sustainability

Review

Plastic Waste Recycling, Applications, and Future Prospects for a Sustainable Environment

Ghulamullah Maitlo [1,*], Imran Ali [2,*], Hubdar Ali Maitlo [3,4], Safdar Ali [5], Imran Nazir Unar [6], Muhammad Bilal Ahmad [7], Darya Khan Bhutto [8], Ramesh Kumar Karmani [9], Shamim ur Rehman Naich [9], Raja Umer Sajjad [10], Sikandar Ali [11] and Muhammad Naveed Afridi [12]

[1] Department of Chemical Engineering, Dawood University of Engineering and Technology, Karachi 74800, Pakistan
[2] Department of Environmental Sciences, Sindh Madressatul Islam University, Aiwan-e-Tijarat Road, Karachi 74000, Pakistan
[3] Key Laboratory of Pollution Process and Environmental Criteria, Ministry of Education, College of Environmental Science and Engineering, Nankai University, Tianjin 300350, China
[4] Department of Energy and Environment Engineering, Dawood University of Engineering and Technology, Karachi 74800, Pakistan
[5] Asian Institute of Fashion Design, Iqra University, Karachi 75500, Pakistan
[6] Department of Chemical Engineering, Mehran University of Engineering and Technology, Jamshoro 76062, Pakistan
[7] MOE Key Laboratory of Thermo-Fluid Science and Engineering, Xi'an Jiaotong University, Xi'an 710049, China
[8] Department of Petroleum and Gas Engineering, Dawood University of Engineering and Technology, Karachi 74800, Pakistan
[9] Department of Computer System Engineering, Dawood University of Engineering and Technology, Karachi 74800, Pakistan
[10] Department of Earth and Environmental Sciences, Hazara University Mansehra, Mansehra 21120, Pakistan
[11] Department of Basic Science and Humanities, Dawood University of Engineering and Technology, Karachi 74800, Pakistan
[12] Department of Civil and Environmental Engineering, Hanyang University, Seoul 04763, Korea
* Correspondence: ghulam.maitlo@duet.edu.pk (G.M.); imranali@hanyang.ac.kr (I.A.)

Abstract: Plastic waste accumulation has been recognized as one of the most critical challenges of modern societies worldwide. Traditional waste management practices include open burning, landfilling, and incineration, resulting in greenhouse gas emissions and economic loss. In contrast, emerging techniques for plastic waste management include microwave-assisted conversion, plasma-assisted conversion, supercritical water conversion, and photo reforming to obtain high-value products. Problems with poorly managed plastic waste are particularly serious in developing countries. This review article examines the emerging strategies and production of various high-value-added products from plastic waste. Additionally, the uses of plastic waste in different sectors, such as construction, fuel production, wastewater treatment, electrode materials, carbonaceous nanomaterials, and other high-value-added products are reviewed. It has been observed that there is a pressing need to utilize plastic waste for a circular economy and recycling for different value-added products. More specifically, there is limited knowledge on emerging plastic waste conversion mechanisms and efficiency. Therefore, this review will help to highlight the negative environmental impacts of plastic waste accumulation and the importance of modern techniques for waste management.

Keywords: plastic waste; emerging strategies; recycling; high-value-added products; sustainable environment

Citation: Maitlo, G.; Ali, I.; Maitlo, H.A.; Ali, S.; Unar, I.N.; Ahmad, M.B.; Bhutto, D.K.; Karmani, R.K.; Naich, S.u.R.; Sajjad, R.U.; et al. Plastic Waste Recycling, Applications, and Future Prospects for a Sustainable Environment. *Sustainability* **2022**, *14*, 11637. https://doi.org/10.3390/su141811637

Academic Editor: Eleni Iacovidou

Received: 26 July 2022
Accepted: 13 September 2022
Published: 16 September 2022

1. Introduction

Considering stability and flexibility, the plastics are impeccably adequate for use with numerous accomplishments [1–3]. Plastics are now the world's third-largest production material, second only to concrete and steel [4]. Similarly, due to its widespread applications across the globe, plastic manufacturing may continue in the future [5,6]. The manufacturing and use of plastic products on a global level have been on the rise since 1950. Approximately 8300 million tons of plastic were made, and 6300 million tons of plastic waste were thrown in landfills or dispersed into the environment [1,7,8]. In addition, about 415 million tons of plastic are produced annually worldwide [9]. China is one of the largest plastics producers in the world. China has an (approximate) 25% share of plastics in the world. In the last five years, plastic production exceeded 77 million tons, while Europe's production exceeded 60 million tons [10]. Approximately 36% of plastics are used for packaging, 16% for construction, 15% for textile, 10% for consumer and institutional products, and the remaining 33% for the transportation of electronics and industrial products.

Plastic-based products are energy-demanding because they need 62–108 MJ of energy to produce 1 kg of plastic materials and more than 4% of oil and gas consumption globally [1]. The contribution of plastic waste to municipal solid waste (MSW) is significant and cannot be ignored [11,12]. For example, plastic materials in MSW in China and the United Kingdom are around 11%, the United States—13%, and the European Union—8% [1]. Sri Lanka, Vietnam, Indonesia, China, and the Philippines contribute approximately 56% of plastic waste [10]. Comparatively, recycling other waste materials (such as metal, paper, and glass) is higher than plastic waste. The recycling rate of metal waste is 80%, paper waste is 60%, and glass waste is around 50%. At the same time, the recycling of plastic waste is nearly 14–18% [1,13]. Likewise, part of recycling, 24% of plastic waste is managed through energy recovery, and the remaining 58–62% has directly been disposed of in landfills or open environments [14]. Due to the poor global waste management policies, around 10–12 tons of non-degradable harmful plastic waste have been dumped in water bodies [15,16]. It is also estimated that 1.2–2.4 tons of plastic waste enter the ocean from rivers annually [17,18].

Plastics are heterogeneous in nature; nonetheless, regarding most of their 'control', such as gasification and incineration, they are processed together, so they are not suitable for mechanical recycling as part of mixed plastics because they contain more polymers [19]. Therefore, specific technologies, such as pyrolysis, can be useful for recycling as a raw material or fuel. Disadvantages of discarded plastic recycling include a lack of plastic waste collection and processing infrastructure, complex recycling processes, low economic returns, and inadequate downstream consumers [20,21]. Furthermore, cheap crude oil promotes virgin plastic production costs lower than recycling [22]. For instance, from 2006 onward, the price of low-density polyethylene (PE) in the United States fell by 95% from USD 480 to USD 26 per ton. Polypropylene (PP) and poly(ethylene terephthalate) (PET) fell by 90% and 7%, correspondingly [23]. The recovery rate proves the severe failure of the traditional "take, make, and discard" model. However, many plastic types are not suitable for this unique system; thus, recycling, recovery, and reusing are better solutions because plastic products may not be fully stopped [24]. For instance, PET-based plastics are more appropriate for infrastructure development [25]. Likewise, the conversion of mixed plastics to their chemical compositions is technically problematic and economically unfeasible [26].

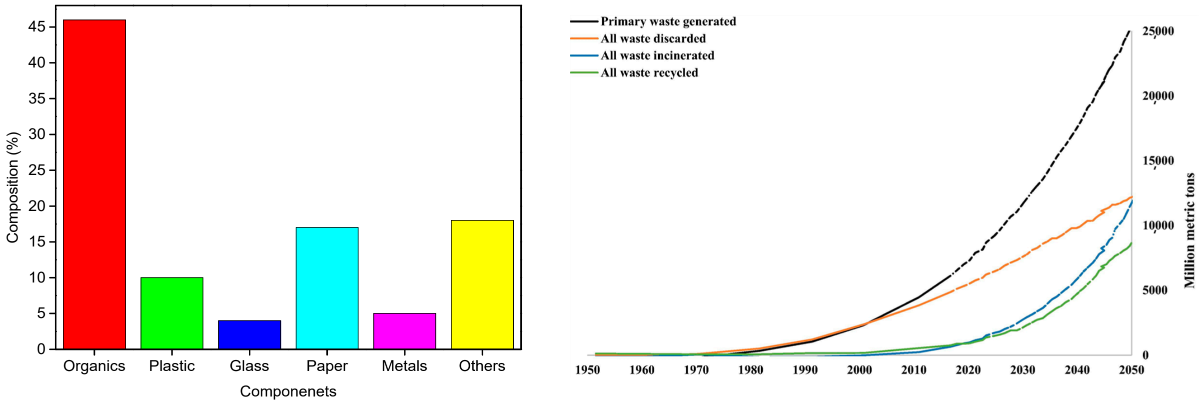
Therefore, long-term solutions are required as a comprehensive approach and circular economy principles, including open-loop and closed-loop systems. These paradigm shifts will further promote the expansion of the recycling system because it decreases the wasting of raw materials and the over-exploitation of resources. Technological innovation minimizes the problem of discarded plastic; however, the sustainability of this innovation and implementation still deserves attention [27,28]. In several recent studies, life cycle assessment (LCA) was used to study the environmental sustainability of one or more systems in specific cases. Schwartz et al. [29] calculated the ecological impact of ten nominated recycling technologies for plastic polymers. Lee et al. [30] evaluated the carbon footprint of converting discarded plastic into energy through pyrolysis in South Korea. Gu et al. [31] performed LCA for discarded plastic management using mechanical recycling in China. Likewise, using pyrolysis technology, LCA was used for chemical recycling of mixed discarded plastic and compared with recycling [32]. Bajpai et al. [33], found that the combination of both chemical and mechanical recycling of lightweight packaging is more environmentally friendly and economically advantageous than mechanical recycling alone. Keldrup et al. [34] found that compared to centralized recycling in Singapore, the impact of categorization and reuse of plastic waste is approximately 7–30% higher.

A historic resolution, entitled "End plastic pollution: towards an internationally legally binding instrument" was passed by the United Nations (UN) Environment Assembly in Nairobi, on 2 March 2022, comprising 175 representatives from different countries, who endorsed ending plastic waste in the environment. The resolution endorsed the establishment of an intergovernmental negotiating committee (INC) to initiate a negotiation, aiming to complete the draft of a legally binding agreement by the end of 2024. The resolution aims to address three main objectives, which would reflect: (i) different alternatives to focus on the full lifecycle of plastic waste, (ii) the design of recyclable and reusable plastic materials and products, and (iii) the need for improved international collaboration to facilitate access to new technology. The European Union (EU) is addressing the global agreement on plastic waste to maintain the global shift to a circular economy, endorsing the UN resolution of March 2022 to end plastic pollution.

Plastic waste accounts for more than 11% of the total MSW disposed of in landfills [35]. Consequently, it is important to design potential strategies for plastic waste management. Therefore, the gist of this review is to discuss an environmentally sustainable plan from a range of different technologies. Furthermore, this review article aims to discuss promising methods for utilizing plastic waste for a circular economy, e.g., the application of plastic waste in construction aggregates, electrode materials, carbonaceous materials, fuel production, wastewater treatment, textile products, and other high-value-added materials. Moreover, the global production of plastic waste and its environmental impacts are critically examined.

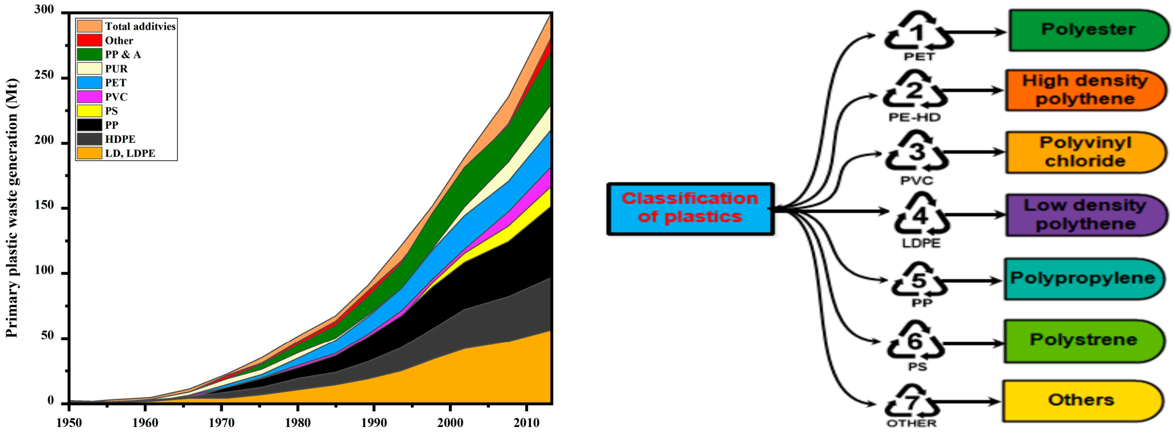
1.1. Production, Types, and Characteristics of Plastic Waste

Figure 1a shows the global contribution of plastic waste in MSW. However, the organic matter, plastic, glass, paper, metal, and others in MSW are 46%, 10%, 4%, 17%, 5%, and 18%, respectively [36]. Figure 1b shows the trend of waste generated, discarded, recycled, and incinerated from 1950 to the data projections for 2050. Figure 1c shows the distribution of global plastic waste generated (in million tons).



(**a**) (**b**)

Figure 1. *Cont.*



(**c**) (**d**)

Figure 1. (**a**) Global MSW composition and plastic waste contribution in MSW. (**b**) Cumulative plastic waste generation and management techniques. Reprinted with permission from Reference [37]. Copyright 2020 Elsevier. (**c**) Distribution of global plastic waste generated (in million tons). Reprinted with permission from Reference [37]. Copyright 2020 Elsevier. (**d**) Classification of different types of plastic.

Updated data show that since 1950, the global plastics industry has increased at an average annual rate of 2.7 times. In 2018, the global market for plastic products was estimated at 359 million tons [38]. The economic developments of many countries worldwide show that the greater the economic growth, the higher the use of plastic. According to statistics, the average annual plastic consumption in the United States is 170 kg, in Belgium 200 kg, in China 46 kg, and in India just 9.7 kg per capita [39]. The classification of plastic is given in Figure 1d. Thermoplastics, e.g., polyethylene, poly(vinyl chloride), polypropylene, polystyrene, polycarbonate, and poly(tetrafluoroethylene) are hardened when cooled [40]. Thermosetting plastics do not undergo plastic deformations when heated [41]. The available plastic materials are abundant, the output is large, the application is wide, the cost is low, and the molding process is easy [42]. Different types of plastics and their characteristics are given in Table 1.

