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Progress in resources recovery from solid wastes for water treatment

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Abstract

This review explores the vast potential of resource recovery from various classes of solid wastes, including food, industrial, and plastic wastes, with a focus on their applications in corrosion inhibition, nanoparticle synthesis, and sustainable energy production. The study highlights the growing need for innovative and eco-friendly solutions to waste management challenges and the shift toward a circular economy. Conducted as a comprehensive review, the work synthesizes information from recent studies and technological advancements to address existing knowledge gaps, particularly concerning the industrial scalability and environmental benefits of resource recovery processes. The review emphasizes the transformative role of food waste-derived corrosion inhibitors, such as those from Carica papaya and orange peel extracts, in protecting metals and alloys. Similarly, plastic wastes have demonstrated promising applications as coating materials and solvent-free corrosion inhibitors. Moreover, the synthesis of nanoparticles from solid wastes, including periwinkle shells and rice husks, has shown significant potential in environmental remediation, catalysis, and water purification. Despite the progress made, knowledge gaps persist in optimizing production techniques and scaling up recovery processes for industrial applications. This review underscores the need for further research and development to harness the full potential of solid waste as a valuable resource.

Recommendations include implementing effective waste management policies, increasing public awareness, and expanding research to enhance efficiency and scalability. This review contributes to the growing body of knowledge aimed at achieving sustainable development through innovative waste recovery strategies.

Keywords: Solid Waste; Resource Recovery; Water Treatment; Corrosion Inhibition; Nanoparticle Synthesis

1. Introduction

Technically, waste is defined as any materials or substances that are disposable, meant to be disposed of, recycled or materials that can provide an avenue for resource recovery or recycling (Basel Convention, 1992). Based on this definition, the life cycle of waste materials ends at the point of disposal, recycling, or recovery of resources. However, before the end of the waste lifecycle, several events are involved starting from generation, storage, treatment, transportation, and/or final disposal (Nurzhan *et al*., 2025). Waste management should be regarded as consistent efforts directed towards the reduction of volume, environmental impact, public health challenges and other harmful impacts inherent in different wastes (Muchangos *et al*., 2025). This implies that different classes of wastes have different characteristics such as physical or chemical compositions (Sing *et al*., 2024)). Waste can also be identified based on their physical states, such as solid wastes, liquid wastes (effluence), gaseous wastes (gaseous pollutants), etc. In Table 1, a summary of the different principles in the classification of wastes is presented. The Table provides some impacts that are associated with each of the presented classes. The presented information indicates that different classes of waste have different impacts on the different components of the environment.

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Table 1 Principles of classification of wastes, sources, and impacts

Principle of Classification	**Classes of Wastes**	**Sources**	**Impacts**	**References**
State (Physical Form)	Solid, Liquid, Gaseous	Households, industries, agriculture	Land and water pollution, air quality degradation	UNEP. (2021).
Hazardousness	Hazardous, Non-Hazardous	Chemical industries, healthcare facilities, municipal waste	Human health risks, soil contamination, groundwater pollution	
Biodegradability	Biodegradable, Non-Biodegradable	Food waste, plastics, metals	Methane emissions, landfill overflows, long-term environmental persistence	United Nations. (2024).
Source	Municipal, Industrial, Agricultural	Residential areas, factories, farms	Urban sanitation issues, water body contamination, loss of biodiversity	World Bank. (2022).
Composition	Organic, Inorganic	Food scraps, e-waste, glass	Greenhouse gas emissions, resource depletion, leaching of toxic materials	Satori et al. (2020).
Manageability	Recyclable, Non-Recyclable	Paper, metals, glass, mixed plastics	Energy savings through recycling, the strain on landfill capacity for non-recyclables	Selvakumar et al. (2025).

The classification of waste based on various principles (as provided in Table 1) demonstrates a technical framework that can provide information regarding their sources, characteristics, impact, and possible management procedures. Wastes can exist in various physical states, including solid, liquid, and gaseous forms, with solid waste being the most significant contributor to water treatment challenges due to its accumulation in aquatic environments. Liquid and gaseous wastes, such as effluents and industrial emissions, also significantly affect water pollution. Solid wastes, when processed, can yield valuable materials like adsorbents or catalysts for water treatment. In contrast, liquid wastes can be treated to recover water and other essential resources through advanced technologies such as membrane filtration and catalytic degradation.

The classification of waste into hazardous and non-hazardous categories reveals the varying degrees of environmental risks they pose. Hazardous waste, such as heavy metals and industrial chemicals, presents significant dangers to water systems, whereas non-hazardous waste generally has a lesser environmental impact. Resource recovery from hazardous waste can focus on extracting materials like metal oxides, which are useful in adsorption and catalysis for water purification. Similarly, non-hazardous waste, including organic materials, can be transformed into biochar or composites to be used as filtration media.

