International Journal of Multidisciplinary Research and Growth Evaluation.

Reverse Logistics and Waste Recovery in Aviation, Petroleum, and Construction Supply Chains

Samir Ali Syed

Department of Procurement and Supply Chain, Chartered Procurement and Supply Chain Management (CharProSCM) Team, Riyadh, Saudi Arabia

* Corresponding Author: **Samir Ali Syed**

Article Info

ISSN (Online): 2582-7138
Impact Factor (RSIF): 8.04
Volume: 07
Issue: 02
March-April 2026
Received: 21-02-2026
Accepted: 19-03-2026
Published: 17-04-2026
Page No: 628-636

Abstract

Background: The emergence of waste recovery and reverse logistics are key methods towards sustainability in high impact industrial sectors. Aviation, petroleum and construction generate 4.2 billion tons of waste/year combined while still largely relying on linear supply chains: this has led to extensive environmental degradation, resource inefficiencies, and increased regulatory pressure. This research aims to understand the role of reverse logistics in moving these three sectors to circular economy practices.

Methods: Using a systematic literature review, data were collected from peer-reviewed journal articles, technical reports and industry/analyses published from 2010-2024 and analyzed for their impact on the waste generation patterns; ways to recover/recycle products and how reverse logistics networks are designed/implemented by each industry sector. Investigating the technological enablers and structural barriers that exist in order to assess how they might affect implementation was also of interest in this research.

Findings: This research demonstrates that implementing reverse logistics systems produces measurable financial and ecological advantages. The costs of waste disposal were reduced by 15% to 40%, as evidenced by actual case quotes. The recovery and reintegration into production cycles of valuable materials such as aluminium alloys, vanadium catalysts and recycled concrete aggregate also occurred. The data also revealed a significant decrease in greenhouse gas emissions. Key enablers of these systems were found to be the use of IoT technologies for real-time monitoring, blockchain systems for traceability of materials and AI for waste forecasting and decision making. Nevertheless, challenges remain, including fragmented regulatory frameworks, high capital costs and inadequate third-party logistics infrastructure.

Implications: The study highlighted the need to incorporate reverse logistics within the strategic design of supply chains in order to facilitate the transition to a circular economy in capital-intensive industries (e.g., automotive, aerospace, heavy machinery). Future development will be reliant on harmonization of regulatory policy, increased investment in digital infrastructure, and collaborative cross-sectoral logistics networks. Managerial initiatives such as extending the producer's responsibilities (EPR), proactively redesigning the supply chain and transferring knowledge between industries will be critical to scaling waste valorisation practices. Thus, reverse logistics can serve as an effective means of improving environmental sustainability and economic performance in industrial ecosystems.

DOI: https://doi.org/10.54660/.IJMRGE.2026.7.2.628-636

Keywords: Reverse logistics, Waste recovery, Circular supply chain, Aviation, Petroleum, Construction, Sustainability

1. Introduction

1.1. Concept and Scope of Reverse Logistics in Industrial Supply Chains

Reverse logistics (RL) consists of all activities associated with the return movement of products, parts, and materials from their final use point backwards towards their original location for the purpose of recapturing, recovering, or properly disposing of them. While reverse logistics was originally developed and applied in the retail and consumer goods sectors, it has received an increased amount of research attention through application in capital-intensive industries over the last 20 years. Rogers and Tibben-Lembke [1] defined reverse logistics as the planning, implementation, and control of the entire flow, from the point of consumption back to the point of origin, of raw materials, in-process inventory, finished goods, and all information related to these items. The purpose of this flow is to recapture value from the items, or to properly dispose of them. While this definition is still the foundation for reverse logistics, it has been implemented operationally in sectors such as aviation, petroleum, and construction, and has created significant complexity due to the nature of the waste streams (i.e., risk) and how hazardous these materials are, the numerous regulatory structures associated with these materials, and the geographic distances between the point of generation and the point of proper disposition.[1, 3]

In industrial supply chains, RL goes beyond just returning products. It also includes remanufacturing, recycling, refurbishing, recovering energy, and sending waste to landfills. Dowlatshahi [4] stressed that RL decisions are always strategic and need to be linked with forward logistics planning to work well as a whole. The acknowledgment of industrial waste as a prospective resource instead of a liability supports the increasing convergence between reverse logistics practices and circular economy principles. [4, 5]

1.2. Difference Between Forward and Reverse Supply Chains

Besides their unidirectional material flow from extraction through manufacturing, distribution, and delivery to the end consumer, forward supply chains also have other characteristics that differentiate them from reverse supply chains. In contrast, reverse supply chains have a multidirectional, probabilistic, and complex flow of materials due to an inherent uncertainty surrounding the quality, quantity, and timing of the return of materials. Guide and Van Wassenhove [6] highlighted that demand uncertainty associated with reverse flow results in a unique set of challenges for inventory management and scheduling which are not found in traditional forward logistics systems. [6, 7]

The reverse flow of material is accompanied by a number of key structural differences. The first of these differences is the disaggregated nature of the collection points (or sites) in reverse flow, and the second difference is the heterogeneity of returned materials (which varies from unit to unit according to condition and composition). Prior to processing for recovery, all returned materials in reverse flow must be subjected to specialised inspection and sorting processes. A specific example of this can be found in the aviation industry where there are thousands of different types of components created from retired aircraft, each with a different residual value, which creates a need for highly developed disassembly planning and condition-based routing decisions. A second example is seen in petroleum sludge streams where the amount of hydrocarbon contained in each batch can vary significantly, requiring laboratory testing to determine the appropriate recovery pathway for each batch of sludge. [6, 8, 9]