Table 1. Different types of plastics and their characteristics.

Plastic	**Proximate Analysis (wt. %)**				**Elemental Analysis (wt. %)**						**Heating Value (MJ/kg)**	**Reference**	**H/C Efficiency**
	V M	FC	A	M	C	H	N	O	S	Cl			
PET	86.83	13.11	0	0.06	62.51	4.19	0	33.30	0	-	30.85	[43]	0.01
	85.0	10.6	4.4	0	66.2	4.9	0	28.9	0	0	-	[44]	0.23
	87.1	12.9	-	-	62.1	4.8	-	33.1			23.92	[45]	0.13
	89.2	10.3	0.1	0.4	62.7	4.4	0	32.8	0	-	23	[46]	0.06
	88.61	11.39	-	-	64.22	4.65	0.05	30.53	0.55	-	-	[47]	0.15
	84.1	13.9	-	-	64.1	3.7	-	34.2	-	-	23.97	[48]	0.11
	83.92	13.78	1.84	0.46	62.48	4.80	0.32	-	0	-	40.34	[49]	0.91
	90.57	9.43	0	0	62.93	4.26	0	32.81	0	-	21.25	[50]	0.03
HDPE	99.46	0	0.34	0	81.45	12.06	0.34	5.36	0.79	0	-	[51]	1.66
	100	0	0	0	82.9	15.47	0	1.63	0	0	-	[44]	2.21
	100	-	-	-	85.43	14.21	0.08	0.15	-	-	38.66	[52]	1.99
	100	0	0	0	85.11	14.57	0.32	0	0	-	-	[53]	2.04
	100	-	-	-	85.86	14.14	-	-	-	-	-	[54]	1.98
	99.7	0.3	-	-	85.71	14.29	0	0	-	-	43.1	[55]	2
	99.9	0	0.1	0	85.5	14.5	0	0	0	-	46.4	[46]	2.04
	99.4	-	0.6	-	83.8	14.2	-	-	0.3	-	-	[56]	2.03

Table 1. *Cont.*

Plastic	Proximate Analysis (wt. %)				Elemental Analysis (wt. %)						Heating Value (MJ/kg)	Reference	H/C Efficiency
	97.15	-	0.8	0	86.5	15.1	-	-	0.25	-	43.01	[48]	2.09
	100	0	0	0	85.4	14.6	-	-	-	-	-	[57]	2.05
PVC	94.9	5.1	0	0	39.6	4.9	0.5	0	1.8	53.2	-	[58]	1.42
	96.41	3.42	0	0.17	38.19	4.94	-	-	-	47.66	21.66	[59]	1.55
	95.8	4.2	0	0	38.7	4.8	0	0	0	56.5	19.3	[60]	1.49
	94.93	5.07	0	0	38.34	4.47	0.23	-	0.61	56.35	20.83	[61]	1.37
	-	-	-	-	39.66	5.24	0	-	0	55.04	20.38	[62]	1.59
	94.7	5.1	0.04	0.2	39.5	4.9	0.5	-	1.8	53.2	20.66	[63]	1.42
	94.78	5.06	0	-	38.56	4.6	0	0	0.4	57.04	19.88	[64]	1.42
	88.95	8.67	2.36	0.02	38.80	5.14	0.09	-	-	53.61	-	[65]	1.58
	94.75		5.25	0.64	38.15	4.35	0.16	-	0.45	56.25	-	[66]	1.35
	94.78	5.06	0	0.16	38.34	4.47	0.23	-	0	56.96	-	[67]	1.38
LDPE	100	0	0	0	82.18	16.37	0	1.45	0	0	-	[44]	2.36
	99.7	-	0.3	-	85.5	14.3	-	-	0.2	-	-	[56]	2.01
	99.9	-	0.1	-	85.9	14	-	-	-	-	43.1	[68]	1.96
	100	0	0	-	85.7	15.3	0	0	0	-	-	[69]	2.02
	99.08	0	0.02	0	86.35	13.58	0	0	0.074	-	46.15	[70]	1.89
	99.7	0.3	0.3	-	85.2	14.1	-	0.5	0.2	-	-	[71]	1.98
	100	0	0	-	85.46	13.54	0	1	-	-	-	[72]	1.88
PP	100	0	0	0	85.1	13.38	0	1.52	0	0	-	[44]	1.86
	100	0	0	0.08	84.80	14.55	0.14	0.28	0.23	-	45.80	[43]	2.05
	99.8	0	0.1	0.2	85.4	14.5	0	0	0	-	46	[46]	2.04
	98.9	-	1.1	-	83.8	13.9	-	-	2.3	-	-	[56]	1.97
	96.9	-	1	0	84.7	15.3	-	-	2.1	-	45.08	[48]	2.15
	93.84	2.04	3.68	0.44	83.28	13.81	0.01	-	0.01	-	44.43	[49]	1.99
	98.54	1.06	-	0.40	83.74	13.71	0.02	0.98	0.08	-	-	[73]	1.95
	99.6	0.1	0.2	0.1	86.5	12.9	0.3	-	0.3	-	37.6	[74]	1.78
	99.85	0	0.15	0	85.03	14.80	0	0	0	-	42.80	[65]	2.09
PS	100	0	0	0	91.2	8.8	0	0	0	0	-	[44]	1.16
	100	-	<0.3	-	90.9	7.7	<0.1	1.4	-	-	-	[75]	>0.99
	99.58	0.05	0.09	0.29	92.12	7.88	-	0.01	-	-	-	[76]	1.03
	99.5	0.5	-	-	92.2	7.8	-	-	-	-	-	[77]	1.02
	99.12	0.39	0.04	-	92.16	7.72	0	0	0.26	0.36	37.45	[64]	1
	99.76	0.24	0	0	92.04	7.29	0	0.67	-	-	-	[72]	0.94
	94.33	4.55	0.28	0.84	89.2	8.78	0.01	-	0	-	40.34	[49]	1.18
	97.71	0.45	0.98	0.86	90.34	9.06	0.29	0.31	-	-	43.58	[78]	1.19
	98.8	0	0.3	0.2	90.4	8.6	0.4	0.6	-	-	42.3	[79]	1.12
	99.24	0.02	0.24	0.50	90.55	7.82	0.17	0	1.22	-	38.60	[65]	1.02
	99.12	0.39	0.04	0.45	86.06	6.27	5.73	1.93	0	-	-	[67]	0.67
PC	80.47	19.48	0.05	0	75.71	5.47	0	18.82	-	-	30.08	[72]	0.49
PU	83.20	10.60	6.20	-	62.69	6.32	6.37	24.01	0.63	-	26.03	[80]	0.37
ABS	100	0	0	0.05	75.44	8.19	4.74	3.44	8.19	-	38.09	[43]	0.99

V denotes volatile matter, A represents ash, FC denotes fixed carbon, M shows moisture content, C shows carbon, H shows hydrogen, O represents oxygen, N denotes nitrogen, S denotes sulfur, Cl shows chlorine, HHV shows higher heating value, LHV denotes lower heating value, G shows gross heating value.

1.2. Plastic Waste Degradation and Socioeconomic Impacts

Although the use of plastics brings many benefits, unmanaged manufacturing, utilization, and discarding methods lead to the exhaustion of non-renewable assets, environmental problems, climate change, and a negative impact on the subsistence of flora and fauna [81]. Petroleum-based plastics in 2015, during their life cycle, emitted an equivalent of 1781 Mt CO_2. If the same trend is sustained, the emissions of petroleum-based plastics are expected to rise to an equivalent of 6500 Mt CO_2. in 2050 [82]. More specifically, between 1950 and 2015, 79% of plastic waste was reported as poorly managed. This means there are 5 billion tons of plastic waste in landfills or the natural environment. By 2050, the cumulative amount of plastic produced will reach 34 billion tons. According to the current consumption level, plastic waste in landfills or the environment will reach 12 billion tons [14]. Sub-Saharan Africa is one of the regions lacking waste-control resources. Waste produced by 2050 will surge by 300%, which coincides with the expected boom in plastic manufacturing in the region, demonstrating the determination of area [83]. Plastic waste, because of its stability, may be categorized as 'persistent pollutants'.

Figure 2 displays the time required for numerous plastic objects to degrade, for instance, the degradation of plastic bottles takes 450 years [84], but microplastics are formed that are ingested by the marine species [85,86] and appear in the form of seafood, salt, and water to us [85]. In oceans, nearly 51 trillion microplastics are floating. These floating microplastics are 500 times more than the stars in our galaxy. Synthetic fabrics, tires, road markings, ship coatings, and plastic particles add microplastics to oceans. Large numbers of animals are entangled in plastics. As per UNESCO statistics [87], more than 1 million birds and more than 0.1 million marine species die each year after ingestion or entanglement of plastic waste. Mato et al. [88] reported that the uptake of hazardous chemicals, i.e., pesticides by plastics, pollute the marine food chain, whereas Tanaka et al. [89] reported high levels of polybrominated diphenyl ethers in 3 of the 12 seabirds analyzed.

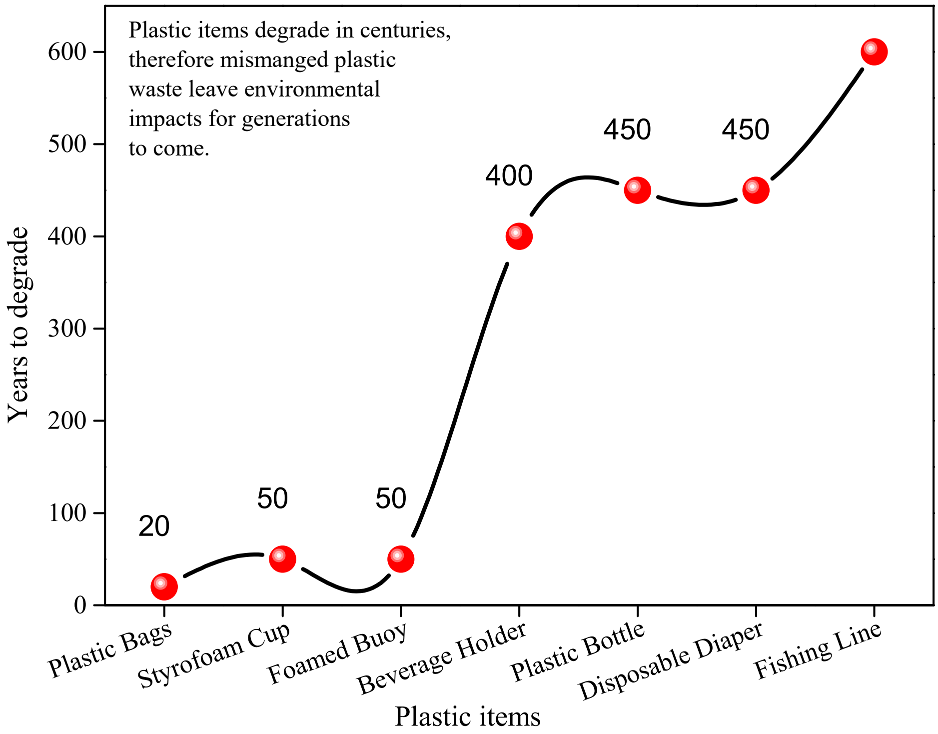
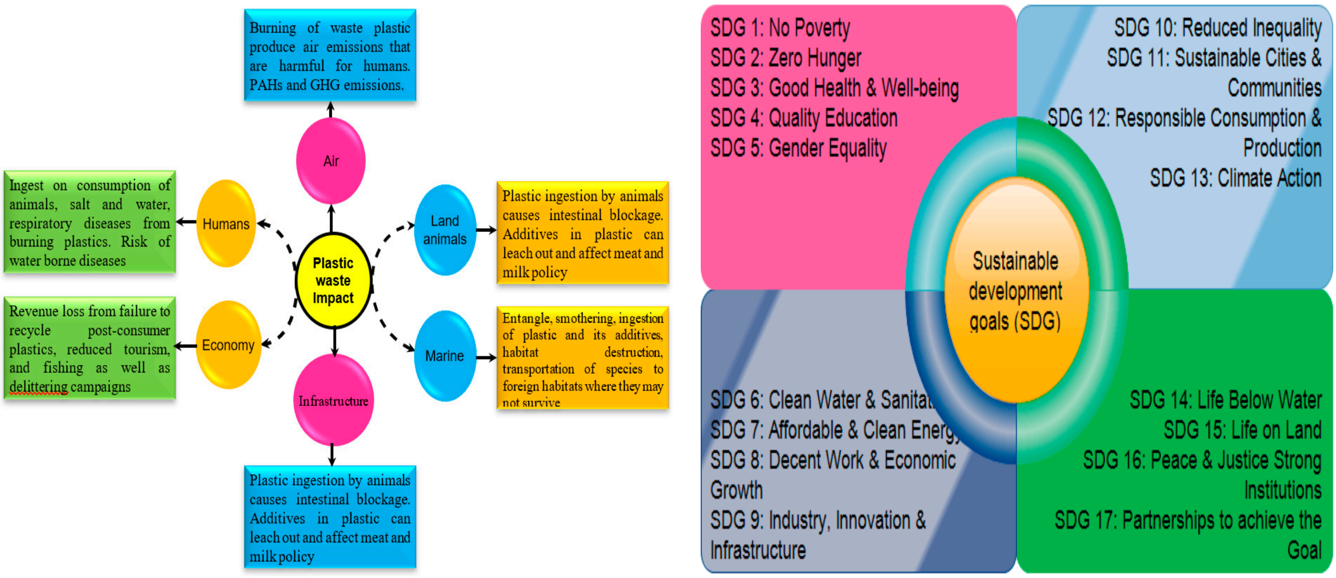


Figure 2. The degradation time of different types of plastic.