Biodegradable and non-biodegradable waste classifications provide further insight into the decomposition potential of waste materials. Biodegradable wastes can be broken down by microorganisms, such as domestic and agricultural wastes, while non-biodegradable waste, such as plastics, persists in the environment with lifecycles that tend to end in the contamination of the environment. Most biodegradable wastes are organic, while most non-biodegradable wastes are inorganic or a combination of organic and inorganic elements or compounds. Some waste can also be classified as radioactive or non-radioactive wastes based on their tendency to produce ionizing radiations (Ramya, *et al*., 2023). Irrespective of their form or class, waste materials must be appropriately managed to reduce their volume and environmental and public health impacts (ref).

Solid waste has outstanding characteristics that relate to some properties such as their biodegradability, volume, persistency in the environment, insolubility/dispersibility, transportation cost, complex composition and management cost. Considering their complexity and other listed properties, the management of solid waste is one of the principal challenges that are facing the waste industries. Resource recovery, recycling, and reuse have been considered as the best options in waste management (Eddy *et al*., 2023b). Resource recovery involves the extraction of useful waste materials, products, or energy from waste. In contrast, recycling involves the breaking down or conversion of waste into new raw materials for further applications in new areas. Reuse is concerned with the technology of using the same waste again without significant processing or alteration in its chemical composition. A consideration of these three waste management technologies indicates that each of them has advantages and disadvantages as shown in Table 3

Table 2 Comparison Table of Recycling, Reuse, and Resource Recovery

Criteria	**Recycling**	**Reuse**	**Resource Recovery**
Definition	Processing waste to create new materials.	Using waste products directly without reprocessing.	Extracting materials or energy from waste.
Advantages	- Conserves natural resources. - Reduces landfill waste. - Reduces energy consumption compared to raw material processing.	- Extends product life. - Low energy requirement. - Cost-effective in some cases.	- Maximizes value from waste. - Generates renewable energy. - Handles mixed waste streams. - Reduces landfill volume.
Environmental Impact	Reduces carbon footprint but requires energy for processing.	Minimal impact, as it avoids disposal altogether.	Significant reduction in environmental pollution through energy recovery.
Economic Impact	Creates job opportunities in recycling industries.	Saves money by reducing the need for new products.	Potential for energy sales and raw material recovery.
Disadvantages	- Requires sorting and cleaning of materials. - Not all materials are recyclable. - Can be energy-intensive.	- Limited applicability for certain waste types. - May not meet product standards.	- Requires advanced technology and infrastructure. - May produce emissions during energy recovery.
Example	Melting aluminium cans to make new ones.	Using glass jars for storage.	Generating biogas from organic waste or recovering metals from e-waste.
Best Use Case	Suitable for clean, sorted materials.	Ideal for durable products.	Effective for complex, contaminated waste streams.

The above comparison (Table 2) presents information on the unique roles and contributions of the three basic waste management systems. Recycling involves converting waste materials into new products, reducing the need for virgin resources, and lowering landfill waste. However, it requires significant energy input and infrastructure for sorting, cleaning, and processing waste, and may not be applicable to all forms of waste materials. On the other hand, reuse focuses on measures to extend the life of materials without reprocessing. It is simple, cost-effective, and requires minimal energy. Nevertheless, reuse is limited by product durability and may not be suitable for contaminated or damaged waste materials. Resource recovery operates by extracting the maximum possible value from waste, either as materials or energy. It can handle complex and mixed waste streams, including contaminated or hazardous materials that are difficult to recycle or reuse. The method has been widely employed for several types of waste materials such as those involving the production of renewable energy (such as biofuel) (Eddy *et* al., 2023c), Corrosion inhibition (El Nemr *et al*., 2024), water purification (Ogoko *et al*., 2023), generation of electricity (Dickson *et al*., 2024), recovering metals from e-waste (Pineda-Vásquez *et al*., 2024), production of industrial raw materials such as catalysts. (Lee *et al*., 2025). Consequently, resource recovery can be considered as the best option because it is an avenue for both energy generation and material extraction, which positioned its application versatility, eco-friendliness, and other benefits that can not be derived from reuse and recycling. The success of recycling requires the availability of clean, sorted waste materials, reuse can be limited by waste material durability, whereas resource recovery technology can be applied to complex and mixed waste streams, including hazardous materials. Therefore, recovery integrates the advantages of recycling and reuse and also addresses their limitations, Given the complexity of the management of solid wastes and the benefits of resource recovery over the other options, this paper is aimed at presenting a review of the progress and achievement concerning resource recovery from solid.