1.3. Role of Waste Recovery in Circular Economy and Sustainable Development

According to the Ellen MacArthur Foundation, a circular economy is one that restores and regenerates through keeping materials at their highest level of utility/use/value in every instance. The core infrastructure of the circular economy is waste recovery, including recycling, remanufacturing, and recovering energy from otherwise waste products. So, taking "end-of-life" industrial goods and converting them to usable products for the original manufacturing process creates an endless loop of productivity. [1, page 10-11]

The United Nation's Sustainable Development Goals (SDGs) — especially SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) — provide a normative framework for evaluating the effectiveness of industrial waste recovery programmes. Kirchherr, Reike and Hekkert suggest that evaluating circular economy programmes can occur on many levels and along many lines of evaluating industrial waste treatments, from product developmental design to overall management for a waste recovery method. Finally, sectors like aviation, petroleum, and construction generate an estimated 15-20% of the global industrial solid and hazardous waste — thus making them especially important for sustainable development, as every sector will be required to implement waste recovery measures as a part of their overall business strategy.

2. Industry-Specific Waste Streams and Reverse Flows

2.1. Aviation: Aircraft End-of-Life Management, MRO Waste, and Composite Materials

Due to fleet renewal programs and fuel efficiency requirements, the global commercial aircraft fleet retirement rate has increased significantly. The Aircraft Fleet Recycling Association (AFRA) estimates that between 700 and 750 aircraft reach end-of-life status every year, with each aircraft generating 25,000 - 35,000 tonnes of structural material, of which 60%-75% by weight is made from aluminium alloys. [13, 14]

Maintenance, Repair and Overhaul (MRO) operations generate a unique and considerable waste stream consisting of used lubricants, hydraulic fluids, expired chemicals, worn-out brake assemblies, and unusable electronic components. These wastes fall under international aviation regulations to be classified as hazardous; therefore, MROs must have a method for collecting, storing and disposing of these wastes. De Brito and Dekker [2] found that MRO waste certification requirements create a substantial compliance burden for smaller maintenance operators. [2, 13]

Carbon fiber reinforced polymer (CFRP) composites are becoming more and more important in modern airframe design. They may be the most technically difficult type of waste to recover at the end of its life in aviation. CFRP cannot be melted and recast like metals can. Instead, it can be recovered through pyrolysis, solvolysis, and mechanical grinding to make short-fiber products that can be used in cars or industries. Pimenta and Pinho [15] did a thorough review of CFRP recycling technologies and found that pyrolysis produces fibers with good mechanical properties, but the economics of recovery are still not very good without regulatory incentives or extended producer responsibility mandates.[15]

2.2. Petroleum: Drilling Waste, Sludge Recovery, and Catalyst Recycling

Globally, the oil & gas industry produces approximately 75 million barrels of drilling wastes each year as a result of exploration and production activities. Because of their content of hydrocarbons, heavy metals, and naturally occurring radioactive material (NORM), these wastes are generally considered hazardous by most regulatory agencies.

Al-Ansary and Al-Tabbaa investigated how drill cuttings are managed and identified current recovery methods as thermal desorption, bioremediation, and encapsulation based applications in road construction.

Refinery sludge primarily derived from API separator bottoms, cleaning of storage tanks, and wastewater treatment, consists of an oily phase (containing hydrocarbons), a viscous water phase (containing suspended solids and residual oil), and a solid phase (containing primarily hydrocarbons). Recovery methods such as solvent extraction, centrifugation, and thermal treatment of sludge facilitate the recovery of hydrocarbons in part while the remaining solids may be co-processed through cement kilns or incinerated in a waste-to-energy facility. The economics of these activities is extremely sensitive to the price of crude oil at the time because they directly affect both the value of the hydrocarbons that are recovered and the level of capital investment that will be undertaken by the operators at the time they are recovered.

Spent heterogeneous catalysts from refinery hydroprocessing and catalytic cracking units have a lot of vanadium, molybdenum, nickel, and cobalt in them. The global market for used catalysts is thought to be around 600,000 tonnes per year, and a large part of that is sent to special refining facilities for hydrometallurgical recovery. Marafi and Stanislaus [17] observed that the economics of recovery are primarily influenced by current metal prices and the existence of hazardous contaminants like vanadium pentoxide, which incurs handling and treatment expenses that partially counterbalance recovery revenues. [17]

2.3. Construction: Demolition Waste, Concrete Recycling, and Material Reuse

The C&D (Construction and Demolition) Sector is the largest source of Solid Waste around the world and the amount produced annually is about 3 billion tons of the total Solid Waste produced by both developed and developing countries. Concrete is estimated to be between 50% and 65% of C&D waste by weight. Therefore, it is a prime candidate for reverse logistics to produce Recycled Aggregate Concrete (RAC)[18, 19]].

Kibert [18] described deconstruction, the process of carefully taking apart buildings in an effort to salvage as many materials as possible, as an important method for preventing Waste at the source. Deconstruction requires more time to plan and execute, an inventory of the materials that will be recovered, more skilled labor to execute the deconstruction process and a higher-Retail price for deconstruction due to all of these reasons. A consequence that results from the above-listed reasons is much higher levels of recovery of designed product for use as new products after completion of deconstruction than were accomplished through the conventional process of demolition. Countries in the European Union have enabled countries in the Union to recover over 90% of C&D Products through requirements for the reporting of C&D Recovery, taxes on Siting of C&D Products on Landfills and Creations of procurement of Recycled Products for use in public works contracts in the Union [18, 19].