Furthermore, humans are worried about the potential impact of consuming marine species containing toxins that are harmful to humans [90], but their impact is still not fully understood [91]. This is worrying, so it is critical to carry out such potential impact assessments. Land animals, including goats, buffaloes, sheep, etc., face similar risks from ingesting plastic, blocking the gastrointestinal tract, and causing death. Chemical substances can escape from such plastics affecting beef and milk. In addition, clogged rainwater drainage systems, parasitic diseases as a breeding ground, indiscriminate fires, and possible respiratory disorders are associated with plastic waste pollution. According to reports, the total annual loss caused by plastic waste is approximately USD 13 billion, including tourism because of lessened aesthetics, recreational actions, and fishing [92]. Figure 3a shows the socioeconomic and environmental impacts of mismanaged plastic waste, and Figure 3b shows sustainable development goals.



(**a**) (**b**)

Figure 3. (**a**) Social, economic, and environmental impacts of mismanaged plastic waste. (**b**) Sustainable development goals and effects of mismanaged plastic waste.

2. Plastic Waste Management Strategies

Due to the non-degradable nature and poor waste management practices, a huge quantity of plastic waste has been accumulated in the environment [93,94]. Post-consumer plastic waste is generally managed through landfills, incineration, and recycling [95]. However, these methods have no substantial effects on decreasing the quantity of discarded plastic waste. Therefore, such techniques have nothing to do with practice because landfills and incineration cause serious environmental issues. Innumerable stakeholders have attempted to substitute the current discarded plastic waste control practices. In addition, reusing and recycling plastic waste is more effective than incineration and landfilling [96]. However, because of the increase in the amount of plastic waste generated every day, the current recycling strategies cannot reduce the negative effects of plastic pollution [97]. Therefore, it is necessary to find sustainable applications for plastic waste management to overcome these problems [98]. Figure 4 shows conventional and emerging strategies to overcome plastic waste problems.

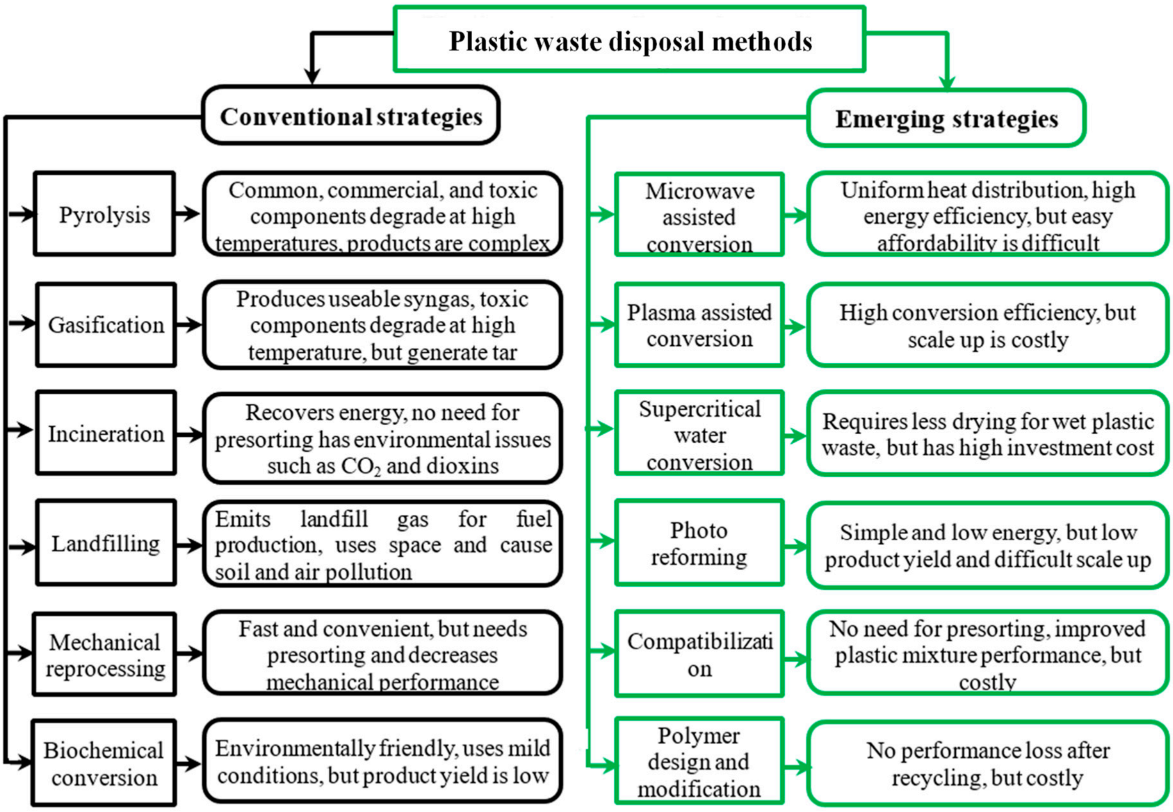


Figure 4. Plastic waste conventional and emerging management technologies. Reprinted with permission from Reference [99]. Copyright 2022 Elsevier.

2.1. Conventional Strategies

2.1.1. Plastic Waste Landfill

Landfilling is an ancient technique to handle solid waste issues, including plastic waste [100]. As per the OECD statistics, it is assessed that 79% of plastic waste is managed using landfills or leaked into the environment [8]. Plastic landfills are considered the last resort for managing plastic waste, as they require a lot of space and can cause long-term pollution problems [101]. Compared to other waste management practices; the operating costs of plastic waste-based landfill processes can be quite low, but the environmental issues of this technique are regularly questioned. Over time, toxic additives and other possible pollutants decomposing from discarded plastic will eventually contaminate the soil and water bodies [102]. Moreover, it is hard for discarded plastic (which has good physiochemical strength and long service life) to decompose naturally. At the same time, plastic waste is light and can float in the wind or on water [103]. Nevertheless, landfilling has severe disadvantages; discarded plastic, due to its low density, large volume, and large landfill space, has aggravated the scarcity of land resources [104]. The engineered landfill can produce synthesis gas that can be collected and used for energy production.

2.1.2. Incineration

Incineration is extensively applied as one of the treatment approaches used to decrease the volume of solid waste [105]. Incineration can reduce approximately 80% to 90% of different kinds of debris, which is an important advantage [106]. The incineration of plastic waste would emit hazardous emissions and detrimental constituents, including particulate matter, dioxins, CO, furans; metals, and volatile organic chlorides [107]. The incineration process helps to dispose of plastic waste on an industrial scale. Moreover, it produces heat energy used for electricity generation and other accomplishments [108]. Incineration of waste with a high moisture content of 60% to 65% is not feasible because it will affect the rate of energy production during incineration [109].

2.1.3. Pyrolysis

In pyrolysis, plastic waste is broken down into carbon monoxide, hydrogen, methane, and high-quality hydrocarbons, which can be used as fuel. Ruj et al. [110] established a process of directly converting mixed discarded plastic, except PVC, into synthesis gas, which is utilized to generate electricity. Huang et al. [111] and colleagues showed that, through accelerated decomposition, plasma pyrolysis reacted completely to the low molecular weight compound methane. The advantage of pyrolysis is that it has the ability to 'carry out' dirty and unsorted plastic waste. Pyrolysis is also non-toxic and has non-environmentally harmful emissions, unlike incineration. The disadvantages of pyrolysis are the lack of product control and low energy efficiency.

2.1.4. Gasification

Plastic waste is degraded by using gasification technology, such as air, steam, and oxygen to generate synthesis gas mainly comprising CO, H_2, and CH_4 [112]. The most frequently used technologies for plastic waste gasification are fixed beds, fluidized beds, and entrained flow gasifiers [113]. The combustion of discarded plastic produces hazardous gases, i.e., carbon dioxide, nitrogen oxide, sulfur oxide, and hydrocarbons [114]. Therefore, syngas produced through gasification is environmentally friendly compared to combustion [115]. The disadvantage of gasification involves air being used as a gasifying agent resulting in a decrease in the calorific value of produced syngas.

2.1.5. Mechanical Reprocessing

The primary recycling method for plastic waste is mechanical reprocessing, which comprises heating, shredding, and remolding [116]. This method of mechanical treatment of plastic waste mainly produces plastics with inferior properties [19]. The number of mechanical reprocessing cycles is limited. Thermal conversion processes, such as gasification and pyrolysis, are commonly used to produce low-value-added products, including syngas and other carbonaceous derivatives [117]. Moreover, in thermochemical conversion processes, high temperatures of 400 °C to 900 °C are maintained to overcome the unfavorable kinetics and thermodynamics of these reactions [117]. The advantages of mechanical reprocessing are that it is less energy intensive and does not use toxic chemicals. The disadvantage is that mechanical reprocessing often decreases the tensile strength of plastics.

2.1.6. Biochemical Conversion

Synthetic polymers having high molecular weights are biodegraded using microorganisms. However, the application of such microorganisms for biodegrading high molecular weight synthetic polymers is limited commercially [118,119]. The microorganisms interact with abiotic elements, particularly light and heat, to alter polymer structures and provide a favorable environment for enzymatic degradation [120]. The bacteria mainly involve the biodegradation of plastic waste, algae fungi found in compost, landfill leachate, and sewage sludge. The bacteria are capable of biodegrading synthetic and natural polymers. Microbial biomass is a waste product of biodegradation [121]. Biochemical conversion of plastic has the advantage of low processing temperatures and high selectivity of products produced. However, they usually require preprocessing phases and long treating times.

The pyrolysis and gasification of plastic waste are most suited for plastic waste conversion into valuable products. Furthermore, these methods are environment-friendly and do not require large spaces for plant installation.

2.2. Emerging Strategies

2.2.1. Microwave-Assisted Conversion

Compared to conventional strategies of plastic waste management, microwave-assisted conversion provides an efficient route for recycling plastic waste [122]. Microwave-assisted recycling of plastic waste accelerates the chemical reactions by reducing the reaction temperature and time, thus acquiring higher chemo-selectivity and production [123]. Furthermore, water as a reaction medium absorbs microwave energy efficiently and can be superheated. Microwave irradiation depolymerized biopolymers, including starch and cellulose, are rapid, efficient, and environmentally friendly [122]. Microwave-assisted conversion provides a circular economy because it produces chemicals used as property enhancers in polymers [124]. Microwave-assisted conversion has some advantages, such as non-contact volumetric heating and higher energy efficiency. The disadvantages are the electrical power and required microwave adsorbents.

2.2.2. Plasma Assisted Conversion

Polystyrene (under atmospheric pressure and ambient temperature) is efficiently hydrogenated using nonthermal plasma-assisted conversion [125]. Plasma-assisted nonthermal H_2 offers a unique source for obtaining a relative hydrogen species, particularly in radicals and ions that effectively break the C-C bond in the polymer structure. Furthermore, the plasma-assisted non-isothermal hydrogenolysis procedure directly valorizes products, excluding pretreatment importance, allowing minimum influence by impurities and contaminants [126]. Plasma-assisted conversion has some advantages, such as a higher yield of syngas and lower tar content. The limitation involves higher energy utilization during the plasma-assisted conversion process.

2.2.3. Supercritical Water Conversion

Traditional plastic waste management strategies cannot produce clean energy [127]. Therefore, supercritical water conversion technology produces efficient and clean energy from plastic waste. Different studies have been conducted to investigate the effect of supercritical water on plastic waste recycling [128]. Bai et al. [129] investigated the pyrolysis behavior of low-density polyethylene and heavy oil using supercritical water at a temperature of 420 °C and observed that HDPE as an H-donor tremendously inhibited the aromatic component condensation and coke formation. High H_2, low CO yields, a high reaction rate, and low tar and char formation are the advantages of this method. This method shows drawbacks for large-scale feasibility and might cause the plugging of reactors during long runs.

2.2.4. Photo Reforming

Researchers have extensively investigated photocatalytic reforming of plastic waste because of its high efficiency and environmentally friendly behavior [130]. Photo-reforming of plastic waste is a promising technology among various plastic waste management techniques, having the potential to harvest solar energy [131]. After harvesting solar energy, it is efficiently converted into high-energy-density hydrogen fuel. The promising solution to the energy crisis involves the photo-reforming of plastic waste because hydrogen is an ideal gas possessing a high energy value and zero environmental emissions [132]. A pretreatment method of plastic waste is commonly applied to enhance the reactivity of plastic photo-reforming to hydrolyze plastic into monomeric ethylene glycol. Moreover, numerous photocatalysts are synthesized for plastic photo-improving to produce hydrogen, including CN/Ni_2P and TiO_2/Pt [132,133].

2.2.5. Compatibilization

Additives allow two polymer resins to bond to improve the final product in compatibilization. Adding additives in plastic recycling facilitates the adherence of plastic blends that are difficult to mix with or adhere to. The plastic materials that are not easily recycled include composite plastics, flexible packaging, and other plastic materials best suited for chemical recycling through compatibilizers. There are high costs associated with the reactions that involve long residence times. Furthermore, such resins may be used as secondary raw material in another product, mitigating dependence on crude oil.

2.2.6. Polymer Design and Modification

In recent years, chemically recyclable polymers have been designed and developed to manage plastic waste at the end of its useable life. The mechanical reprocess degrades polymer quality and results in residual impurities after multiple reuse cycles [134]. Nevertheless, via depolymerization, chemical recycling can recover the precursor building blocks. The polymers that can easily be converted into monomers require low temperature (e.g., -40 °C) polymerization and are not suited for practical use. Moreover, chemically recyclable polymers suffer poor performance and are not extensively used as many virgin polymers. The recyclable liquid crystalline polymer composite was developed by Kort et al. [135] that can be recycled several times without a decrease in the mechanical properties by maintaining the molecular weight of the polymer. Although, the polymer design and modification are not used extensively because of the poor performance as compared to virgin plastic.

3. Applications of Plastic Waste in Different Sectors

3.1. Application of Plastic Waste in Construction

Currently, the application of discarded plastic in construction is considered one of the emerging concepts for managing large amounts of plastic waste and reducing environmental risks. The use of plastic waste is becoming one of the most stimulating processes in construction and has been extensively investigated in the last few years [136,137]. The application of discarded plastic in civil construction reduces the intake of natural aggregates. Many scientists have worked on the possibility of using various types of plastic waste for construction activities [138]. Much research has been conducted on multiple applications, such as masonry [139,140], pavement [141], and aggregate replacement in concrete [142,143]. Several investigations have previously been performed to evaluate the characteristics of discarded plastic as a fine and coarse aggregate.