2. Solid Waste and their Environmental Impacts

Table 3 provided offers a comprehensive overview of the environmental impacts of various solid waste types, which is highly valuable for a review manuscript. It successfully incorporates a wide range of waste types, from municipal solid waste (MSW) to biomedical, agricultural, and industrial waste. The information shown in Table 3, contains detailed assessment of the environmental impacts of various solid waste types across different environmental domains, such as soil, water, air, plants, and animals. Municipal solid waste has its primary sources trace to households and commercial areas (Abdel-Shafy & Mansour, 2018). The environmental impact of MSW includes landfill overflow and leachate contamination of groundwater, leading to soil fertility loss (Adedara, *et al*., 2023). MSW can also show a significant impact on plant growth through the contamination of the soil, which also implies that the risks would be shared by plants and animals through the food chain (Kong *et al*., 2022). Studies have shown that during the burning or incineration of MSW, the release of harmful gases can contribute to the pollution of the air and cause respiratory issues in humans and animals (Tran *et* al., 2023; Yu *et al*., 2018).

Solid waste can also originate from plastics, especially from packaging materials and consumer products. Due to their non-biodegradable nature, they can persist in the environment,

with the potential of causing marine litter, soil pollution, and microplastic accumulation (Jerie *et al*., 2024). In soil, plastic blocks plant growth by reducing aeration, while in animals, entanglement and ingestion of plastics often result in injury or death. In water systems, microplastics accumulate, posing risks to aquatic species and food chains.

The combustion of plastic waste can produce toxic fumes, which, due to their nature and composition, can provoke severe health challenges such as numbness, rashes in the skin, nausea, headache, nausea, tinkling of the fingers, confusion, and respiratory and neurological disorders (Pathak *et al*., 2023).

Agricultural solid waste can originate from crop residues, animal manure and other sources that are associated with agricultural practices (Saberi Riseh *et al*., 2024). Such wastes also include those from animals such as abattoir waste (bones, horns, etc), wastes from crustacean shells, domestic birds' feathers, etc (Eddy *et al*. (2024a), Several studies have shown that the major impacts of agricultural wastes are those associated with the large volume of solid waste generation, consequences of biodegradability and solubility in water (Tesfamariam, *et* al., 2022; Xu *et al*., 2024). Reported impacts of agricultural wastes on the aquatic system are nutrient enrichment, increase in algal bloom population, disruption of the aquatic ecosystem and eutrophication as well as subsequent attacks on aquatic biota due to the reduction in the volume of dissolved oxygen (de Sadeleer & Woodhouse, 2024). Some cases of toxic gas emission (such as methane) and subsequent air pollution have been identified with the decay of some plant wastes (Wu *et al*., 2024). Similar findings have also confirmed that burning plant waste can generate toxic gases to the atmosphere, at a level that reflects a significant contribution to local atmospheric pollution (Pinakana *et al*., 2024).

Food wastes is those generated by eatery/restaurant, households, and food/beverage or alcohol production industries (Sahoo *et al*., 2024). Most food wastes are biodegradable, and their decomposition can generate air pollutants such as methane. Hence, improper management of food waste can contribute to unfavorable climate issues such as global warming (Amicarelli et al., 2021). Also, substantial documentation on the attraction of pests, by food wastes and the consequences habitat destruction and overgrazing have also been widely reported in the literature Grangxabe, *et al*., 2024. Studies have also shown that leachates from decomposed food waste can also facilitate eutrophication through the enrichment of water bodies with nutrients that can create an ecological imbalance in the water (Chan *et al*., 2025).

Demolition and construction waste have been found to significantly negatively impact several environmental components, including air, land, and water (Kong & Ma, 2020; Sagan & Mach, 2025). Cases of air pollution through particulates distribution, have widely been linked with construction wastes (Rahman *et al*., 2023). Some studies have also reported that this class of waste (originating from building materials, debris, and demolition activities) has the potential to facilitate habitat destruction, soil contamination, dust pollution and obstruction of photosynthesis (Elshaboury *et* al., 2022; Sagan & Mach, 2025). Incident of water contamination as a consequence of the entrance of hazardous leachates from construction materials to the aquatic body have also been reported along with consequences such as enhanced sedimentation, precipitation of toxic and relatively stable water contaminants and distortion of aquatic habitats (El-Saadony *et al*., 2023). Finally, respiratory-associated health issues and other medical abnormalities have been reportedly linked to exposure to dust exposure from construction sites (Wang *et al*., 2023).