High Value C&D Products to the construction industry include structural steel and aluminum; in markets where buildings have been "systematically" (using a plan for taking apart the buildings to recover the most amount of salvageable C&D material) deconstructed instead of mechanically demolished, the reuse of both structural steel and structural aluminum is approaching 85%90% to be reused from original condition to new product condition. Additionally, timber, brick and architectural fittings have substantial potential for reuse; however, the development of markets for secondary C&D materials that have gone through a certification process for quality is highly uneven and depends on quality certifications [19, 20].

2.4. Regulatory and Environmental Compliance Challenges

Regulatory frameworks governing industrial waste management differ greatly between national and regional jurisdictions. This leads to confluence of regulatory requirements for multinational businesses who operate across many of these jurisdictions. Regulatory frameworks developed within the EU (Waste Framework Directive, 2008/98/EC and its amendments) run on a hierarchical principle of waste management where prevention, reuse or recycling are given priority over energy recovery and disposal. For example, the RCRA and CERCLA create different regimes for the classification and liability of hazardous industrial wastes in the US.

Due to the lack of harmonized international standards for characterizing industrial waste and for certifying the recovery of such waste, movement of industrial waste across borders and globally developing secondary material markets is stymied. Scott, Selin and Shiers [21] suggested that regulatory heterogeneity presents a systemic barrier to optimizing reverse logistics networks in capital-intensive industries, and called for the multilateral convergence of regulatory frameworks as a condition precedent for scaling circular economies [21].

Table 1: Classification of Industrial Waste Types Across Aviation, Petroleum, and Construction Sectors

Industry	Waste Category	Specific Waste Types	Estimated Volume/Year
Aviation	MRO Waste	Used lubricants, hydraulic fluids, depleted chemicals	~500,000 t globally
Aviation	End-of-Life Aircraft	Aluminum/titanium alloys, composites, avionics	~700 aircraft/year
Aviation	Composite Materials	CFRP, fiberglass, structural panels	~12,000 t/year
Petroleum	Drilling Waste	Drill cuttings, contaminated mud, brine	~8 million t/year
Petroleum	Refinery Sludge	API separator sludge, tank bottom sludge	~11 million t/year
Petroleum	Spent Catalysts	Molybdenum, vanadium, nickel-bearing catalysts	~600,000 t/year
Construction	Demolition Debris	Concrete, masonry, mixed rubble	~3 billion t/year
Construction	Excavation Soil	Contaminated and uncontaminated soil	~800 million t/year
Construction	Structural Steel	Recovered beams, rebar, cladding	~100 million t/year

Source: Compiled from multiple industry reports and peer-reviewed literature.

Table 1 presents a structured classification of the principal waste categories generated across the three focal industries, encompassing waste type, specific material composition, and estimated annual generation volumes. The data underscore the scale and diversity of industrial waste streams requiring integrated reverse logistics responses.

3. Reverse Logistics Network Design and Processes

3.1. Collection, Sorting, Transportation, and Recovery Processes

The design of a reverse logistics network is about the planned and systematic collection of waste at or close to where it is generated—from the point of generation to its disposal. According to Fleischmann *et al*. [22], optimal reverse logistics network designs include multiple distribution points for recovering materials. They also discussed the importance of collection efficiency as a critical factor influencing the performance of the overall reverse logistics system, since there are irreversible losses after collection.

In the aviation industry, boneyards (also called aircraft disassembly facilities) are places designed to process aircraft at the end of their useful lives (i.e., through dismantling) with the purpose of future reuse of at least some components. Notable examples include the boneyards in the Mojave Desert (USA) and Teruel (Spain) referred to previously [22, 23].

Sorting is used as a process to separate materials that are recovered from other sources into categories based upon their type, condition and recovery pathway. Industrial sorting operations have begun to increasingly utilise technologies such as hyperspectral imaging and X-ray fluorescence (XRF) for non-destructive composition analysis, thereby improving the accuracy of decisions being made concerning routing destination(s) for the materials. Also, in the construction industry on-site crushing and screening equipment can convert concrete rubble into recycled aggregate on-site in real time, thereby avoiding the need for transportation costs to a centralised processing facility [22, 23].

When planning transportation logistics in reverse supply chains, you have to follow rules about dangerous materials. This means that you can't take certain routes, you have to get your vehicles certified, and you have to keep records. The European Agreement on the International Carriage of Dangerous Goods by Road (ADR) and similar agreements in other parts of the world require compliance costs that hit smaller waste producers and third-party logistics providers the hardest. [2, 21]

3.2. Centralized vs. Decentralised Reverse Logistics Systems

When looking at whether to use a centralised or decentralised configuration for reverse logistics, you will be faced with a trade-off between economies of scale and responsiveness. A centralised system uses a small number of large facilities (e.g., for sorting, testing and recovering materials) and can afford to implement advanced sorting, testing and recovering technologies efficiently. A decentralised approach has a much shorter distance (and lower cost) for transporting returned goods to processing sites, and provides improved access for collection (e.g., collection will be easier to obtain), but at the cost of less advanced sorting, testing and recovery processes. [22, 24]