Most plastic waste from previous research was refined into small particles to obtain a suitable size [144]. Then small plastic particles were added to various building activities including bricks, mortar, pavement, concrete, and others. Coppola et al. [145] showed that 10% and 25% of mortar comprising plastic aggregate could achieve tensile strengths of 35.12 and 22.86 MPa, respectively, which passed the American Concrete Institute's buildings standards (17.25 MPa). It is eminent that several patents have been approved for the use of discarded plastic as a composite material. Despite the proliferation of research, the making and use of discarded plastic as a manufacturing material is limited. The discarded plastic treatment industry has not yet developed, and most plastic waste products are used on a small-scale [146]. Figure 5 shows the schematic of plastic waste applications in construction activities.

Since construction materials are made from plastic waste, various environmental problems significantly impact the successful implementation. According to Zhang et al. [147], plastic trash can release small pollutants, negatively affecting the public and industry. Research studies on plastic waste applications in different construction activities are given in Table 2.

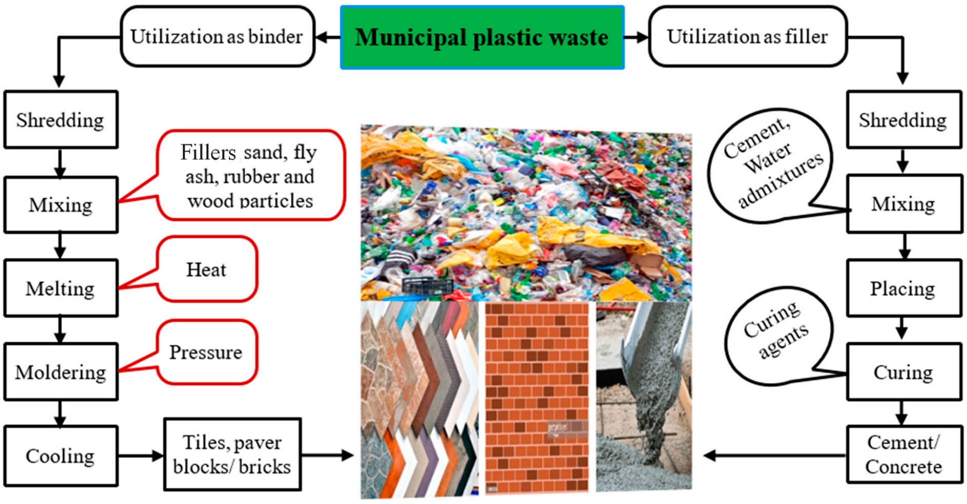


Figure 5. Schematic diagram showing the application processes of plastic waste as a construction material.

Table 2. Plastic waste applications in different construction activities.

Types of Composites	Types of Replacement	Types of Plastic	Percentage of Replacement (%)	Reference
Concrete	Fine	E-plastic	0, 5, 10, 15, 20	[148]
	Fine	Various	0, 15, 20, 30, 40, 50	[142]
	–	PET	0, 1, 3, 5, 7, 10	[149]
	Fine	HDPE	0, 10, 20	[150]
	Coarse	–	0, 15, 30	[138]
	Coarse	PVC	0, 25, 50, 75, 100	[151]
	Fine	Styrofoam	0, 30, 40, 50	[152]
	Fine	Various	0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55	[153]
	Coarse	MPW	0, 0.5, 1, 1.5, 2	[154]
	Fine	PET	0, 2.5, 5, 7.5	[155]
	Fine	PET	0, 5, 10, 15, 20	[156]
	Coarse	HDPE	0, 5, 10, 15, 20	[157]
	Fine and Coarse	Various	0, 5, 10, 15, 20	[158]
	Fine	PP	0–10	[159]
	Coarse	PS	0, 20, 40, 60, 80, 100	[160]
	Fine and Coarse	E-plastic	0, 5, 10, 15, 20, 25	[161]
	Coarse	E-plastic	0, 10, 20, 30	[162]
	Coarse	PS	0, 45, 67, 73, 82	[163]
	Fine	PET	0, 1, 2, 3	[164]
	Coarse	PET	0, 5, 10, 20	[165]
	Fine	E-plastic	0, 2, 4, 6, 8, 10	[166]
	Coarse	–	100	[167]
	Coarse	PS	0, 10, 20, 30, 40	[168]
	Coarse	PET	0, 5, 10, 15	[169]
	Coarse	HDPE	0, 10, 20, 30	[170]
	Fine	-	0, 5, 10, 15	[171]
	Fine	EPS	0, 15, 20, 25	[172]
	Coarse	HDPE	0, 25, 50	[173]
	Coarse	E-Plastic	0, 5, 10, 15, 18, 20	[143]
	Fine	PS	0, 25, 50, 70, 100	[174]
	Fine	PET	0, 10, 20, 30, 40, 50	[175]
	Fine	PVC & PP	0, 15, 30, 45, 60	[176]

Table 2. *Cont.*

Types of Composites	Types of Replacement	Types of Plastic	Percentage of Replacement (%)	Reference
Brick	–	Polyester	0, 10, 15, 20, 30	[140]
	Fine	PET	8	[177]
	Fine and Coarse	Various	0, 50, 100	[178]
	Coarse	LDPE	0, 5, 10, 15, 20	[179]
	Fine	LDPE	0, 20, 25, 30, 50	[180]
	Coarse	PET	0,1,3, 7	[139]
	Fine	PET	–	[181]
	Fine	EPS	0, 20, 30, 40, 50	[182]
	Fine	PP	0, 5, 10, 20, 100	[183]
	Fine	PET	0, 1, 1.5, 2, 2.5	[184]
	Fine	Various	10	[185]
	Fine	HDPE	3	[186]
	Fine	LDPE	0, 5,10, 15, 20	[187]
	Fine	E-plastic	0–10	[188]
	–	PET	0.5, 1, 1.5, 2	[189]
	Fine	HDPE&LDPE	0, 5, 10, 15 20, 25	[190]
	Coarse	PET	0, 5, 10, 15	[191]
Paver block	Coarse	PET & PP	0, 10, 20, 30	[192]
	Fine	PVC	0, 10, 20, 30	[193]
	Coarse	HDPE	0, 2, 4, 6, 8, 10	[141]
	Fine	PET	0, 25, 30	[194]
	Coarse	HDPE	0, 2, 4, 6, 8, 10	[195]
Mortar	Fine	LDPE	0, 10, 20, 30, 50	[196]
	Fine	Various	0, 10, 25, 50	[197]
	Fine	PP	0, 100, 150, 200	[198]
	Coarse	PP	0, 5, 7.5, 10, 12.5, 15	[199]
	Fine	PP & PE	0, 10, 25	[200]
	Fine	PP & PE	0, 10, 25	[145]
	Fine	PET & Polyolefin	0, 10, 15, 20	[201]
	Fine	PET	0, 5, 10, 15	[202]
	Fine	PC	0, 3, 10, 20, 50	[203]
	Fine	E-plastic	0, 2.5, 5, 7.5, 10, 12.5	[144]
	Fine	LDPE	0, 5, 10, 20, 30, 40, 50, 60	[204]
	Fine	PET	0, 2.5, 5, 10, 15, 20	[205]
	Fine	PET, POM, ABS, PC	0, 5, 15, 20	[206]

3.2. Application of Plastic Waste as an Electrode Material

Microbial fuel cell (MFC) is an emerging technique used for sustainably obtaining bioelectricity from the treatment of organic waste [207,208]. This method uses microorganisms and organic debris as raw materials and biocatalysts to generate bioelectricity. In recent years, numerous researchers have worked on improving MFC performance. In this regard, advanced conductive electrode materials have been introduced as anodes and cathodes to reduce MFC construction and operation costs [209]. Table 3 compares the bio-electrochemical system's different electrode materials derived from plastic waste.

Table 3. Comparison of different electrode materials derived from plastic waste for the bio-electrochemical system.

Types of MFC	Biocatalyst	Anode	Preparation Methods	Cathode	Open Circuit Potential (mV)	Power Density (mW m^{-2})	Reference
Single Chamber	*E. coli*	PANI/Graphene@carbon Cloth	In-situ electro polymerization	Platinum@Carbon Cloth	836	884 ± 96	[210]
Dual Chamber	*E. coli*	Fe-t-MOF/PANI@Stainless steel mesh	Chemical polymerization	Fe-t-MOF/PANI@Stainless steel mesh	670	680	[211]
Mediator Free Dual Chamber	*Shewanella putrefacien*	PANI/CNT@Graphene felt	Electropolymerization	Carbon Cloth	450	257	[212]
Dual Chamber	*Synthetic wastewater*	PANI/Polypyrrole@Stainless steel wool	Electrochemical polymerization	Platinum@Carbon Pape	595	2880	[213]
Mediator Free Dual Chamber	*S. oneidensis*	PANI/TiO_2@Graphene	Chemical polymerization	PANI/TiO_2@Graphene	880	1459	[214]
Dual Chamber	*Domestic sludge*	NiO/PANI@Carbon Felt	In-situ polymerization	Carbon felt	589.6	1078.8	[215]
Dual Chamber	*Shewanella putrefaciens*	PANI/Large mesoporous carbon (LMC)@Carbon Cloth	In situ chemical polymerization	Carbon Cloth	780	1280	[216]
Single Chamber	*Shewanella putrefaciens*	($MnFe_2O_4$)/Polyaniline (PANI)@Carbon Cloth	Hydrothermal	($MnFe_2O_4$)/Polyaniline (PANI)@Carbon cloth	871		[217]
Single Chamber	*Simulated wastewater*	PANI@stainless steel plates	Electro polymerization	Platinum@Carbon Paper	730	100	[218]

The electrodes based on Fe-t-MOF and PANI composite materials in MFC applications require more investigation. The high-efficiency MOF-based electrode catalytic performance provides new insight into the field of MFC electrodes. The PANI-based composite material improves the prepared electrode material conductivity and is cheaper than the platinum-based electrode. The diagram of converting plastic waste into electrode materials is shown in Figure 6.

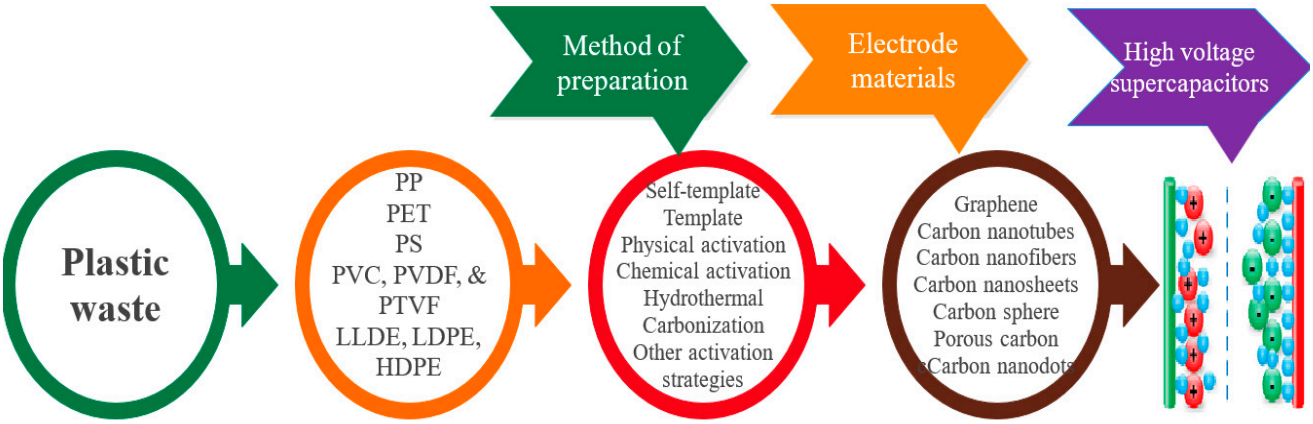


Figure 6. Application of plastic waste as an electrode material.

3.3. *Application of Plastic Waste in the Formation of Carbonaceous Nanomaterials*

The beneficial impacts on the ecological system have made the recycling of plastic waste a captivating issue in the scientific world. Chaudhary et al. [219] highlighted the sustainable approach of transforming plastic waste comprising bottles, used cups, and polyethylene bags via simple heating to fluorescent carbon dots (C-dots). The obtained C-dots displayed absorption peaks at around 260 nm with sizes of 5–30 nm. Recycling has produced structural changes in plastic waste and affected the optical properties of C-dots. The toxicity profiling of C-dots has been successfully tested by employing multi-assay bio-compatible activities, i.e., antibacterial and antifungal activities. The potential prospective of C-dots derived from plastic waste has been explored in analytical applications involving selective copper metal ion sensing in aqueous media. Chaudhary et al. [219] highlighted the potential accomplishment in preserving the environmental fate and responding to the budding social hitch of plastic waste. The conversion of plastic debris in forming different types of carbonaceous nanomaterials is depicted in Figure 7.