Table 3 Impacts of Solid Wastes on the Environment, Plants, Animals, Water, and Air

Solid Waste Type	Source	Environmental Impact	Impact on Plants	Impact on Animals	Impact on Water	Impact on Air	References
Municipal Solid Waste (MSW)	Households, commercial areas	Landfill overflow, leachate contamination of groundwater, air pollution from waste burning.	Leachates contaminate soil, reducing fertility	Ingestion of waste leads to gastrointestinal blockages	Leachate contaminates groundwater, potentially affecting drinking water	Air pollution from burning waste, contributing to smog	Zhang et al. (2024)
Plastic Waste	Packaging, consumer products	Non-biodegradability leads to marine litter, soil pollution, and microplastic accumulation. Ingestion of microplastics affects human health, linked to carcinogenic effects.	Blocks plant growth in soil, reduces aeration	Entanglement, ingestion of plastics causing death	Microplastics contaminate water bodies, harming aquatic life	Burning plastics releases toxic fumes, contributing to air pollution	Pilapitiya & Ratnayake (2024)
Agricultural Waste	Crop residues, animal manure	Methane emissions, soil degradation, and eutrophication from nutrient runoff. Poor handling leads to zoonotic diseases, contamination of drinking water	Excess nutrients cause algal blooms, smothering plants	Eutrophication reduces oxygen for aquatic animals	Nutrient runoff leads to eutrophication, reducing water quality	Methane emissions from waste burning contribute to air pollution	Ataei et al. (2025)
Food Waste	Restaurants, households	Methane emissions from decomposition, attracts pests, and causes landfill overload	Attracts pests, leading to overgrazing and vegetation loss	Habitat destruction due to pest activity	Decomposing food waste releases harmful substances into water	Methane and other gases from decomposition contribute to air pollution	Batool et al. (2023)
Construction and Demolition Waste	Building materials, debris	Habitat destruction, soil contamination, and dust pollution. Dust exposure	Dust settles on leaves, reducing photosynthesis	Habitat destruction and increased	Leachates may contaminate water sources,	Dust pollution impacts air	Antunes et al. (2025)

		causes respiratory issues, leachates may contain hazardous substances.		sedimentation in water	affecting aquatic ecosystems	quality and human health	
Electronic Waste (E-Waste)	Discarded electronics	Toxic heavy metals leach into soil and water, improper recycling releases harmful fumes. Releases heavy metals like lead and cadmium, causing neurological and developmental problems	Soil contamination affects plant health	Heavy metals accumulate in animals, causing toxicity	Leaching of heavy metals contaminates water bodies, harming aquatic life	Toxic fumes from improper recycling contribute to air pollution	Jain et al. (2023)
Industrial Waste	Factories, production facilities	Toxic pollutants, groundwater contamination, and disruption of aquatic ecosystems. Toxic chemicals lead to skin, respiratory, and long-term health complications	Acidic or alkaline waste damages plant roots	Toxic chemicals bioaccumulate in the food chain	Contaminates groundwater and water bodies, disrupting ecosystems	Releases toxic gases, contributing to air pollution and health risks	Khoshsepehr et al. (2023)
Biomedical Waste	Hospitals, healthcare facilities	Spread of infections, improper disposal contaminates soil and water. Infectious diseases spread from improperly disposed syringes and medical equipment	Soil contamination affects plant growth	Infectious diseases spread through contact or ingestion	Contaminates water sources with pathogens and chemicals	Airborne pathogens from improper disposal contribute to health risks	Agarwal et al. (2025)
Paper and Cardboard Waste	Offices, packaging	Contributes to deforestation, air pollution from burning, and landfill space usage	Blocks soil pores, affecting root growth	Habitat loss from excessive resource exploitation	Can cause leachate in landfills affecting water quality	Burning paper generates air pollution, including particulate matter	Belle et al. (2024)

Environmental and health challenges associated with other solid wastes listed in Table 3 can also be severed. For example, e-waste can lead to consequences arising from heavy metal toxicity (Nyeko *et al*., 2023), industrial wastes can affect all components of the environment, including man through the food chain (Raphela, *et al*., 2024), and some biomedical wastes are radioactive and can generate dangerous ionizing radiation (Aundhia,*et al*., 2025) while paper wastes can contribute to deforestation and block soil pores, impeding root growth and affecting plant health. They have been reported to be carcinogenic, mutagenic and genetic to a good extent (Singh *et al*., 2022).

3. Options for Solid Waste Management and Challenges

Solid waste management is crucial in promoting sustainable development and environmental conservation. With the rise in urbanization and industrialization, managing various types of solid waste has become an increasingly complex challenge. This literature review examines different waste management methods and their challenges and argues that resource recovery is the most sustainable and effective solution. Table 4 presents different management options for the various classes of solid waste that were presented in Table 3 and reviewed under the same sections. From Table 4, it is evident that the available options vary with the type of solid waste, indicating that not all the options are suitable for all forms of waste, probably due to differences in forms, composition, biodegradability and other waste characteristics. Challenges common among the different management options are also highlighted in Table 4.