Alumur, Nickel and Sobieski [24] examined how to design a multi-echelon reverse logistics network when the outcome is uncertain. Their findings indicate that if the volume of materials returned is sufficiently large, hub-and-spoke configurations will yield lower total costs than fully decentralised reverse logistics systems. On the other hand, in dispersed markets with low-volume waste generation (e.g., small construction contractors) decentralised reverse logistics systems will yield better overall economic performance than centralised systems.[24]

3.3. Role of Third-Party Reverse Logistics Providers

A rise of Third-Party Reverse Logistics (3PRL) providers has helped create an intermediary layer in the management of industrial wastestreams while providing specialized solutions for collection, sorting, transportation and processing for generators who lack the scale or technical capabilities to manage reverse flow internally. The 3PRL sector is estimated to manage roughly 35% of total hazardous industrial waste flows within Europe, and growing at rates faster than conventional contract logistics. Meade and Sarkis, assessed performance dimensions for selecting 3PRL providers through the use of a multi-criteria decision framework and found that the selection dimensions were defined as technical expertise, regulatory compliance capacity, geographic coverage, and information systems integration. The development of Extended Producer Responsibility (EPR) legislation in multiple jurisdictions has increased the demand for 3PRL services by establishing legal obligations for each producer to manage the end of life phase for their products and materials.

Table 2: Comparative Analysis of Centralised, Decentralised, and Hybrid Reverse Logistics Systems

Dimension	Centralized System	Decentralized System	Hybrid System
Collection Point	Single regional hub	Multiple local sites	Tiered network nodes
Economies of Scale	High (consolidated flow)	Low (fragmented volumes)	Moderate
Transport Cost	High (long haul)	Low (short haul)	Medium
Processing Flexibility	Low	High	High
Setup Cost	High	Low–Medium	Medium–High
Responsiveness	Low	High	High
Regulatory Compliance	Easier (centralized audit)	Complex (multi-site)	Moderate
Suited Industry	Petroleum (catalysts)	Construction (demolition)	Aviation (MRO)
Technology Integration	High (ERP, AI)	Moderate	High
Third-Party (3PL) Role	Full outsourcing	Partial outsourcing	Collaborative

Source: Adapted from Alumur *et al*. [24], Fleischmann *et al*. [22], and Meade & Sarkis [26].

Table 2 provides a detailed multi-dimensional comparison of centralised, decentralised, and hybrid reverse logistics configurations, illustrating the strategic trade-offs managers must navigate when designing recovery networks for diverse industrial contexts. The hybrid model, which layers centralised processing capability over distributed collection networks, is increasingly preferred in the aviation MRO sector.

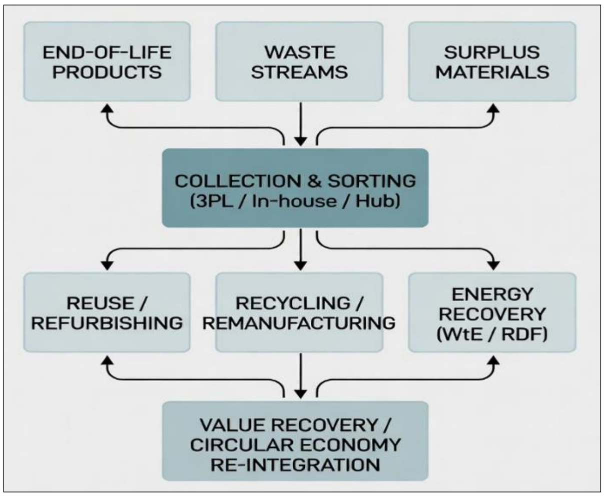

Fig 1: Reverse Logistic Conceptual Framework

Figure 1 presents the conceptual framework underpinning this study, illustrating the flow of end-of-life products, waste streams, and surplus materials through collection, sorting, and recovery stages, ultimately re-entering the circular economy value chain. Digital enablers—including IoT, blockchain, and AI—operate as horizontal integrators across all process layers.

4. Waste Recovery and Value Creation Mechanisms

4.1. Recycling, Remanufacturing, Refurbishing, and Energy Recovery

The waste recovery hierarchy in industrial supply chains is a continuum of value capture options, with re-use of materials being the highest and landfill disposal or energy recovery being the lowest. Recycling transforms waste into secondary raw materials through either physical or chemical processes that degrade the material's quality relative to that of the original input. Recycling aluminium from the aviation industry's structures is an example of high-value recycling; 95% of the energy was recovered from the use of that particular material and only 5% to create greenhouse gases as opposed to the primary aluminium production process [10, 11]/[15].

Remanufacture is the process of returning a used product or part to the original factory specifications for performance; remanufacturing generally commands a higher price than recycled material when sold on the user market and is produced with far less energy than production of new parts. Remanufacturing engines and overhauling avionics are established businesses in the aviation industry; the global aviation remanufactured business was approximately $15 billion in 2022. Examples in the petroleum industry are the remanufacturing of pump and compressor refineries; this adds 5-10 years to the life of assets while costing 30-50% of the new cost of the same equipment [6, 17].