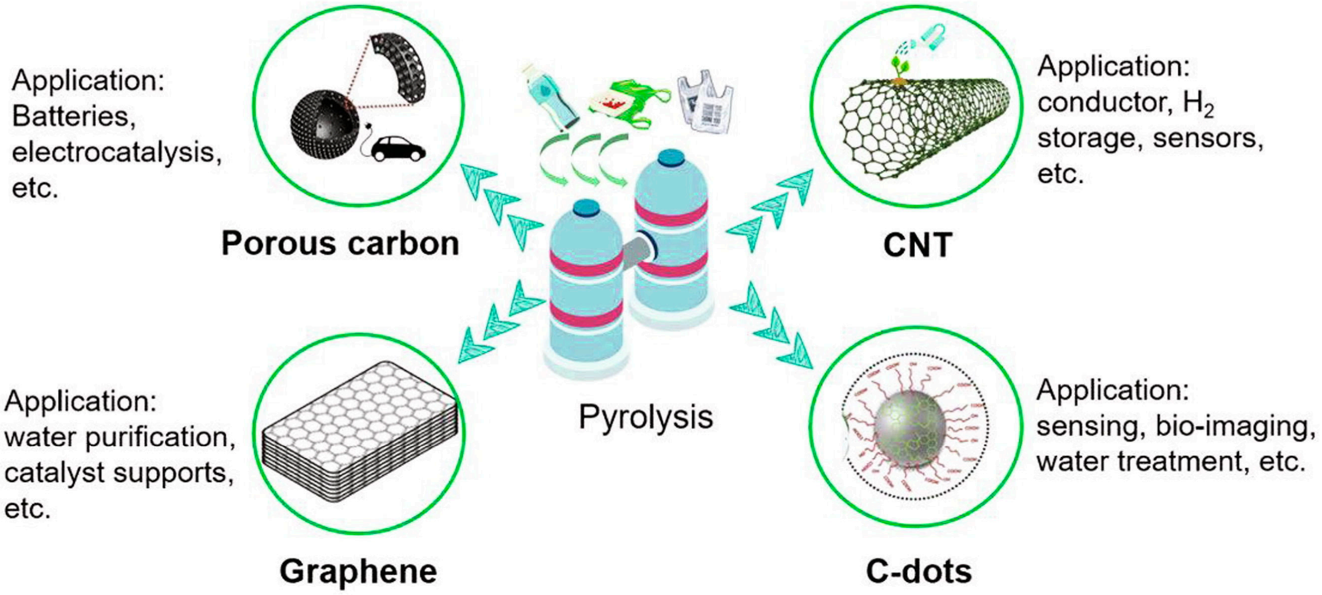


Figure 7. Nano-catalyzed pyrolysis carbonization of plastic waste in forming different types of carbonaceous nanomaterials. Reprinted with permission from Reference [220]. Copyright 2022 Elsevier.

3.4. Application of Plastic Waste in Fuel Production

Single-use plastic bags, disposable food containers, food wrap films, and their main components of polyethylene, polypropylene, and poly(vinyl chloride) can be photocatalytically transformed into valuable fuels without using sacrificial agents. Jiao et al. [221] described that plastic wastes could be converted into C_2 fuels over a photocatalyst under simulated natural environment conditions. Plastic waste was degraded into CO_2 by a photooxidative C–C bond cleavage; then the produced CO_2 was reduced into valuable C_2 fuels by a photoinduced C–C bond coupling. Szarka et al. [222,223] noted that PVC could be converted into oily products by a simple (and relatively low temperature) thermo-oxidative process. Figure 8 shows the schematic diagram of converting plastic waste into C2 fuel production via the photocatalytic process. Liu et al. [224] reported a direct method to selectively convert polyolefins to branched, liquid fuels, including diesel, jet, and gasoline-range hydrocarbons over nanomaterials in hydrogen. The process proceeds via tandem catalysis with the initial activation of the polymer, then subsequent cracking. Transforming plastic waste into fuel may help address the white pollution crisis and harvest highly valuable multi-carbon fuels.

3.5. Application of Plastic Waste in Wastewater Treatment

Plastic waste materials can be used to synthesize membranes and carbon-based adsorbent materials for wastewater treatment and reclamation. Adamczak et al. [225] synthesized an ultrafiltration membrane from polystyrene waste material. The synthesized membrane was used to treat river surface water. The polystyrene waste ultrafiltration membrane was tested with different concentrations of waste polymer to determine the membrane with the most favorable properties. Kumari et al. [226] converted solid waste plastic into activated carbon nanofibers through chemical activation and carbonization processes. The synthesized activated carbon nanofibers treated the thymol blue dye in wastewater via adsorption. These applications offered a great avenue for recycling plastic waste regardless of modifications or technical works to fulfill the important objective of water and wastewater treatment [227,228]. Fabrication of activated carbon materials from plastic waste for wastewater treatment is shown in Figure 9.

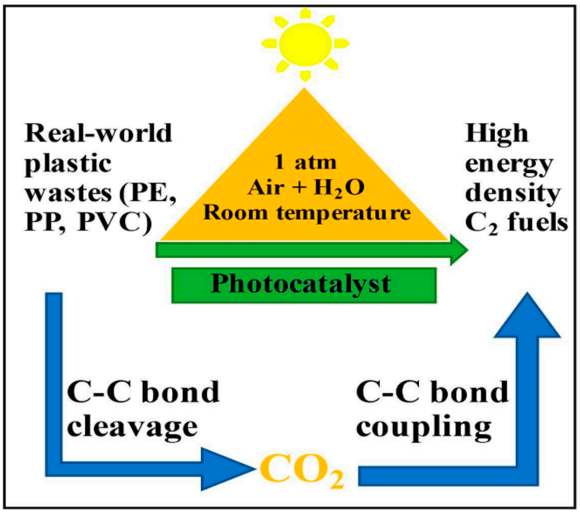


Figure 8. The schematic diagram for converting plastic wastes into valuable fuel production. Reprinted with permission from Reference [99]. Copyright 2022 Elsevier.

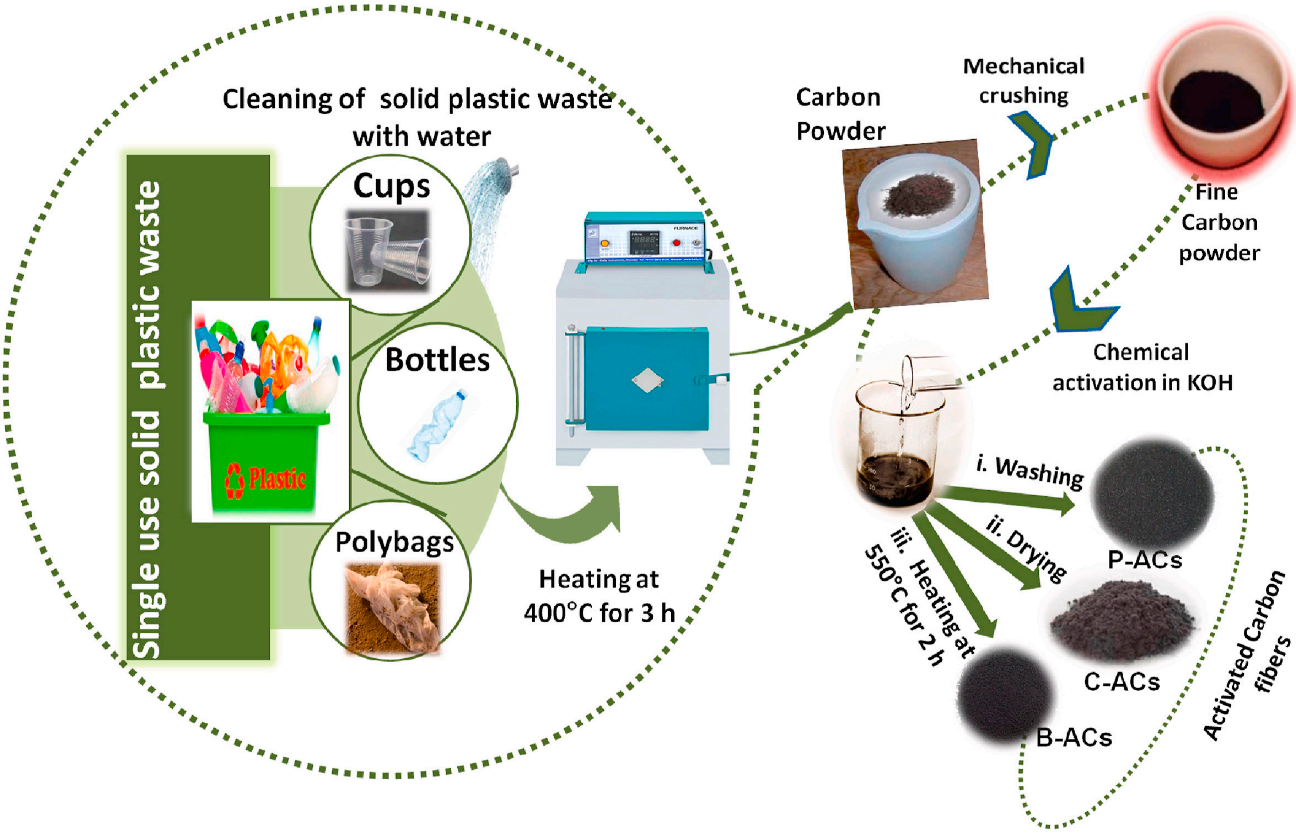


Figure 9. Schematic diagram showing the fabrication of activated carbon materials from plastic waste for wastewater treatment. Reprinted with permission from Reference [226]. Copyright 2022 Elsevier.

3.6. Application of Plastic Waste in Textile Products

Figure 10 shows plastic waste conversion into valuable textile products [229]. Recently, the Anta group had a breakthrough; overcoming many technical barriers, they developed a proficient method for producing polyester fiber from plastic bottles. The waste plastic bottles of 1 L and 550 mL were recycled using single energy technology clothing and resulted in a 30–50% reduction in overall processing costs compared to international brands. In China, carpet making by using waste plastic is well developed. A Shandong-based carpet manufacturing company has recycled around 2.6 billion waste plastic bottles to make 6 million blankets. Recycling plastic bottles not only reduces pollution but also comes with economic benefits. Another example is the red carpet used in China's military parade in 2019; it was spectacular, environmentally friendly, and prepared with 400,000 waste plastic bottles. The better functional properties observed in textiles and carpets produced by this technology are abrasion resistance, better elasticity, mildew, and insect resistance compared to animal and plant fibers [230].

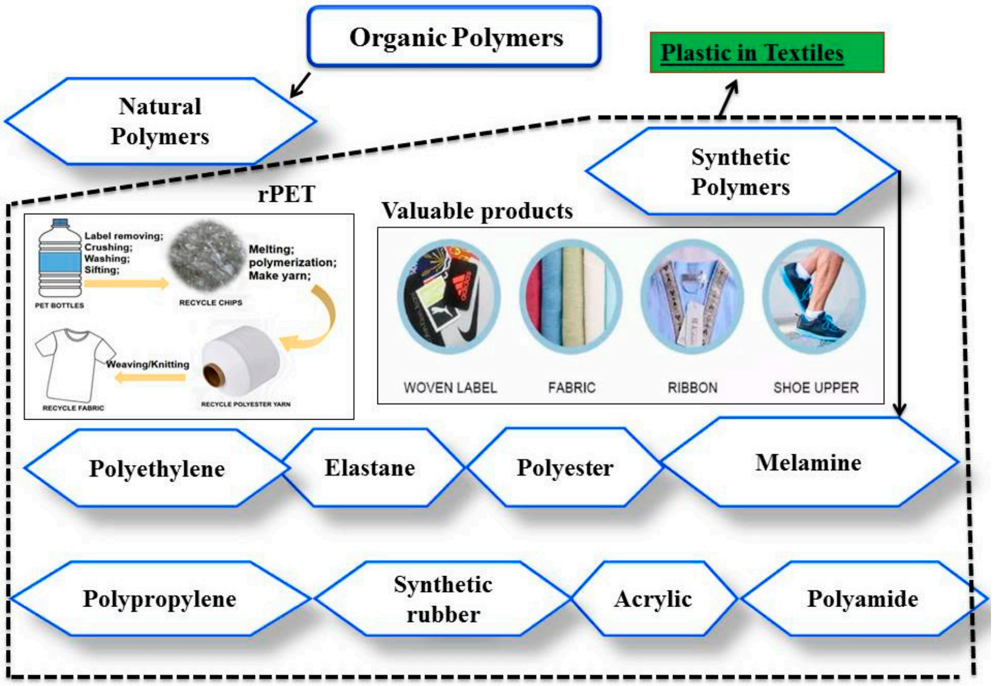


Figure 10. Application of plastic waste in various Textile products.

Watson et al., 2020, reported that 50–75% of synthetic textiles collected in Europe had been recycled or reused in other value-added textile products. Most non-reusable synthetic materials have been landfilled or incinerated [231]. PET is the most common fiber for sportswear, but acrylic, elastane, nylon, and propylene are also used. Fiber blends and functional coatings are commonly used in textiles for specific applications, such as footwear, which is comfortable, resistant to extreme weather, and fashionable. In sportswear textiles, moisture regulation and temperature are important characteristics to assure adequate thermal insulation while releasing body heat and sweat during exercise. A textile in sportswear also requires stretch ability for free movement and coatings for reduced wear and tear or injuries.

3.7. Application of Plastic Waste in Other High-Value-Added Products

Biological valorization can be used to recycle plastic waste and develop effective plastic waste recycling strategies. Kim et al. [232] evaluated the feasibility of the valorization of plastic waste for its recycling. For biological plastic waste valorization, plastic debris was depolymerized by chemical hydrolysis, and terephthalic acid and ethylene glycol monomers were converted to a variety of higher-value chemicals using various metabolically engineered whole-cell microbial catalysts. By introducing a terephthalic acid degradation pathway into microbes, terephthalic acid was converted into high-value-added aromatic or aromatic derived chemicals, namely, protocatechuic acid, gallic acid, pyrogallol, catechol, muconic acid, and vanillic acid, to be used for manufacturing pharmaceuticals, cosmetics, sanitizers, animal feeds, and bioplastic monomers, as shown in Figure 11.