Table 4 Overview of Solid Waste Management Methods

Type of Solid Waste	Management Option	Principles	Challenges	References
Organic Waste	Composting	Biological decomposition	Odor control, limited to biodegradable waste	Singh et al. (2022)
Municipal Solid Waste	Landfilling	Controlled disposal	Leachate, land scarcity	Ferronato et al. (2021)
Industrial Waste	Incineration	High-temperature combustion	Toxic emissions, ash disposal	Ferronato et al. (2021)
Mixed Waste	MBT	Mechanical and biological treatment	High investment costs	Wilson et al. (2019)
Plastic Waste	Recycling	Material conversion	Contamination, market volatility	Geyer et al. (2017)

Landfilling involves the controlled disposal of waste in designated landfill sites. However, this method faces several challenges, including land scarcity, the generation of leachate, greenhouse gas emissions, and long-term environmental degradation. Incineration refers to the combustion of waste materials at high temperatures to reduce volume and generate energy. While it helps reduce waste volume, it also comes with high operational costs, the emission of toxic substances such as dioxins and furans, and difficulties with ash disposal. Composting is the biological decomposition of organic waste by microorganisms, resulting in nutrient-rich compost. However, it is limited to biodegradable waste and encounters issues such as odor control and the need for proper aeration. Mechanical Biological Treatment (MBT) combines mechanical separation and biological treatment to recover materials and stabilize waste. It requires a significant capital investment, complex operations, and its efficiency largely depends on the composition of the waste. Recycling involves converting waste materials into new products. While this method is beneficial, it faces challenges such as contamination of recyclables, high sorting costs, and market volatility for recycled materials.

Resource recovery involves extracting valuable materials and energy from waste, transforming it into a resource rather than a problem. This process offers numerous advantages, including environmental benefits like a reduction in landfill use and decreased pollution. It also generates economic gains by producing revenue from recovered materials and energy. Additionally, energy recovery reduces reliance on fossil fuels, contributing to energy efficiency. Resource recovery supports a circular economy by promoting sustainable production and consumption patterns. According to Wilson et al. (2019), resource recovery can reduce waste management costs by up to 30%, all while minimizing environmental impacts. Singh et al. (2022) further emphasize that combining resource recovery with traditional waste management methods enhances overall efficiency. It is evidence from the above that the listed conventional waste management methods have some benefits but are faced with significant environmental, economic and health consequences. Resource recovery seems to have better sustainable solutions than other methods because it deals with the conversion of waste into valuable products and is in line with several SDGs as presented in Table 5. The Table further supports the unique capacity of resource recovery in solving problems associated with other waste management protocols, as shown in Table 5

Table 5 Waste Management Methods, Relevant SDGs, and Resource Recovery Advantages

Waste Management Method	Relevant SDGs	Resource Recovery
Recycling	SDG 9, SDG 11, SDG 12, SDG 13	Reclaims materials like metals, plastics, and paper, reducing the need for virgin resources.
Composting	SDG 2, SDG 13, SDG 15	Converts organic waste into nutrient-rich compost, improving soil health and reducing chemical fertilizers.
Anaerobic Digestion	SDG 7, SDG 9, SDG 12, SDG 13	Produces biogas as renewable energy and nutrient-rich digestate for agriculture.
Waste-to-Energy	SDG 7, SDG 11, SDG 13	Converts non-recyclable waste into electricity and heat, reducing fossil fuel reliance.
Landfill Gas Capture	SDG 7, SDG 13	Captures methane for conversion into electricity or fuel.
Mechanical-Biological Treatment (MBT)	SDG 12, SDG 13	Recovers recyclables and produces refuse-derived fuel (RDF).
Chemical Recycling	SDG 9, SDG 12	Break down plastics into chemical components for high-quality material production.
E-Waste Management	SDG 9, SDG 12	Extracts precious metals (gold, silver, palladium) and rare earth elements for electronics reuse.

The presented data shows various waste management techniques, their alignment with specific Sustainable Development Goals (SDGs), and the corresponding benefits that could be obtained if resource recovery is implemented. The listed methods support multiple SDGs, particularly those promoting clean energy (SDG 7), responsible production and consumption (SDG 12), and climate action (SDG 13). Resource recovery methods applied to recycling, anaerobic digestion, and chemical recycling can contribute to reducing landfill dependence and consequently promote the conservation of raw materials. Also, while landfills can generate gases such as methane, the complementary application of resource recovery can provide a technology for capturing the methane for further applications in other fields such as fuel, power generation, etc. Resource recovery enables sustainable material cycles by extracting valuable components from waste; it can provide an alternative source to expensive industrial raw materials. For example, the application of resource recovery methods such as anaerobic digestion and waste-to-energy provide alternate energy sources and reduce reliance on fossils. The economic advantages of resource recovery may include the reduction of importation rate, production costs and scarcity of raw materials.

