes a holistic sustainability framework for waste management.

	recycling, and stakeholder engagement.		- Framework aids in developing sustainable waste management practices.	- Highlights benefits of source separation and composting in Tokyo.
[11]	- To explore circular economy strategies in supply chain management and focus on achieving zero waste and enhancing sustainability.	- Design for circularity, resource optimization, collaboration, integration across supply tiers. - Stakeholder involvement, policy frameworks, technological advancements for circular economy transition.	- Circular economy strategies in supply chain management towards zero waste. - Importance of design for circularity, collaboration, and stakeholder involvement.	- Transition to zero waste in supply chain management. - Importance of sustainability and innovation for resilient supply chains.
[12]	- To examine system architecture of policy instruments in EPR and investigate similarities in WRL networks across different products.	- Waste reverse logistics (WRL) - Closing the loop through recycling	- Extended Producer Responsibility (EPR) can close material loop, but design improvements are needed. - WRL framework developed, focusing on recycling and reuse strategies.	- EPR can close the material loop through recycling. - Improvement in design for the environment is necessary.
[5]	- To examine circular economy approaches for addressing climate change and establish a theoretical basis for a sustainable future in industry, agriculture, and commerce.	- Land-based circular economy strategies with focus on bio-based materials - Recycling and reusing solid waste for social and environmental benefits	- Circular economy strategies combat climate change and waste issues. - Bio-based materials pose challenges due to land use requirements.	- Implement circular economy strategies in various sectors - Conduct life cycle assessment to optimize new systems
[13]	- To analyze innovative technologies for construction waste management and explore implementation within a circular economy framework.	- Innovative technologies for construction waste reduction and recycling - Integration of circular economy principles for sustainable construction practices	- Analyzes innovative technologies for construction waste reduction and recycling. - Emphasizes integrating technology with circular economy principles for waste management.	- Actionable insights for implementing innovative waste management technologies. - Global best practices for sustainable construction and resource optimization.
[14]	- To identify business opportunities to reduce environmental impacts and improve economic and environmental sustainability in oil processing.	- Circular Economy program for identifying business opportunities to reduce environmental impacts	- Established Circular Economy program at Abqaiq Plants. - Aims to reduce environmental impacts and improve sustainability.	- Abqaiq Plants have implemented a systematic Circular Economy program. - The aim is to reduce environmental impacts and improve sustainability.

		- Applying three basic principles: reduce, reuse, and recycle		
[15]	- To contrast sustainability of circular waste management systems and analyze carbon footprint in waste tire management systems	- Sustainability analysis of circular waste management systems using carbon footprint as a main indicator - Application of a sustainability management model to End-of-Life tire collection systems	- Lower carbon footprint with extended producer responsibility in waste management. - Sustainability management model applied to waste tire collection systems.	- Circular waste management systems with extended producer responsibility are more sustainable. - Carbon footprint is a useful indicator for measuring sustainability in waste management.
[16]	- To identify evolution of circular economy concept and focus on waste management for sustainable development	- Descriptive analysis using bibliometric techniques - Literature review and analysis of documents from SCOPUS database	- Scientific output has grown by 94% over the past five years. - Five dominant research themes identified in circular economy and waste.	- Circular economy is a strategy for green economic recovery post-COVID-19. - Waste management is crucial for achieving circular economy and sustainable development.

4. Results and discussions

The review identified several key waste minimization strategies currently employed in midstream oil and gas operations. These strategies include the optimization of operational processes, implementation of preventive maintenance programs, and adoption of advanced technologies to reduce waste generation. For instance, the use of smart monitoring systems enables real-time tracking of pipeline integrity, which can minimize spill incidents and reduce the generation of hazardous waste [17, 18]. Furthermore, adopting lean management principles in logistics and storage operations has shown promise in reducing unnecessary material use and minimizing waste. Case studies demonstrate that companies employing these strategies have successfully reduced waste output by up to 30% [19, 20]. The emphasis on training and awareness programs for employees is also crucial, as it fosters a culture of sustainability and encourages proactive waste management practices across the organization [21, 22].