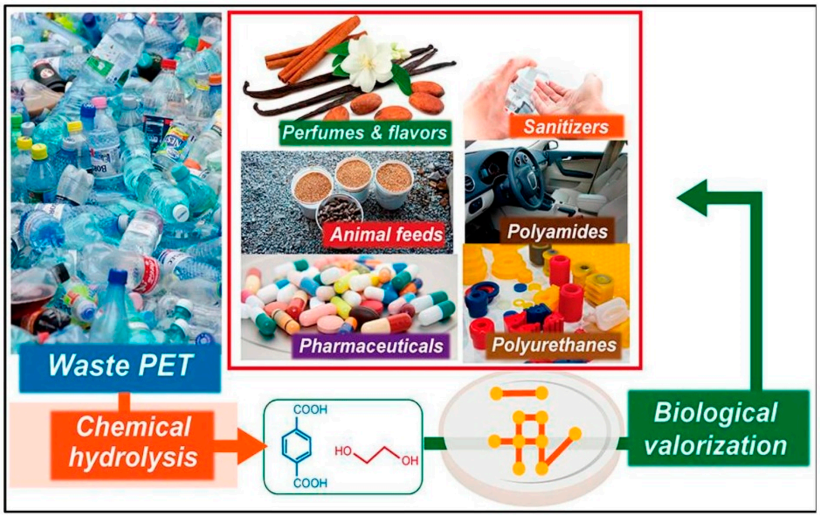


Figure 11. Schematic diagram of plastic waste recycling into high-value-added products. Reprinted with permission from Reference [99]. Copyright 2022 Elsevier.

4. Prospects

- Human activities pose ecological consequences and the increasing demand for resources and energy has resulted in a significant perspective on plastic waste management. The government and other related stakeholders should attain proper sustainable waste management strategies to maintain environmental sustainability.
- From the perspective of plastic waste recycling, most current studies focus on PET. Research should be expanded to other types of plastic waste (such as PP, PS, PVC, etc.) to minimize the burden on the environment.
- The government and responsible agencies should set regulations that will promote the further use of recycled plastic waste for construction purposes.
- Current plastic waste technologies for the conversion of plastic waste into textile products are not mature. Further research may be carried out to overcome the technical issues associated with this technology.
- Awareness sessions may be conducted in educational institutions and public places for the importance of plastic waste management and environmental sustainability.
- Innovation is an integrated approach used to achieve meaningful improvement and highlight the issues and challenges of fossil-based plastics.

5. Conclusions

Over the years, humans have massively deteriorated Earth's natural ecosystems, i.e., due to the high rate of synthetic plastic production/consumption, which is being discarded in the open environment without proper handling. A landfill is currently one of the main methods used for plastic waste management; however, its real-world application is extremely inefficient and inadequate. Recycling is another important method for handling plastic waste. The most effective plastic treatment method is to convert plastic waste into high-value-added components, such as tiles, paver blocks, concrete, sanitizers, perfumes, graphene, electrode materials, carbon nanotubes, etc. It has been determined that plastic is an unavoidable part of our lives, and its demand is increasing. Due to poor waste management practices, the current usage of plastic is unsustainable. Society faces a serious threat of plastic waste pollution that is being underestimated. We must decrease the amount of plastic waste dispersed on roads and rivers; construction materials established from recycled plastic waste are more durable and cost-effective. Appropriate handling of plastic waste provides a platform for creating wealth. Contact with toxic chemicals utilized during plastic production and improper waste control can pose serious problems to humans and the environment. Therefore, governments, regulatory bodies, and health administrations worldwide must take action, and consider the sustainable manufacturing, applications, and disposal of plastic waste.

Author Contributions: G.M. and I.A. performed the data entry, manuscript writing, and arrangement. H.A.M. and R.U.S. worked on the relevance of data regarding plastic waste application in electrode manufacturing. D.K.B. and S.A. (Sikandar Ali) worked on plastic waste conversion technologies. I.N.U. and S.u.R.N. performed applications related to aggregates in the concrete and construction industries. R.K.K. and M.B.A. performed the electrochemical analysis of plastic waste materials. S.A. (Safdar Ali) and M.N.A. worked on applying plastic waste to textiles and other valuable products. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors acknowledge the management of the Dawood University of Engineering and Technology and Sindh Madressatul Islam University for providing research facilities and the environment during this study. Additionally, H.A.M. acknowledges the grant from the National High-Level Foreign Experts (project nos. QN20200002003 and QN2022125001).

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

PET	poly(ethylene terephthalate)	CH_4	methane
LCA	life cycle assessment	H_2	hydrogen
HDPE	high density polyethylene	TiO_2	titanium dioxide
PVC	poly(vinyl chloride)	MPa	mega pascal
LDPE	low density polyethylene	MSW	municipal solid waste
PP	polypropylene	PANI	polyaniline
PS	polystyrene	MFC	microbial fuel cell
FC	fixed carbon	MOF	metal organic framework
HHV	higher heating value	PVDF	poly(vinylidene fluoride)
LHV	lower heating value	PTFE	poly(tetrafluoroethylene)
Cl	chlorine	LLDE	linear low-density polyethylene
MJ/Kg	millijoule per kilogram	mV	milli volt
H/C	hydrogen/carbon	CNT	carbon nanotubes
CO_2	carbon dioxide	Mn	manganese
Mt	million tons	Fe_2O_4	ferrous oxide
SDG	sustainable development goals	CO	carbon monoxide

References

1. Hossain, M.U.; Ng, S.T.; Dong, Y.; Amor, B. Strategies for mitigating plastic wastes management problem: A lifecycle assessment study in Hong Kong. *Waste Manag.* **2021**, *131*, 412–422. [CrossRef] [PubMed]
2. Klemeš, J.J.; Fan, Y.V.; Jiang, P. Plastics: Friends or foes? The circularity and plastic waste footprint. *Energy Sources Part A Recovery Util. Environ. Eff.* **2021**, *43*, 1549–1565. [CrossRef]
3. Joseph, B.; James, J.; Kalarikkal, N.; Thomas, S. Recycling of medical plastics. *Adv. Ind. Eng. Polym. Res.* **2021**, *4*, 199–208. [CrossRef]
4. Watts, J. Concrete: The most destructive material on Earth. *Guardian* **2019**, *25*, 1–9.
5. Mihai, F.-C.; Gündoğdu, S.; Markley, L.A.; Olivelli, A.; Khan, F.R.; Gwinnett, C.; Gutberlet, J.; Reyna-Bensusan, N.; Llanquileo-Melgarejo, P.; Meidiana, C. Plastic pollution, waste management issues, and circular economy opportunities in rural communities. *Sustainability* **2021**, *14*, 20. [CrossRef]
6. Kumar, R.; Verma, A.; Shome, A.; Sinha, R.; Sinha, S.; Jha, P.K.; Kumar, R.; Kumar, P.; Das, S.; Sharma, P. Impacts of plastic pollution on ecosystem services, sustainable development goals, and need to focus on circular economy and policy interventions. *Sustainability* **2021**, *13*, 9963. [CrossRef]

7. Boucher, J.; Friot, D. *Primary Microplastics in the Oceans: A Global Evaluation of Sources*; Iucn Gland: Gland, Switzerland, 2017; Volume 10.
8. Watkins, E.; Schweitzer, J.-P.; Leinala, E.; Börkey, P. Policy Approaches to Incentivise Sustainable Plastic Design. 2019. Available online: https://www.oecd-ilibrary.org/environment/policy-approaches-to-incentivise-sustainable-plastic-design_233ac351-en (accessed on 3 September 2022).
9. Azoulay, D.; Villa, P.; Arellano, Y.; Gordon, M.F.; Moon, D.; Miller, K.A.; Thompson, K.; Kistler, A. *Plastic & Health: The Hidden Costs of a Plastic Planet*; CIEL: Geneva, Switzerland, 2019.
10. Rhodes, C.J. Plastic pollution and potential solutions. *Sci. Prog.* **2018**, *101*, 207–260. [CrossRef]
11. Barchiesi, M.; Chiavola, A.; Di Marcantonio, C.; Boni, M.R. Presence and fate of microplastics in the water sources: Focus on the role of wastewater and drinking water treatment plants. *J. Water Process Eng.* **2021**, *40*, 101787. [CrossRef]
12. Xu, Q.; Xiang, J.; Ko, J.H. Municipal plastic recycling at two areas in China and heavy metal leachability of plastic in municipal solid waste. *Environ. Pollut.* **2020**, *260*, 114074. [CrossRef]
13. Haward, M. Plastic pollution of the world's seas and oceans as a contemporary challenge in ocean governance. *Nat. Commun.* **2018**, *9*, 667. [CrossRef]
14. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*, e1700782. [CrossRef]
15. Hu, H.; Jin, D.; Yang, Y.; Zhang, J.; Ma, C.; Qiu, Z. Distinct profile of bacterial community and antibiotic resistance genes on microplastics in Ganjiang River at the watershed level. *Environ. Res.* **2021**, *200*, 111363. [CrossRef] [PubMed]
16. Bulannga, R.B.; Schmidt, S. Uptake and accumulation of microplastic particles by two freshwater ciliates isolated from a local river in South Africa. *Environ. Res.* **2022**, *204*, 112123. [CrossRef] [PubMed]
17. Maghsodian, Z.; Sanati, A.M.; Tahmasebi, S.; Shahriari, M.H.; Ramavandi, B. Study of microplastics pollution in sediments and organisms in mangrove forests: A review. *Environ. Res.* **2022**, *208*, 112725. [CrossRef] [PubMed]
18. James, K.; Kripa, V.; Vineetha, G.; Padua, S.; Prema, D.; Babu, A.; John, S.; John, S.; Lavanya, R.; Joseph, R.V. Microplastics in the environment and in commercially significant fishes of mud banks, an ephemeral ecosystem formed along the southwest coast of India. *Environ. Res.* **2022**, *204*, 112351. [CrossRef]
19. Ragaert, K.; Delva, L.; Van Geem, K. Mechanical and chemical recycling of solid plastic waste. *Waste Manag.* **2017**, *69*, 24–58. [CrossRef]
20. Tesfaye, W.; Kitaw, D. Conceptualizing reverse logistics to plastics recycling system. *Soc. Responsib. J.* **2020**, *17*, 686–702. [CrossRef]
21. Siltaloppi, J.; Jähi, M. Toward a sustainable plastics value chain: Core conundrums and emerging solution mechanisms for a systemic transition. *J. Clean. Prod.* **2021**, *315*, 128113. [CrossRef]
22. Schyns, Z.O.; Shaver, M.P. Mechanical recycling of packaging plastics: A review. *Macromol. Rapid Commun.* **2021**, *42*, 2000415. [CrossRef]
23. Demetrious, A.; Crossin, E. Life cycle assessment of paper and plastic packaging waste in landfill, incineration, and gasification-pyrolysis. *J. Mater. Cycles Waste Manag.* **2019**, *21*, 850–860. [CrossRef]
24. Bucknall, D.G. Plastics as a materials system in a circular economy. *Philos. Trans. R. Soc. A* **2020**, *378*, 20190268. [CrossRef] [PubMed]
25. Mohan, H.T.; Jayanarayanan, K.; Mini, K. Recent trends in utilization of plastics waste composites as construction materials. *Constr. Build. Mater.* **2020**, *271*, 121520. [CrossRef]
26. Mastellone, M.L. Technical description and performance evaluation of different packaging plastic waste management's systems in a circular economy perspective. *Sci. Total Environ.* **2020**, *718*, 137233. [CrossRef] [PubMed]
27. Urbinati, A.; Chiaroni, D.; Toletti, G. Managing the introduction of circular products: Evidence from the beverage industry. *Sustainability* **2019**, *11*, 3650. [CrossRef]
28. Heacock, M.; Kelly, C.B.; Asante, K.A.; Birnbaum, L.S.; Bergman, Å.L.; Bruné, M.-N.; Buka, I.; Carpenter, D.O.; Chen, A.; Huo, X. E-waste and harm to vulnerable populations: A growing global problem. *Environ. Health Perspect.* **2016**, *124*, 550–555. [CrossRef]
29. Schwarz, A.; Ligthart, T.; Bizarro, D.G.; De Wild, P.; Vreugdenhil, B.; van Harmelen, T. Plastic recycling in a circular economy; determining environmental performance through an LCA matrix model approach. *Waste Manag.* **2021**, *121*, 331–342. [CrossRef]
30. Lee, D.; Nam, H.; Wang, S.; Kim, H.; Kim, J.H.; Won, Y.; Hwang, B.W.; Kim, Y.D.; Nam, H.; Lee, K.-H.; et al. Characteristics of fractionated drop-in liquid fuel of plastic wastes from a commercial pyrolysis plant. *Waste Manag.* **2021**, *126*, 411–422. [CrossRef]
31. Gu, F.; Guo, J.; Zhang, W.; Summers, P.A.; Hall, P. From waste plastics to industrial raw materials: A life cycle assessment of mechanical plastic recycling practice based on a real-world case study. *Sci. Total Environ.* **2017**, *601–602*, 1192–1207. [CrossRef]
32. Jeswani, H.; Krüger, C.; Russ, M.; Horlacher, M.; Antony, F.; Hann, S.; Azapagic, A. Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery. *Sci. Total Environ.* **2021**, *769*, 144483. [CrossRef]
33. Volk, R.; Stallkamp, C.; Steins, J.J.; Yogish, S.P.; Müller, R.C.; Stapf, D.; Schultmann, F. Techno-economic assessment and comparison of different plastic recycling pathways: A German case study. *J. Ind. Ecol.* **2021**, *25*, 1318–1337. [CrossRef]
34. Kerdlap, P.; Purnama, A.R.; Low, J.S.C.; Tan, D.Z.L.; Barlow, C.Y.; Ramakrishna, S. Comparing the environmental performance of distributed versus centralized plastic recycling systems: Applying hybrid simulation modeling to life cycle assessment. *J. Ind. Ecol.* **2021**, *26*, 252–271. [CrossRef]
35. Chan, W.W.; Lam, J. Environmental accounting of municipal solid waste originating from rooms and restaurants in the Hong Kong hotel industry. *J. Hosp. Tour. Res.* **2001**, *25*, 371–385. [CrossRef]