4. Review of Resource Recovery from Solid Wastes

Several works recording the recovery of resources from different classes of solid wastes have been published in the literature. This section resents a review of some of the known applications of resource recovery in the management of food, industrial, plastic, and other wastes.

Food waste is widely generated by every home in the world, taking a lead value of about The SDGs 12.3 aims to reduce the volume of food waste by half before 2030 (Nazibudin *et al*., 2025). Currently, the estimated generation amount as of 2024 was 30.5 billion tons for ten developed countries. Therefore, this projection cannot be achieved without the implementation of diverse waste management technology that can effectively process large volumes of food waste to other products through resource recovery. Some reported conversion of food wastes to useful products have been documented especially conversion to corrosion inhibitors, nanoparticles, catalysts, biofuel, raw materials for various industries, etc.

Studies conducted by Eddy *et al*. (2022) showed that ethanol extract of Carica papaya leaf is an efficient corrosion inhibitor against the corrosion of aluminum in HCL solution. The study showed efficiencies at various concentrations of the extracts and various temperatures and periods of contact. In all variations, the obtained inhibition efficiencies were comparable to the standard range expected for most excellent corrosion inhibitors. Ukpe (2019) also carried out a similar study on the effectiveness of orange peel as a corrosion inhibitor for aluminum in acidic media. Inhibition efficiencies recorded under various temperatures, times, concentrations and pH indicated significant functionality. Barghourt, *et* al. (2022) also observed high inhibition efficiency against the corrosion of mild steel in saline solution when an extract of orange peels was added to the corrodent. Efficiency approaching 98% was reported with sustainable capacity to function for a reasonable period. In both cases, the effectiveness of the plant extracts was aligned to their phytochemical constituents. Successful recovery of resources for corrosion inhibition has also been reported for ethanol extracts of Musa *Sapientum* (Eddy and Ebenso, 2008) and *Musa asuminate* (Eddy *et al*., 2008). These studies indicated average inhibition efficiency above 80% with results that were comparable to those obtained from some commercial based on other corrosion inhibitors (Folorunso, 2023). A review published by Eddy *et al*. (2023a) on plant wastes as corrosion inhibitors, several forms of wastes were found to be functional as corrosion inhibitors. Their review indicated that the basic principles that enable their effectiveness as corrosion inhibitors are their phytochemical constituents, especially those whose structures aligned with aromatic ring and the possession of hetero atoms (N, O, P, multiple bonds, pi-electrons, conjugated systems and large molecular mass. They concluded that these phytochemicals are active in the inhibition process if they can be adsorbed on the surface to prevent corrosion attacks. Other food wastes reported in the literature as effective corrosion inhibitors are presented in Table 6 along with the metals/alloy corrosion they inhibited and reported average efficiency.

Table 6 Literature values on the inhibition of corrosion by food waste

Food waste	**Aggressive medium**	**Metal/Alloy**	**Inhibition efficiency (%)**	**References**
Fermented Punica granatum waste	Acidic	Iron	40.00	Magni et al. (2020)
Waste cooking oil	Acidic	Mild steel;	99.96	Cholidah *et al*. (2024)
Green ostrich fat waste	Acidic	Steel	94.00	Errami, *et al*. (2024)
Cattle manure	Acidic	Steel	95.00	Mondal *et al*. (2025)
Sorghum wastes from Brewery	Acidic	Aluminium	80.00	Ukpe (2019)
Green tea waste	Acidic medium	Mild steel	85.00	Ali & Ahmed (2021)
Orange peel	Acidic	Mild steel	85.00	Pereira & Silva (2022)
Banana peel	Acidic	Steel	7.00	Adeyemi & Olayanju (2021)

Plastic waste has also been found to be effective as coating materials against the corrosion of some metals. For example, Lalita *et al*. (2024) observed improved coating of mild steel surfaces using plastic waste and attributed the success to effective barrier formation. Hameed *et al*. (2017) also observed that solvent-free glycolysis of plastic wastes produced Bis-(3-hydroxy-propyl)-terephthalate, which was very effective against the corrosion of carbon steel in an acidic medium. The inhibition efficiency was attributed to the molecular structure and properties of the glycolysis product. Brewery waste was found to be useful as an inhibitor by Ukpe (2019). The analyzed waste, mostly sorghum-derived waste materials, showed a composition that reflected compounds that meet the requirements for effective corrosion inhibition (Eddy *et al*., 2010; Odoemelam *et al.,* 2009). Table 7 shows some operational electricity plants in various countries that is currently relying on solid wastes as their feedstocks.