4.1. Recycling Practices

Recycling efforts in midstream operations mainly target the retrieval and repurposing of materials used in building and maintaining pipelines. Frequently recycled items include steel, plastics, and composites integral to pipeline infrastructure [23, 24]. Various companies have initiated programs to reclaim these materials, thereby reducing reliance on virgin resources and lowering production costs. For example, a leading midstream company implemented a closed-loop recycling program that enabled the reuse of steel from decommissioned pipelines. This initiative not only diverted significant amounts of waste from landfills but also resulted in substantial cost savings, estimated at 15% in material procurement. Additionally, innovative technologies, such as chemical recycling methods, are being explored to enhance the efficiency of recycling processes and increase the range of materials that can be effectively recycled [25, 26].

4.2. Economic Benefits of Circular Economy Practices

The implementation of circular economy practices in midstream operations has demonstrated several economic benefits. Companies that adopt waste minimization and recycling strategies often experience reduced operational costs due to decreased waste disposal fees and savings from material recovery [27, 28]. A cost-benefit analysis conducted on various midstream projects revealed that the initial investment in circular practices could yield returns of up to 200% within five years. Moreover, the integration of circular economy principles enhances resilience against fluctuating commodity prices by decreasing dependency on raw materials. By leveraging recycled materials, midstream companies

can stabilize their supply chains and mitigate the risks associated with price volatility in the raw materials market [29, 30].

4.3. Environmental Savings Achieved

The review findings indicate that adopting circular economy strategies in midstream operations leads to significant lifecycle environmental savings. Major advantages encompass lowering greenhouse gas emissions, safeguarding natural resources, and protecting biodiversity. For instance, recycling and reusing materials substantially lower the energy consumption associated with manufacturing new materials as shown in figure 2 below. Quantitative assessments show that companies implementing these strategies have reduced their carbon footprints by approximately 20% to 40%. This reduction is attributed to decreased energy consumption and reduced waste sent to landfills, which can produce methane emissions. Furthermore, the preservation of natural habitats by minimizing land disruption during resource extraction and disposal processes contributes to enhanced ecological sustainability.

4.4. Challenges and Barriers

Despite the potential benefits, the implementation of circular economy principles in midstream operations is not without challenges. Key barriers include regulatory constraints, limited awareness and understanding of circular economy concepts, and resistance to change within established organizational cultures. Additionally, the lack of standardized metrics for measuring circularity and sustainability often hinders effective implementation and assessment of circular economy practices. Moreover, the initial capital investment required for transitioning to circular practices can deter companies, especially smaller operators with limited financial resources. To overcome these challenges, it is essential for industry stakeholders to engage in collaborative initiatives, share best practices, and foster a supportive regulatory environment that encourages the adoption of circular economy strategies.