Energy recovery through waste-to-energy (WtE) incineration or co-processing in cement kilns is the last option for recovering industrial waste. It is only used for materials that can't be recycled or remanufactured in a cost-effective way. Several jurisdictions have approved the use of petroleum sludge as an alternative fuel and raw material (AFR) in cement kilns. This means that it can be used instead of both fossil fuels and new minerals. [16, 17]

4.2. Economic and Environmental Benefits of Waste Valorisation

A growing body of empirical research supports the economic argument for waste valorisation in capital-heavy industries. A lifecycle cost analysis of aluminium recapture from decommissioned aircraft performed by Huisman and colleagues [13] indicates a net present value advantage of USD 2,000 to USD 4,500 per metric tonne compared to landfill disposal after taking into account the costs to collect, process, and have a market for aluminium recapture. Gasoline catalyst recovery from the crude oil refining process yields USD 400–900 per metric tonne of spent catalyst recovered, greatly exceeding the disposal cost of USD 120–180 per metric tonne at a licensed hazardous waste facility.[13, 17]

The environmental benefits of waste valorisation are equally compelling. Based on a review of lifecycle assessment research performed by Pimenta and Pinho [15], the recycling of one metric tonne of aluminium used in aviation structures prevents the emission of nine metric tonnes of CO2-e relative to primary aluminium production. The use of recycled aggregate concrete has been shown to reduce embodied carbon by 40–60% versus using virgin aggregate, as well as provide lower negative environmental impacts associated with quarrying and transportation emissions.[15, 19]

4.3. Trade-offs Between Recovery Cost and Sustainability Gains

Waste valorisation has been documented to have some advantages, but the economic viability of each recovery option can be significantly affected by both cost-sustainability trade-offs. A good example of the economic viability of the various recovery options (as shown with CFRP recycling) is the costs associated with each process. The pyrolysis process allows for the recovery of fibres; however, although 70-90% of the original tensile strength of virgin fibre can be recovered from pyrolysis, the pyrolysis process requires highly capital-intensive infrastructure, extremely close temperature control, and generates by-product gases that must undergo treatment prior to their release into the surrounding air and/or water. As such, break-even processing costs for pyrolysis are reported to be between USD 300 – 450. In addition, the processing costs for pyrolysis are approximately equivalent to or greater than the market revenues of recycled short fibres. [15, 25]

As a result, decision-makers will need to develop multi-criteria frameworks that consider the economics, environmental implications and regulatory framework around the various recovery pathways. Srivastava [27] developed a framework for this purpose and demonstrated that using a carbon tax or emissions trading scheme to assign a price to environmental externalities will change the relative attractiveness of the various recovery pathways for many cases and will, therefore, make previously unviable recycling processes financially feasible. [27]

Table 3: Industry-Wise Waste Recovery Methods and Value Recovery Rates

Recovery Method	Aviation Application	Petroleum Application	Construction Application	Value Recovery (%)
Recycling	Aluminum/titanium smelting	Catalyst metal recovery	Concrete aggregate reuse	40–70%
Remanufacturing	Engine/APU overhaul	Pump/compressor rebuild	Structural steel reuse	60–85%
Refurbishing	Avionics/cabin components	Instrumentation repair	Fixtures and fittings	50–75%
Energy Recovery	Composite incineration (WtE)	Sludge co-processing	Biomass/waste RDF	20–45%
Material Upcycling	CFRP into short-fibre products	Spent catalyst as filler	Recycled aggregate concrete	30–60%
Reuse	Serviceable parts (USM)	Drill pipe rotation	Timber/brick reuse	70–90%

Source: Compiled from Pimenta & Pinho [15], Marafi & Stanislaus [17], Kibert [18], and Guide & Van Wassenhove [6].

Table 3 summarises the principal recovery methods applicable across the three industrial sectors and provides indicative value recovery rates based on current commercial practice. Reuse consistently yields the highest value recovery, while energy recovery produces the lowest, reinforcing the waste hierarchy principle as a framework for strategic decision-making.

Table 4: Cost–Benefit Analysis of Industrial Waste Recovery Strategies

Recovery Strategy	Industry	Recovery Cost (USD/t)	Revenue/Saving (USD/t)	Net Benefit (USD/t)	CO2 Reduction (kg/t)	Feasibility Rating
Aluminum recycling	Aviation	180–220	350–500	130–320	8,500–9,200	High
CFRP short-fibre reuse	Aviation	300–450	200–380	-50 to +80	1,800–2,400	Medium
Catalyst metal recovery	Petroleum	120–180	400–900	220–780	600–1,200	High
Sludge WtE co-processing	Petroleum	80–130	50–120	-30 to +40	350–700	Medium
Drill cutting recycling	Petroleum	60–100	30–70	-30 to +10	200–450	Low–Medium
Concrete aggregate reuse	Construction	10–30	25–60	15–30	300–600	High
Structural steel reuse	Construction	50–90	200–450	150–360	1,500–2,100	High
Demolition timber reuse	Construction	20–50	80–200	60–150	400–900	High

Source: Compiled from Srivastava [27], Huisman *et al*. [13], Marafi & Stanislaus [17], and Al-Ansary & Al-Tabbaa [16].

Table 4 presents a consolidated cost–benefit analysis of selected waste recovery strategies, encompassing per-tonne recovery costs, revenue or savings generated, net benefit, CO_2 reduction potential, and overall feasibility rating. The data reveal that aluminium recycling, structural steel reuse, and concrete aggregate recovery represent the highest net-benefit and highest-feasibility options, providing clear prioritisation guidance for industrial sustainability investment.