Table 7 Location and generation capacity of some solid waste-based electricity generating plants

Waste Type	**Location of Plant**	**Capacity of Electricity Generated**	**References**
Biomass (Wood waste)	Fortum, Finland	31.84 MW	Fortum (2024)
Wood and Agricultural Waste	Burnside, Australia	181 MW	Dastjerdi *et al*. (2019)
Tire Waste (Rubber)	Cyprus	17. 8MW	Tsangas *et al*. (2024)

Plastic Waste	Copenhagen, Denmark (Amager Bakke Plant)	63 MW	Kamuk (2024)
Sewage Sludge	Vienna, Austria	0.76 GW	eeNews Europe (2024)
Agricultural Waste	Punjab, India	77.3 MW	Sangeet and Kumar (2020)
Wood Waste (Wood Chips)	Kota Kinabalu, Malaysia	36 MW	Fazeli *et al*. (2016)

Concerning the conversion of solid wastes to nanoparticles, they have wider applications because of their mechanical, electrical, electronic, thermal, surface, optical, physicochemical, and photoluminescence properties. For example, waste crustacean shells such as periwinkle, oyster, crab, mussel shells, etc), egg shells. Animal bones (fish, chicken, goat), shells of some plant seeds (coconut, palm kernel, etc), peels of some fruits (orange, pineapple, etc) and other solid waste materials are good precursors for various nanoparticles as shown in Table 8 below. Some reported applications of the nanoparticles are also included in the Table. 8. An overview of the Table confirms that various types of wastes have been applied for the synthesis of nanoparticles and that these nanoparticles have vast applications. Therefore, resource recovery towards the synthesis of nanoparticles has significant benefits that cover research, industries, the environment, electronics, and other sectors.

Table 8 Literature values for resource recovery from solid wastes for the synthesis of different types of nanoparticles

Solid waste	**Nanoparticles**	**Applications**	**References**
Periwinkle shells	CaO	Purification of tetracycline-contaminated water	Eddy *et al*. (2024a)
Oyster shells	CaO	Applied as a photocatalysts for the degradation of crystal violet dye in water	Eddy *et al*. (2024b)
Periwinkle	CaO	Treatment of water contaminated byPb^{2+}	Eddy *et al*. (2024c)
Eggshells	CaO	Antifungal and heavy metal removal from aqueous solution	Hemmami *et al*. (2024)
Rice husk	SIo_2	Anode-lithium-ion battery	Sudarman *et al*. (2024)
Maize wastes	SiO_2	Some predictions	Folorunso & Udongwo (2024)
Waste *Phaseolus vulgaris*	Carbon quantum dots	Fluorescence sensor for detecting plasticizer	Thakur *et al*. (2024)
Aluminium foil waste	Al_2O_3	Antimicrobial action	Saleh *et al*. (2024)
Onions peel waste	ZnO	The peel catalyzed the synthesis, and the nanoparticles showed significant antioxidant and antimicrobial effect	Islam *et al*. (2024)
Plastic Waste (Polyethylene)	Carbon nanotube (CNT)	No reported application but CNT has vast area applications	Li *et al*. (2020)

Table 9 presents a summary of the various sectors solid waste recovery can be useful and cut across, industrial, environmental, electronic, electrical and other sectors. The Table also presents information on some solid wastes not addressed in the previous sections, in addition to their various properties.

Table 9 Applications of Various Solid Wastes in Resource Recovery for Sustainable Development

Waste Material	Resource Recovered	Application	References
Food waste	Biogas (Methane)	Used for energy production (electricity generation, heating, and fuel), compost, and bioplastics production	Tchobanoglous & Kreith (2002)
Plastic waste	Chemicals (e.g., hydrocarbons, oils)	Used for fuel production (pyrolysis and gasification), biodiesel, and chemicals for industrial applications	Ilyas & Sapuan (2021)
Paper waste	Chemical products (e.g., cellulose, lignin)	Used for bioenergy production, compost, and in adsorbent production for water treatment	Ghosh & Chowdhury (2014)
Wood waste	Bio-oil, syngas, and charcoal	Used for bioenergy (via pyrolysis), biodiesel, and as a source of energy in industrial processes	Pardo & Pivkin (2022)
Textile waste	Chemical recovery (dyes, fibers, etc.)	Used in producing biofuels, biodiesel, adsorbents for water purification, and bio-based nanoparticles	Thrift & Stone (2019)
Electronic waste (e-waste)	Precious metals (gold, silver, copper)	Used for the recovery of high-value metals for electronics, biodiesel production, and fertilizers	Babu & Parvathi (2020)
Organic waste (e.g., yard waste)	Biogas and compost	Used for renewable energy production, soil enrichment, production of biofuels, and fertilizers	Díaz & Savage (2016)
Agricultural waste	Biofuels, biochemicals (e.g., ethanol)	Used in the production of biofuels (ethanol, biodiesel), fertilizers, bio-based chemicals, and nanoparticle synthesis	Zhang & He (2021)
Algae waste	Biofuels, biodiesel, pigments	Used for biofuel (biodiesel), adsorbents for water purification, and in the production of nanoparticles	Zubair et al. (2022)
Rubber waste	Biofuels, chemicals	Used for biodiesel, bio-oil, and chemicals for industrial applications, including in the production of photocatalysts	Memon et al. (2020)
Wooden Pallets	Biofuels, chemicals (e.g., bio-oil, syngas)	Used for bioenergy (pyrolysis), production of biofuels, and biochar for agricultural use	Faisal & Bhuiyan (2021)
Glass waste	Silica, alkali, and other by-products	Used for the production of chemicals, including for cement manufacturing and as a raw material in the production of adsorbents	Awasthi et al. (2021)
Construction and Demolition Waste (CDW)	Aggregates, metals, and minerals	Used for the recovery of aggregates for construction, metals for recycling, and for producing sustainable building materials	Bovea & Powell (2021)
Tire waste	Steel, carbon black, and oil	Used for recovering steel for recycling, carbon black in rubber, and oil for energy production	Choi et al. (2021)
Farming plastic waste	Chemicals, energy (e.g., fuel)	Used for the recovery of chemicals, biofuels, and other energy resources through pyrolysis	Niu & Xu (2020)