36. Mazhandu, Z.; Muzenda, E.; Mamvura, T.A.; Mohamed, B.; Nhubu, T. Integrated and Consolidated Review of Plastic Waste Management and Bio-Based Biodegradable Plastics: Challenges and Opportunities. *Sustainability* **2020**, *12*, 8360. [CrossRef]
37. Ayeleru, O.O.; Dlova, S.; Akinribide, O.J.; Ntuli, F.; Kupolati, W.K.; Marina, P.F.; Blencowe, A.; Olubambi, P.A. Challenges of plastic waste generation and management in sub-Saharan Africa: A review. *Waste Manag.* **2020**, *110*, 24–42. [CrossRef]
38. Barnes, D.K.; Morley, S.A.; Bell, J.; Brewin, P.; Brigden, K.; Collins, M.; Glass, T.; Goodall-Copestake, W.P.; Henry, L.; Laptikhovsky, V. Marine plastics threaten giant atlantic marine protected areas. *Curr. Biol.* **2018**, *28*, R1137–R1138. [CrossRef]
39. Trotta, J.T.; Watts, A.; Wong, A.R.; LaPointe, A.M.; Hillmyer, M.A.; Fors, B.P. Renewable thermosets and thermoplastics from itaconic acid. *ACS Sustain. Chem. Eng.* **2018**, *7*, 2691–2701. [CrossRef]
40. Ning, F.; Cong, W.; Qiu, J.; Wei, J.; Wang, S. Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling. *Compos. Part B Eng.* **2015**, *80*, 369–378. [CrossRef]
41. Chen, R.; Li, Q.; Xu, X.; Zhang, D. Comparative pyrolysis characteristics of representative commercial thermosetting plastic waste in inert and oxygenous atmosphere. *Fuel* **2019**, *246*, 212–221. [CrossRef]
42. Jiang, J.; Liu, X.; Lian, M.; Pan, Y.; Chen, Q.; Liu, H.; Zheng, G.; Guo, Z.; Schubert, D.W.; Shen, C. Self-reinforcing and toughening isotactic polypropylene via melt sequential injection molding. *Polym. Test.* **2018**, *67*, 183–189. [CrossRef]
43. Sajdak, M. Impact of plastic blends on the product yield from co-pyrolysis of lignin-rich materials. *J. Anal. Appl. Pyrolysis* **2017**, *124*, 415–425. [CrossRef]
44. Chhabra, V.; Bhattacharya, S.; Shastri, Y. Pyrolysis of mixed municipal solid waste: Characterisation, interaction effect and kinetic modelling using the thermogravimetric approach. *Waste Manag.* **2019**, *90*, 152–167. [CrossRef] [PubMed]
45. Chattopadhyay, J.; Kim, C.; Kim, R.; Pak, D. Thermogravimetric characteristics and kinetic study of biomass co-pyrolysis with plastics. *Korean J. Chem. Eng.* **2009**, *25*, 1047. [CrossRef]
46. Navarro, M.V.; López, J.M.; Veses, A.; Callén, M.S.; García, T. Kinetic study for the co-pyrolysis of lignocellulosic biomass and plastics using the distributed activation energy model. *Energy* **2018**, *165*, 731–742. [CrossRef]
47. Ansah, E.; Wang, L.; Shahbazi, A. Thermogravimetric and calorimetric characteristics during co-pyrolysis of municipal solid waste components. *Waste Manag.* **2016**, *56*, 196–206. [CrossRef]
48. Chattopadhyay, J.; Pathak, T.S.; Srivastava, R.; Singh, A.C. Catalytic co-pyrolysis of paper biomass and plastic mixtures (HDPE (high density polyethylene), PP (polypropylene) and PET (polyethylene terephthalate)) and product analysis. *Energy* **2016**, *103*, 513–521. [CrossRef]
49. Singh, R.K.; Ruj, B.; Sadhukhan, A.K.; Gupta, P. A TG-FTIR investigation on the co-pyrolysis of the waste HDPE, PP, PS and PET under high heating conditions. *J. Energy Inst.* **2020**, *93*, 1020–1035. [CrossRef]
50. Chen, L.; Wang, S.; Meng, H.; Wu, Z.; Zhao, J. Study on Gas Products Distributions During Fast Co-pyrolysis of Paulownia Wood and PET at High Temperature. *Energy Procedia* **2017**, *105*, 391–397. [CrossRef]
51. Chin, B.L.F.; Yusup, S.; Al Shoaibi, A.; Kannan, P.; Srinivasakannan, C.; Sulaiman, S.A. Comparative studies on catalytic and non-catalytic co-gasification of rubber seed shell and high density polyethylene mixtures. *J. Clean. Prod.* **2014**, *70*, 303–314. [CrossRef]
52. Chen, W.; Shi, S.; Zhang, J.; Chen, M.; Zhou, X. Co-pyrolysis of waste newspaper with high-density polyethylene: Synergistic effect and oil characterization. *Energy Convers. Manag.* **2016**, *112*, 41–48. [CrossRef]
53. Xiong, S.; Zhuo, J.; Zhou, H.; Pang, R.; Yao, Q. Study on the co-pyrolysis of high density polyethylene and potato blends using thermogravimetric analyzer and tubular furnace. *J. Anal. Appl. Pyrolysis* **2015**, *112*, 66–73. [CrossRef]
54. Kai, X.; Yang, T.; Shen, S.; Li, R. TG-FTIR-MS study of synergistic effects during co-pyrolysis of corn stalk and high-density polyethylene (HDPE). *Energy Convers. Manag.* **2019**, *181*, 202–213. [CrossRef]
55. Arregi, A.; Amutio, M.; Lopez, G.; Artetxe, M.; Alvarez, J.; Bilbao, J.; Olazar, M. Hydrogen-rich gas production by continuous pyrolysis and in-line catalytic reforming of pine wood waste and HDPE mixtures. *Energy Convers. Manag.* **2017**, *136*, 192–201. [CrossRef]
56. Zhou, L.; Wang, Y.; Huang, Q.; Cai, J. Thermogravimetric characteristics and kinetic of plastic and biomass blends co-pyrolysis. *Fuel Processing Technol.* **2006**, *87*, 963–969. [CrossRef]
57. Kim, Y.-M.; Jae, J.; Kim, B.-S.; Hong, Y.; Jung, S.-C.; Park, Y.-K. Catalytic co-pyrolysis of torrefied yellow poplar and high-density polyethylene using microporous HZSM-5 and mesoporous Al-MCM-41 catalysts. *Energy Convers. Manag.* **2017**, *149*, 966–973. [CrossRef]
58. Lu, P.; Huang, Q.; Bourtsalas, A.C.; Chi, Y.; Yan, J. Synergistic effects on char and oil produced by the co-pyrolysis of pine wood, polyethylene and polyvinyl chloride. *Fuel* **2018**, *230*, 359–367. [CrossRef]
59. Cao, B.; Sun, Y.; Guo, J.; Wang, S.; Yuan, J.; Esakkimuthu, S.; Bernard Uzoejinwa, B.; Yuan, C.; Abomohra, A.E.-F.; Qian, L.; et al. Synergistic effects of co-pyrolysis of macroalgae and polyvinyl chloride on bio-oil/bio-char properties and transferring regularity of chlorine. *Fuel* **2019**, *246*, 319–329. [CrossRef]
60. Ephraim, A.; Pham Minh, D.; Lebonnois, D.; Peregrina, C.; Sharrock, P.; Nzihou, A. Co-pyrolysis of wood and plastics: Influence of plastic type and content on product yield, gas composition and quality. *Fuel* **2018**, *231*, 110–117. [CrossRef]
61. Zhou, H.; Long, Y.; Meng, A.; Li, Q.; Zhang, Y. Interactions of three municipal solid waste components during co-pyrolysis. *J. Anal. Appl. Pyrolysis* **2015**, *111*, 265–271. [CrossRef]
62. Chen, L.; Wang, S.; Meng, H.; Wu, Z.; Zhao, J. Synergistic effect on thermal behavior and char morphology analysis during co-pyrolysis of paulownia wood blended with different plastics waste. *Appl. Therm. Eng.* **2017**, *111*, 834–846. [CrossRef]

63. Tang, Y.; Huang, Q.; Sun, K.; Chi, Y.; Yan, J. Co-pyrolysis characteristics and kinetic analysis of organic food waste and plastic. *Bioresour. Technol.* **2018**, *249*, 16–23. [CrossRef]
64. Wu, J.; Chen, T.; Luo, X.; Han, D.; Wang, Z.; Wu, J. TG/FTIR analysis on co-pyrolysis behavior of PE, PVC and PS. *Waste Manag.* **2014**, *34*, 676–682. [CrossRef] [PubMed]
65. Gunasee, S.D.; Carrier, M.; Gorgens, J.F.; Mohee, R. Pyrolysis and combustion of municipal solid wastes: Evaluation of synergistic effects using TGA-MS. *J. Anal. Appl. Pyrolysis* **2016**, *121*, 50–61. [CrossRef]
66. Chen, R.; Zhang, J.; Lun, L.; Li, Q.; Zhang, Y. Comparative study on synergistic effects in co-pyrolysis of tobacco stalk with polymer wastes: Thermal behavior, gas formation, and kinetics. *Bioresour. Technol.* **2019**, *292*, 121970. [CrossRef] [PubMed]
67. Meng, A.; Chen, S.; Long, Y.; Zhou, H.; Zhang, Y.; Li, Q. Pyrolysis and gasification of typical components in wastes with macro-TGA. *Waste Manag.* **2015**, *46*, 247–256. [CrossRef] [PubMed]
68. Gunasee, S.D.; Danon, B.; Görgens, J.F.; Mohee, R. Co-pyrolysis of LDPE and cellulose: Synergies during devolatilization and condensation. *J. Anal. Appl. Pyrolysis* **2017**, *126*, 307–314. [CrossRef]
69. Yu, D.; Hui, H.; Li, S. Two-step catalytic co-pyrolysis of walnut shell and LDPE for aromatic-rich oil. *Energy Convers. Manag.* **2019**, *198*, 111816. [CrossRef]
70. Zheng, Y.; Tao, L.; Yang, X.; Huang, Y.; Liu, C.; Zheng, Z. Study of the thermal behavior, kinetics, and product characterization of biomass and low-density polyethylene co-pyrolysis by thermogravimetric analysis and pyrolysis-GC/MS. *J. Anal. Appl. Pyrolysis* **2018**, *133*, 185–197. [CrossRef]
71. Zhou, L.; Zou, H.; Wang, Y.; Le, Z.; Liu, Z.; Adesina, A.A. Effect of potassium on thermogravimetric behavior and co-pyrolytic kinetics of wood biomass and low density polyethylene. *Renew. Energy* **2017**, *102*, 134–141. [CrossRef]
72. Jin, W.; Shen, D.; Liu, Q.; Xiao, R. Evaluation of the co-pyrolysis of lignin with plastic polymers by TG-FTIR and Py-GC/MS. *Polym. Degrad. Stab.* **2016**, *133*, 65–74. [CrossRef]
73. Yao, D.; Yang, H.; Chen, H.; Williams, P.T. Co-precipitation, impregnation and so-gel preparation of Ni catalysts for pyrolysis-catalytic steam reforming of waste plastics. *Appl. Catal. B Environ.* **2018**, *239*, 565–577. [CrossRef]
74. Pinto, F.; Miranda, M.; Costa, P. Production of liquid hydrocarbons from rice crop wastes mixtures by co-pyrolysis and co-hydropyrolysis. *Fuel* **2016**, *174*, 153–163. [CrossRef]
75. Sophonrat, N.; Sandström, L.; Zaini, I.N.; Yang, W. Stepwise pyrolysis of mixed plastics and paper for separation of oxygenated and hydrocarbon condensates. *Appl. Energy* **2018**, *229*, 314–325. [CrossRef]
76. Oyedun, A.O.; Gebreegziabher, T.; Ng, D.K.S.; Hui, C.W. Mixed-waste pyrolysis of biomass and plastics waste—A modelling approach to reduce energy usage. *Energy* **2014**, *75*, 127–135. [CrossRef]
77. Zhang, H.; Xiao, R.; Nie, J.; Jin, B.; Shao, S.; Xiao, G. Catalytic pyrolysis of black-liquor lignin by co-feeding with different plastics in a fluidized bed reactor. *Bioresour. Technol.* **2015**, *192*, 68–74. [CrossRef] [PubMed]
78. Özsin, G.; Pütün, A.E. Insights into pyrolysis and co-pyrolysis of biomass and polystyrene: Thermochemical behaviors, kinetics and evolved gas analysis. *Energy Convers. Manag.* **2017**, *149*, 675–685. [CrossRef]
79. Muneer, B.; Zeeshan, M.; Qaisar, S.; Razzaq, M.; Iftikhar, H. Influence of in-situ and ex-situ HZSM-5 catalyst on co-pyrolysis of corn stalk and polystyrene with a focus on liquid yield and quality. *J. Clean. Prod.* **2019**, *237*, 117762. [CrossRef]
80. Jin, Q.; Wang, X.; Li, S.; Mikulčić, H.; Bešenić, T.; Deng, S.; Vujanović, M.; Tan, H.; Kumfer, B.M. Synergistic effects during co-pyrolysis of biomass and plastic: Gas, tar, soot, char products and thermogravimetric study. *J. Energy Inst.* **2019**, *92*, 108–117. [CrossRef]
81. Enfrin, M.; Hachemi, C.; Hodgson, P.D.; Jegatheesan, V.; Vrouwenvelder, J.; Callahan, D.L.; Lee, J.; Dumée, L.F. Nano/micro plastics–Challenges on quantification and remediation: A review. *J. Water Process Eng.* **2021**, *42*, 102128. [CrossRef]
82. Zheng, J.; Suh, S. Strategies to reduce the global carbon footprint of plastics. *Nat. Clim. Chang.* **2019**, *9*, 374–378. [CrossRef]
83. Williams, M.; Gower, R.; Green, J.; Whitebread, E.; Lenkiewicz, Z.; Schröder, P. *No Time to Waste: Tackling the Plastic Pollution Crisis before It's Too Late*; Tearfund: London, UK, 2019.
84. Ritchie, H.; Roser, M. Plastic Pollution. Our World in Data. 2018. Available online: https://ourworldindata.org/plastic-pollution (accessed on 25 July 2022).
85. Lusher, A.L.; Hernandez-Milian, G.; O'Brien, J.; Berrow, S.; O'Connor, I.; Officer, R. Microplastic and macroplastic ingestion by a deep diving, oceanic cetacean: The True's beaked whale Mesoplodon mirus. *Environ. Pollut.* **2015**, *199*, 185–191. [CrossRef]
86. Zhang, K.; Hamidian, A.H.; Tubić, A.; Zhang, Y.; Fang, J.K.H.; Wu, C.; Lam, P.K.S. Understanding plastic degradation and microplastic formation in the environment: A review. *Environ. Pollut.* **2021**, *274*, 116554. [CrossRef] [PubMed]
87. UNESCO, N. Facts and Figures on Marine Pollution. 2017. Available online: https://ioc.unesco.org/topics/marine-pollution (accessed on 25 July 2022).
88. Mato, Y.; Isobe, T.; Takada, H.; Kanehiro, H.; Ohtake, C.; Kaminuma, T. Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. *Environ. Sci. Technol.* **2001**, *35*, 318–324. [CrossRef] [PubMed]
89. Tanaka, K.; Takada, H.; Yamashita, R.; Mizukawa, K.; Fukuwaka, M.-a.; Watanuki, Y. Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. *Mar. Pollut. Bull.* **2013**, *69*, 219–222. [CrossRef] [PubMed]
90. Gallo, F.; Fossi, C.; Weber, R.; Santillo, D.; Sousa, J.; Ingram, I.; Nadal, A.; Romano, D. Marine litter plastics and microplastics and their toxic chemicals components: The need for urgent preventive measures. *Environ. Sci. Eur.* **2018**, *30*, 13. [CrossRef] [PubMed]
91. Smith, M.; Love, D.C.; Rochman, C.M.; Neff, R.A. Microplastics in seafood and the implications for human health. *Curr. Environ. Health Rep.* **2018**, *5*, 375–386. [CrossRef]