5. Technological and Digital Enablers

5.1. Use of IoT, Blockchain, and Digital Tracking Systems

The use of sensor networks connected via Internet of Things (IoT) technology has improved the ability of industries to monitor in real-time how waste is generated and managed. In oil production facilities, flow meters and spectroscopic equipment connected to IoT networks allow for continuous monitoring of what is in drilling fluids at all stages of drilling, which allows for more timely decisions about managing waste and automating regulatory reporting.

Companies that have waste containment devices with weight and level sensors connected to IoT networks, for example, can have their collection process automatically triggered by sensors, thereby eliminating the risk that overflow would occur, or that a collection run will occur unnecessarily. [28, 29]

Blockchain will provide effective solutions for managing traceability issues associated with reverse logistics systems with multiple stakeholders. Chain-of-custody documentation is essential if companies are to comply with regulations as well as develop secondary markets and manage liability. In addition, Saberi *et al*. [29] have provided a summary of several studies that show that by creating an immutable record of transactions, automating processes through smart contracts, and enabling companies from different geographic areas to verify transactions through a decentralized system, fraud and misrepresentation in secondary markets for materials (especially for high-value recovered metals and certified recycled construction aggregates) can be significantly reduced.[29]

5.2. Data Analytics for Waste Forecasting and Recovery Optimisation

Using machine learning and advanced data analytic techniques is becoming more common in projects involving waste stream characterization, recovery yield forecasting, and optimizing reverse logistics networks. Predictive maintenance algorithms for aircraft component monitoring help predict when a component will fail so that it can be scheduled for removal and refurbished instead of being replaced in an unplanned manner and wasted. The same type of predictive maintenance approaches are utilized in managing catalysts in refineries where analytical models help estimate catalyst deactivation rates and optimize the regeneration and replacement cycles. Using stochastic optimization models for designing reverse logistics networks, which include a probabilistic component to the demand or supply of returned materials, Trochu, Chaabane, and Ouhimmou applied their research to the construction industry and found that creating a data-driven network could decrease total system costs between 18-27% compared with creating a deterministic plan for the same network.

5.3. Automation and Smart Sorting Technologies

Automated sorting systems that use conveyor-based near-infrared (NIR) spectroscopy, robotic pick-and-place, and computer vision are slowly taking the place of manual sorting in construction waste recovery facilities. These systems can identify materials with more than 95% accuracy while processing 20 to 40 tonnes per hour. This greatly increases the purity and, as a result, the market value of the sorted material fractions. High capital costs make it hard for medium-sized recovery operators to use these technologies, but equipment manufacturers are making it easier for them to get started by offering modular leasing options. [22, 25]

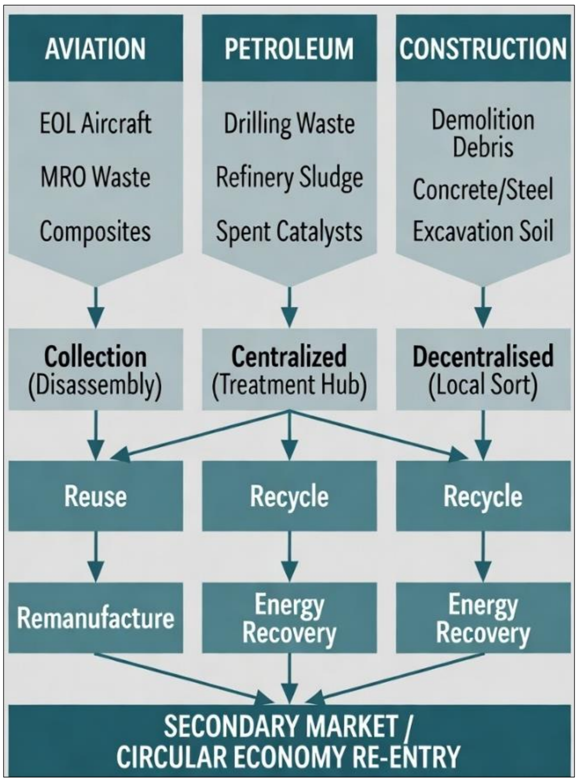

Fig 2: Industry Waste Flow Diagram

Figure 2 illustrates the waste recovery flow pathways for all three industrial sectors, showing how distinct waste streams—from aviation, petroleum, and construction—converge through collection, assessment, and grading stages before entering common recovery channels. The diagram highlights the parallel structure of recovery options across sectors and identifies the point of re-entry into secondary material markets or circular economy production loops.

6. Managerial and Policy Implications

6.1. Strategic Decision-Making for Sustainable Supply Chain Design

Senior-level supply chain managers for businesses involved in aviation, oil and gas, and construction face the increasing challenge of determining how best to incorporate reverse logistics into their decisions regarding forward supply chain design. A specific example of design for reverse logistics includes selecting materials, joining methods, and assembly configurations that will make future recovery possible at the end of a product's useful life. Material standardisation and a reduction in the number of composite-metal hybrid joints in an aircraft's structure, for example, can lead to reduced disassembly complexity and improved recovery rates of aluminium at the end of life. [2, 14, 15]

Developed by Seuring and Müller [3], a conceptual framework for sustainable supply chain management was proposed that places reverse logistics as an integral part of supply chain strategy, rather than a separate waste management function. In particular, their framework identifies supplier collaboration, performance measurement, and risk management as essential elements in achieving systemic sustainability outcomes; these same elements apply equally to the management of industrial waste recovery programmes.[3]