5. Possible Solution to Current Challenges

The present challenges in resource recovery from solid wastes include inefficient waste segregation, limited industrial scalability of recovery technologies, and inadequate awareness of the environmental and economic benefits of waste valorization. Many recovery processes remain energy-intensive and costly, posing barriers to their adoption by industries. Additionally, the lack of standardized methodologies for optimizing the synthesis of corrosion inhibitors and nanoparticles from waste materials hampers reproducibility and consistency in results. Poor infrastructure for waste collection and management further exacerbates the problem, particularly in developing countries.

To overcome these challenges, the adoption of advanced technologies for automated waste sorting and processing is essential. Governments and industries should invest in research and development to optimize resource recovery techniques and reduce their associated energy and cost requirements. Public-private partnerships can facilitate the establishment of centralized resource recovery facilities to promote industrial adoption. Raising public awareness about the value of solid waste through educational campaigns will encourage better waste disposal practices. Establishing policy frameworks that support waste valorization initiatives, including tax incentives and subsidies for green technologies, can drive innovation and adoption. By integrating these solutions, resource recovery from solid waste can become a key driver for sustainable development and environmental conservation.

6. Conclusion

The review presented in this work underscores the significant progress made in resource recovery from various classes of solid wastes, including food, industrial, and plastic wastes, as well as other categories. Food waste, being one of the most abundant forms, has proven valuable for producing corrosion inhibitors, nanoparticles, catalysts, biofuels, and other useful products. Notable examples include using plant extracts, such as Carica papaya and orange peel, as effective corrosion inhibitors for different metals and alloys. These findings emphasize the potential of phytochemical constituents in food waste for corrosion inhibition. Plastic waste has also shown effectiveness as coating materials for corrosion prevention, while solvent-free glycolysis products derived from plastic waste have demonstrated significant inhibition efficiency. Additionally, due to their composition, brewery and agricultural waste have proven useful as corrosion inhibitors.

Solid waste recovery has further advanced through the synthesis of nanoparticles with applications in environmental remediation, industrial processes, and electronics. Various solid waste materials, such as periwinkle shells, eggshells, and rice husks, have served as excellent precursors for nanoparticles used in water purification, catalysis, heavy metal removal, and other applications. The synthesis and application of nanoparticles from waste materials highlight the vast opportunities for resource recovery in sustainable development. The tables provided in this work offer comprehensive insights into the generation capacities of electricity from solid waste plants globally and the potential applications of synthesized nanoparticles.

The findings from this review affirm the crucial role of resource recovery in addressing environmental, energy, and industrial challenges. However, despite the promising advances, there is still a need for further research and industrial adoption of sustainable waste recovery technologies. The use of waste materials for corrosion inhibition, energy production, and nanoparticle synthesis demonstrates these recovery processes' environmental and economic value. Continued investment in research, technological innovation, and the development of scalable methods is necessary to harness the potential of resource recovery for sustainable development fully.

Based on the insights gained, it is recommended that governments, industries, and research institutions collaborate to promote resource recovery technologies. Effective waste management policies should encourage the segregation and collection of solid wastes for reuse. Furthermore, comprehensive public awareness campaigns are necessary to educate communities on the importance of waste recovery and its contribution to a circular economy. Expanding research efforts to optimize production methods and enhance the efficiency of resource recovery processes will also be essential for driving sustainable development and environmental conservation.

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