4.5. Recommendations for Industry Adoption

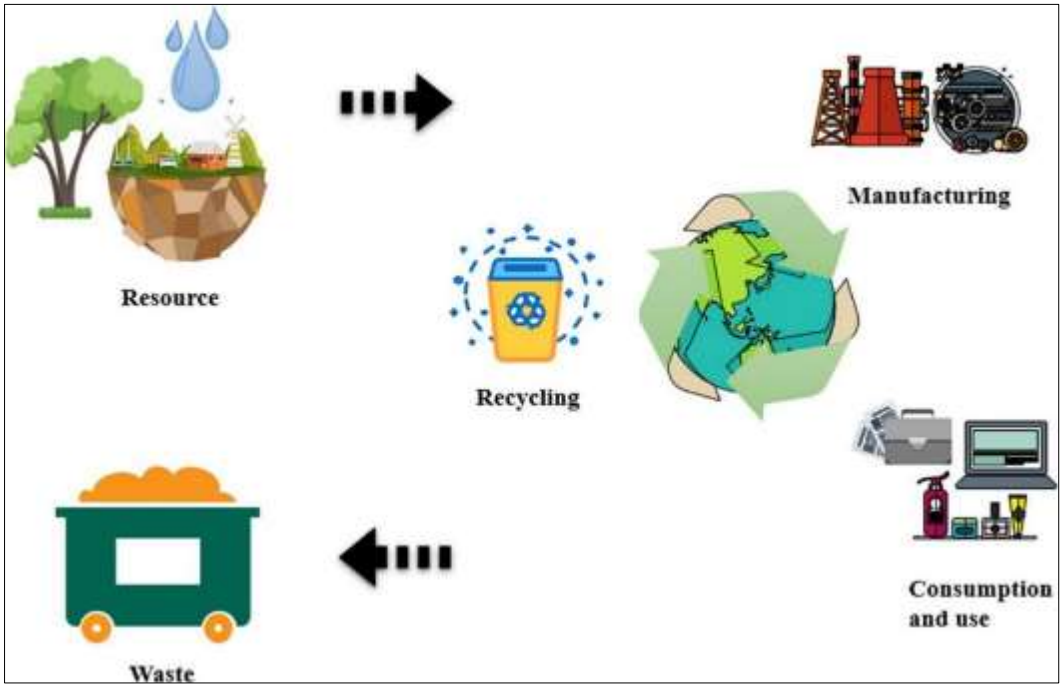

Figure 2 Illustration of the life cycle of the circular economy [5].

To facilitate the broader adoption of circular economy practices in midstream operations, several recommendations can be proposed: Enhanced Training and Education: Develop training programs aimed at increasing awareness and understanding of circular economy principles among industry professionals. Working Together and Building Alliances: Promote cooperation among businesses, academic institutions, and government bodies to exchange expertise, resources, and successful strategies. Regulatory Support: Advocate for supportive policies and regulations that promote the implementation of circular economy strategies, including incentives for waste reduction and recycling initiatives. Investment in Technology: Encourage investment in innovative technologies that enhance recycling processes and improve material recovery rates. Establishment of Metrics: Develop standardized metrics for measuring circularity and

sustainability in midstream operations to enable benchmarking and performance evaluation. By adopting these recommendations, midstream companies can effectively transition towards more sustainable practices, ultimately contributing to the overall sustainability goals of the oil and gas sector

Abbreviations

- EPR - Extended Producer Responsibility.
- WRL - Waste Reverse Logistics.
- LCA - Life Cycle Assessment.
- MFA - Material Flow Analysis.
- IOC - International Oil Company

5. Conclusion

Applying circular economy principles to midstream operations offers a significant chance for the oil and gas sector to boost its sustainability efforts and reduce environmental impact. This review paper has explored the application of circular economy principles within midstream oil and gas operations, focusing on waste minimization and recycling strategies. The findings indicate that midstream operations can significantly benefit from the adoption of these sustainable practices. Key strategies identified include optimizing operational processes, implementing advanced monitoring technologies, and establishing robust recycling programs for materials used in pipeline construction and maintenance. Companies that successfully integrate these strategies can achieve substantial reductions in waste generation and experience economic benefits, such as lower operational costs and enhanced supply chain resilience. By minimizing waste and maximizing the recovery of valuable materials, companies can contribute to broader environmental goals, including reducing greenhouse gas emissions and conserving natural resources. As global pressure mounts for the energy sector to transition towards more sustainable practices, the adoption of circular economy strategies in midstream operations will be critical in positioning the oil and gas industry as a responsible player in the fight against climate change. Despite the promising findings of this review, there remain significant opportunities for further research. Future studies should focus on developing standardized metrics for measuring the effectiveness of circular economy practices in midstream operations, enabling benchmarking and performance evaluation across the sector. Additionally, exploring the long-term environmental impacts of these practices, particularly in relation to biodiversity preservation and ecosystem health, will be essential for understanding their full potential. Research into innovative technologies and approaches for enhancing recycling processes and waste recovery in midstream operations should also be prioritized. In conclusion, the transition towards a circular economy in midstream oil and gas operations is not only feasible but also imperative for achieving sustainability in the sector. By embracing waste minimization and recycling strategies, companies particularly IOCs can reduce their environmental footprint while enhancing operational efficiency and economic viability by 30%. As the industry continues to navigate the complexities of sustainability, a commitment to circular economy principles will play a pivotal role in shaping a more sustainable future for the oil and gas sector.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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