6.2. Role of Government Regulations and Extended Producer Responsibility

Extended producer responsibility (EPR) laws are now considered the main way to create a financial incentive for businesses in an industrial supply chain to internalise their costs on how to manage a product at the end of its life cycle. EPR systems require companies that produce consumer goods to take on the responsibility of collecting and recovering their products (and any materials that make up those products) once they are disposed of by consumers. This results in creating direct financial incentives for manufacturers to implement design strategies that support recovery of their products. The approaches being taken in the EU's Waste Electrical and Electronic Equipment (WEEE) regulations, Industrial Emissions Directive, and proposed changes to packaging EPR requirements are part of an overall trend in creating greater producer liability through regulation. [20, 21]

In aviation, indirect financial incentives for implementing carbon-efficient waste management strategies (and, in particular, for using some amount of recovered secondary material to replace primary aluminium) are derived from two main sources of regulation: the EU Emissions Trading System, and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) from ICAO. Finally, the petroleum refining industry has to contend with a growing number of waste management regulations under the EU's Best Available Techniques (BAT) framework for the refining industry. Additionally, this framework contains specific minimum standards for managing both catalysts and sludges during the refining processes.[16, 21]

6.3. Integration of Reverse Logistics into Corporate Sustainability Strategies

Integrating reverse logistics into corporate sustainability reporting frameworks (e.g., GRI Standard 306 (Waste), CDP disclosures, SBTi commitments) has transformed waste management from being a function of various operations to being an organization-wide emphasis from the board level down. Owners of large manufacturing companies in China have found that reverse logistics and corporate environmental performance are positively correlated according to Zhu *et al*.'s [28] findings, which may also apply directly to resource-intensive industrial companies within the business world. [27, 28]

Many industrial companies have been able to support investments in reverse logistics through implementation of their own internal carbon pricing systems as a method of quantifying the avoided carbon cost of waste recovery methods communicated as well as valuing that cost as a metric associated with project appraisals. These companies report a significantly higher portion of their total investment in recycling and remanufacturing infrastructure among those with either a price of \$50-\$100 per ton CO2-e of internal carbon versus those doing no such pricing mechanisms or committed directly to that form of investment where comparing them to their peers. [27, 29]

6.4. Implementation Barriers and Emerging Trends

Despite the clear advantages of implementing industrial reverse logistics, there are still many hurdles that prevent its successful implementation. These barriers include: i) significant initial investment to develop appropriate processing infrastructure; ii) waste being produced in a fragmented and geographically dispersed manner leading to problems with collecting this waste; iii) uncertain market prices for secondary materials leading to insecurity about making long-term investments in this area; iv) complex regulations and the lack of uniformity between jurisdictions that create issues when implementing a common standard across jurisdictions; v) a shortage of trained personnel to operate sophisticated sorting and material recovery technologies.[2, 24, 25]

There are also a number of emerging trends that are transforming the future of industrial reverse logistics including: the establishment of urban mining platforms which will aggregate small individually produced waste streams from many different locations; the emergence of networks of industrial symbiosis which involve firms exchanging surplus material directly with other businesses located in close proximity to them; and the introduction of digital product passports which are mandated by EU circular economy laws and are used to provide transparency about where materials originate from and what they contain as they progress through the various stages of supply chains. [29, 30]

7. Conclusion

The review of existing literature regarding reverse logistics and waste recovery practices in aviation, petroleum and construction sectors indicates that although the three sectors collectively generate waste streams of billions of tonnes annually, the amount of waste recovered through value recovery is very low in most geographic regions. The main findings of this study are: 1) Waste streams in each sector have very different chemical and physical properties, which require a different type of reverse logistics network configuration in each sector (e.g. centralised disassembly facilities for aviation, decentralised on-site processing for construction); 2) Economic viability of waste recovery is primarily driven by commodity prices, carbon pricing signals, and producer responsibility regulatory structures; 3) Innovations in digital technologies (e.g. IoT sensor networks for monitoring, blockchain technology for traceability, predictive analytics) will be major enablers of improved performance for reverse logistics systems; and 4) Third-party reverse logistics providers will be key players in industrial waste management systems and should have appropriate regulatory frameworks and market development incentives in place to encourage their development.

Implementing reverse logistics best practices and waste recovery programs across these three industries is expected to result in an estimated 2–4 billion tons of CO2 per year, substantially contributing to the global target of reducing climate change. From an economic standpoint, the value of all of the industrial waste materials currently being thrown away is estimated to be more than USD 200 billion per year, based on low estimates of the market value of these materials as secondary to their original use. This emphasizes the scale of the opportunity to create economic value.

Currently, there are still multiple significant research gaps in the area of reverse logistics. These include: the need for complete and reliable benchmarking frameworks for evaluating the performance of multi-industry and reverse logistics; empirical studies to assess the net economic and environmental benefits of using digital enablers to support the recovery of industrial waste; comparative studies on the effectiveness of EPR schemes across regions and industries; and an evaluation of the social aspects of transforming to a new reverse logistics process, such as retraining workers and the resulting distributional impacts.

This review offers practitioners several actionable strategies: the implementation of design-for-recovery principles in procurement and asset management; investment in IoT-enabled waste stream monitoring; the establishment of strategic partnerships with certified 3PRL providers; proactive involvement in EPR scheme design processes; and the integration of avoided waste management costs into capital project appraisal frameworks. For policymakers, the top priorities are to make industrial waste rules the same in all areas, strengthen EPR rules in capital-intensive industries, and create certification systems for secondary material markets. Together, these steps would speed up the shift of the aviation, oil, and construction supply chains toward circular economy principles, which would have big and long-lasting benefits for the environment.

References

1. Rogers DS, Tibben-Lembke RS. Going backwards: reverse logistics trends and practices. Reverse Logistics Executive Council; 1999.
2. De Brito MP, Dekker R. A framework for reverse logistics. In: Dekker R, Fleischmann M, Inderfurth K, Van Wassenhove LN, editors. Reverse logistics: quantitative models for closed-loop supply chains. Berlin: Springer; 2004. p. 3–27.
3. Seuring S, Müller M. From a literature review to a conceptual framework for sustainable supply chain management. J Clean Prod. 2008;16(15):1699–1710.
4. Dowlatshahi S. Developing a theory of reverse logistics. Interfaces. 2000;30(3):143–155.
5. Govindan K, Soleimani H, Kannan D. Reverse logistics and closed-loop supply chain: a comprehensive review to explore the future. Eur J Oper Res. 2015;240(3):603–626.
6. Guide VDR Jr, Van Wassenhove LN. The evolution of closed-loop supply chain research. Oper Res. 2009;57(1):10–18.
7. Stock JR, Mulki JP. Product returns processing: an examination of practices of manufacturers, wholesalers/distributors, and retailers. J Bus Logist. 2009;30(1):33–62.
8. Sarvari PA, Yücesan E, Demirel E. Challenges and opportunities of reverse logistics in the aviation industry. Int J Prod Econ. 2016;183(B):354–366.
9. Merkert R, Swidan H. Flying with(out) a safety net: financial hedging in the airline industry. Transp Res Part E Logist Transp Rev. 2019;127:206–219.
10. Ellen MacArthur Foundation. Towards the circular economy: economic and business rationale for an accelerated transition. Isle of Wight: Ellen MacArthur Foundation; 2013.
11. Kirchherr J, Reike D, Hekkert M. Conceptualizing the circular economy: an analysis of 114 definitions. Resour Conserv Recycl. 2017;127:221–232.
12. Stahel WR. The circular economy. Nature. 2016;531(7595):435–438.
13. Huisman J, Leroy P, Tertre F, *et al*. Prospective scenarios on e-waste volumes and recycling rates. Rotterdam: WEEE Forum; 2017.
14. Aircraft Fleet Recycling Association (AFRA). Best practice guideline for aircraft disassembly and material management. Washington DC: AFRA; 2021.
15. Pimenta S, Pinho ST. Recycling carbon fibre reinforced polymers for structural applications: technology review and market outlook. Waste Manag. 2011;31(2):378–392.
16. Al-Ansary M, Al-Tabbaa A. The management and recycling of oil-contaminated soils in the Gulf Cooperation Council region. J Environ Manag. 2007;82(2):160–175.
17. Marafi M, Stanislaus A. Spent catalyst waste management: a review. Part I. Development in hydroprocessing catalyst waste reduction and use. Resour Conserv Recycl. 2008;52(6):859–873.
18. Kibert CJ. Sustainable construction: green building design and delivery. 4th ed. Hoboken (NJ): Wiley; 2016.
19. Tam VWY. On the effectiveness of implementing a waste management plan method in construction. Waste Manag. 2008;28(6):1072–1080.
20. European Commission. Directive 2008/98/EC of the European Parliament and of the Council on Waste and Repealing Certain Directives. Off J Eur Union. 2008.
21. Skinner I, Selin H, Shiers D. Waste management and resource recovery in environmental policy: regulation and management. Local Environ. 2007;12(5):493–507.
22. Fleischmann M, Beullens P, Bloemhof-Ruwaard JM, Van Wassenhove LN. The impact of product recovery on logistics network design. Prod Oper Manag. 2001;10(2):156–173.
23. Hatcher GD, Ijomah WL, Windmill JFC. Design for remanufacture: a literature review and future research needs. J Clean Prod. 2011;19(17–18):2004–2014.
24. Alumur SA, Nickel S, Sobieski I. Multi-period reverse logistics network design. Eur J Oper Res. 2012;220(1):67–78.
25. Soleimani H, Govindan K. Reverse logistics network design and planning utilizing conditional value at risk. Eur J Oper Res. 2014;237(2):487–497.
26. Meade L, Sarkis J. A conceptual model for selecting and evaluating third-party reverse logistics providers. Supply Chain Manag Int J. 2002;7(5):283–295.
27. Srivastava SK. Green supply-chain management: a state-of-the-art literature review. Int J Manag Rev. 2007;9(1):53–80.
28. Zhu Q, Sarkis J, Lai KH. Green supply chain management: pressures, practices and performance within the Chinese automobile industry. J Clean Prod. 2007;15(11–12):1041–1052.
29. Saberi S, Kouhizadeh M, Sarkis J, Shen L. Blockchain technology and its relationships to sustainable supply chain management. Int J Prod Res. 2019;57(7):2117–2135.
30. Trochu J, Chaabane A, Ouhimmou M. Reverse logistics network redesign under uncertainty for wood waste in the CRD industry. Resour Conserv Recycl. 2018;128:32–47.

How to Cite This Article

Syed SA. Reverse logistics and waste recovery in aviation, petroleum, and construction supply chains. International Journal of Multidisciplinary Research and Growth Evaluation. 2026;7(2):628–636. doi:10.54660/.IJMRGE.2026.7.2.628-636.