92. Raynaud, J. *Valuing Plastics: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry*; UNEP: Nairobi, Kenya, 2014.
93. Wurm, F.R.; Spierling, S.; Endres, H.J.; Barner, L. Plastics and the Environment—Current Status and Challenges in Germany and Australia. *Macromol. Rapid Commun.* **2020**, *41*, 2000351. [CrossRef]
94. Lee, A.; Liew, M.S. Ecologically derived waste management of conventional plastics. *J. Mater. Cycles Waste Manag.* **2020**, *22*, 1–10. [CrossRef]
95. Mousavimehr, M.; Nematzadeh, M. Post-heating flexural behavior and durability of hybrid PET–Rubber aggregate concrete. *Constr. Build. Mater.* **2020**, *265*, 120359. [CrossRef]
96. Assamoi, B.; Lawryshyn, Y. The environmental comparison of landfilling vs. incineration of MSW accounting for waste diversion. *Waste Manag.* **2012**, *32*, 1019–1030. [CrossRef]
97. Shen, M.; Song, B.; Zeng, G.; Zhang, Y.; Huang, W.; Wen, X.; Tang, W. Are biodegradable plastics a promising solution to solve the global plastic pollution? *Environ. Pollut.* **2020**, *263*, 114469. [CrossRef]
98. Dey, T.K.; Jamal, M. Separation of microplastics from water-What next? *J. Water Process Eng.* **2021**, *44*, 102332. [CrossRef]
99. Zhao, X.; Korey, M.; Li, K.; Copenhaver, K.; Tekinalp, H.; Celik, S.; Kalaitzidou, K.; Ruan, R.; Ragauskas, A.J.; Ozcan, S. Plastic waste upcycling toward a circular economy. *Chem. Eng. J.* **2022**, *428*, 131928. [CrossRef]
100. Nanda, S.; Berruti, F. Municipal solid waste management and landfilling technologies: A review. *Environ. Chem. Lett.* **2021**, *19*, 1433–1456. [CrossRef]
101. Lastovina, T.A.; Budnyk, A.P. A review of methods for extraction, removal, and stimulated degradation of microplastics. *J. Water Process Eng.* **2021**, *43*, 102209. [CrossRef]
102. Alabi, O.A.; Ologbonjaye, K.; Awosolu, O.; Alalade, O. Public and environmental health effects of plastic wastes disposal: A review. *J. Toxicol. Risk Assess.* **2019**, *5*, 1–13.
103. Ware, R.L.; Rowland, S.M.; Rodgers, R.P.; Marshall, A.G. Advanced chemical characterization of pyrolysis oils from landfill waste, recycled plastics, and forestry residue. *Energy Fuels* **2017**, *31*, 8210–8216. [CrossRef]
104. Adam, V.; Nowack, B. European country-specific probabilistic assessment of nanomaterial flows towards landfilling, incineration and recycling. *Environ. Sci. Nano* **2017**, *4*, 1961–1973. [CrossRef]
105. dos Santos, I.F.S.; Mensah, J.H.R.; Gonçalves, A.T.T.; Barros, R.M. Incineration of municipal solid waste in Brazil: An analysis of the economically viable energy potential. *Renew. Energy* **2020**, *149*, 1386–1394.
106. Yogalakshmi, K.N.; Singh, S. Plastic waste: Environmental hazards, its biodegradation, and challenges. In *Bioremediation of Industrial Waste for Environmental Safety*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 99–133.
107. Guptaa, B.K.; Singhb, S. To Study the feasibility of Coarse and Fine plastic Aggregates in Concrete. *Int. J. Appl. Eng. Res.* **2018**, *13*, 5815–5822.
108. Uekert, T.; Kuehnel, M.F.; Wakerley, D.W.; Reisner, E. Plastic waste as a feedstock for solar-driven H 2 generation. *Energy Environ. Sci.* **2018**, *11*, 2853–2857. [CrossRef]
109. Scott, G. *Polymers and the Environment*; Royal Society of Chemistry: London, UK, 1999.
110. Punčochář, M.; Ruj, B.; Chatterj, P. Development of process for disposal of plastic waste using plasma pyrolysis technology and option for energy recovery. *Procedia Eng.* **2012**, *42*, 420–430. [CrossRef]
111. Tang, L.; Huang, H.; Zhao, Z.; Wu, C.; Chen, Y. Pyrolysis of polypropylene in a nitrogen plasma reactor. *Ind. Eng. Chem. Res.* **2003**, *42*, 1145–1150. [CrossRef]
112. Acomb, J.C.; Wu, C.; Williams, P.T. Control of steam input to the pyrolysis-gasification of waste plastics for improved production of hydrogen or carbon nanotubes. *Appl. Catal. B Environ.* **2014**, *147*, 571–584. [CrossRef]
113. Lopez, G.; Artetxe, M.; Amutio, M.; Alvarez, J.; Bilbao, J.; Olazar, M. Recent advances in the gasification of waste plastics. A critical overview. *Renew. Sustain. Energy Rev.* **2018**, *82*, 576–596. [CrossRef]
114. Panda, A.K.; Singh, R.K.; Mishra, D. Thermolysis of waste plastics to liquid fuel: A suitable method for plastic waste management and manufacture of value added products—A world prospective. *Renew. Sustain. Energy Rev.* **2010**, *14*, 233–248. [CrossRef]
115. Navarro, M.V.; Martínez, J.D.; Murillo, R.; García, T.; López, J.M.; Callén, M.S.; Mastral, A.M. Application of a particle model to pyrolysis. Comparison of different feedstock: Plastic, tyre, coal and biomass. *Fuel Processing Technol.* **2012**, *103*, 1–8. [CrossRef]
116. Suzuki, G.; Uchida, N.; Tuyen, L.H.; Tanaka, K.; Matsukami, H.; Kunisue, T.; Takahashi, S.; Viet, P.H.; Kuramochi, H.; Osako, M. Mechanical recycling of plastic waste as a point source of microplastic pollution. *Environ. Pollut.* **2022**, *303*, 119114. [CrossRef]
117. Ray, R.; Thorpe, R. A comparison of gasification with pyrolysis for the recycling of plastic containing wastes. *Int. J. Chem. React. Eng.* **2007**, *5*, 1–14. [CrossRef]
118. Lear, G.; Kingsbury, J.; Franchini, S.; Gambarini, V.; Maday, S.; Wallbank, J.; Weaver, L.; Pantos, O. Plastics and the microbiome: Impacts and solutions. *Environ. Microbiome* **2021**, *16*, 2. [CrossRef]
119. Muneer, F.; Rasul, I.; Azeem, F.; Siddique, M.H.; Zubair, M.; Nadeem, H. Microbial polyhydroxyalkanoates (PHAs): Efficient replacement of synthetic polymers. *J. Polym. Environ.* **2020**, *28*, 2301–2323. [CrossRef]
120. Amobonye, A.; Bhagwat, P.; Singh, S.; Pillai, S. Plastic biodegradation: Frontline microbes and their enzymes. *Sci. Total Environ.* **2021**, *759*, 143536. [CrossRef] [PubMed]
121. Siracusa, V. Microbial degradation of synthetic biopolymers waste. *Polymers* **2019**, *11*, 1066. [CrossRef] [PubMed]
122. Bäckström, E.; Odelius, K.; Hakkarainen, M. Trash to treasure: Microwave-assisted conversion of polyethylene to functional chemicals. *Ind. Eng. Chem. Res.* **2017**, *56*, 14814–14821. [CrossRef]

123. Arias, J.J.R.; Thielemans, W. Instantaneous hydrolysis of PET bottles: An efficient pathway for the chemical recycling of condensation polymers. *Green Chem.* **2021**, *23*, 9945–9956. [CrossRef]
124. Valerio, O.; Muthuraj, R.; Codou, A. Strategies for polymer to polymer recycling from waste: Current trends and opportunities for improving the circular economy of polymers in South America. *Curr. Opin. Green Sustain. Chem.* **2020**, *25*, 100381. [CrossRef]
125. Chen, X.; Wang, Y.; Zhang, L. Recent progress in the chemical upcycling of plastic wastes. *ChemSusChem* **2021**, *14*, 4137–4151. [CrossRef]
126. Kondyurin, A.; Bilek, M. *Ion Beam Treatment of Polymers: Application Aspects from Medicine to Space*; Newnes: London, UK, 2014.
127. Carvajal Rodríguez, L.V.; Benavides Fernández, C.D. Recent Trends to Address Plastic Waste at the Global Level. In *Impact of Plastic Waste on the Marine Biota*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 81–99.
128. Hopewell, J.; Dvorak, R.; Kosior, E. Plastics recycling: Challenges and opportunities. *Philos. Trans. R. Soc. B Biol. Sci.* **2009**, *364*, 2115–2126. [CrossRef]
129. Bai, B.; Jin, H.; Fan, C.; Cao, C.; Wei, W.; Cao, W. Experimental investigation on liquefaction of plastic waste to oil in supercritical water. *Waste Manag.* **2019**, *89*, 247–253. [CrossRef]
130. Tang, J.-H.; Sun, Y. Visible-light-driven organic transformations integrated with H 2 production on semiconductors. *Mater. Adv.* **2020**, *1*, 2155–2162. [CrossRef]
131. Zhang, F.; Zhao, Y.; Wang, D.; Yan, M.; Zhang, J.; Zhang, P.; Ding, T.; Chen, L.; Chen, C. Current technologies for plastic waste treatment: A review. *J. Clean. Prod.* **2021**, *282*, 124523. [CrossRef]
132. Gong, X.; Tong, F.; Ma, F.; Zhang, Y.; Zhou, P.; Wang, Z.; Liu, Y.; Wang, P.; Cheng, H.; Dai, Y. Photoreforming of plastic waste poly (ethylene terephthalate) via in-situ derived CN-CNTs-NiMo hybrids. *Appl. Catal. B Environ.* **2022**, *307*, 121143. [CrossRef]
133. Uekert, T.; Kasap, H.; Reisner, E. Photoreforming of nonrecyclable plastic waste over a carbon nitride/nickel phosphide catalyst. *J. Am. Chem. Soc.* **2019**, *141*, 15201–15210. [CrossRef] [PubMed]
134. Christensen, P.R.; Scheuermann, A.M.; Loeffler, K.E.; Helms, B.A. Closed-loop recycling of plastics enabled by dynamic covalent diketoenamine bonds. *Nat. Chem.* **2019**, *11*, 442–448. [CrossRef] [PubMed]
135. de Kort, G.W.; Bouvrie, L.H.C.; Rastogi, S.; Wilsens, C.H.R.M. Thermoplastic PLA-LCP Composites: A Route toward Sustainable, Reprocessable, and Recyclable Reinforced Materials. *ACS Sustain. Chem. Eng.* **2020**, *8*, 624–631. [CrossRef]
136. Almeshal, I.; Tayeh, B.A.; Alyousef, R.; Alabduljabbar, H.; Mustafa Mohamed, A.; Alaskar, A. Use of recycled plastic as fine aggregate in cementitious composites: A review. *Constr. Build. Mater.* **2020**, *253*, 119146. [CrossRef]
137. Zhao, Z.; Xiao, F.; Amirkhanian, S. Recent applications of waste solid materials in pavement engineering. *Waste Manag.* **2020**, *108*, 78–105. [CrossRef]
138. Aldahdooh, M.A.A.; Jamrah, A.; Alnuaimi, A.; Martini, M.I.; Ahmed, M.S.R.; Ahmed, A.S.R. Influence of various plastics-waste aggregates on properties of normal concrete. *J. Build. Eng.* **2018**, *17*, 13–22. [CrossRef]
139. Akinwumi, I.I.; Domo-Spiff, A.H.; Salami, A. Marine plastic pollution and affordable housing challenge: Shredded waste plastic stabilized soil for producing compressed earth bricks. *Case Stud. Constr. Mater.* **2019**, *11*, e00241. [CrossRef]
140. Barros, M.M.; de Oliveira, M.F.L.; da Conceição Ribeiro, R.C.; Bastos, D.C.; de Oliveira, M.G. Ecological bricks from dimension stone waste and polyester resin. *Constr. Build. Mater.* **2020**, *232*, 117252. [CrossRef]
141. Panimayam, S.; Chinnadurai, P.; Anuradha, R.; Pradeesh, K.; Jaffer, A.U. Utilisation of waste plastics as a replacement of coarse aggregate in paver blocks. *Int. J. ChemTech Res.* **2017**, *10*, 211–218.
142. Pooja, P.; Vaitla, M.; Sravan, G.; Reddy, M.P.; Bhagyawati, M. Study on Behavior of Concrete with Partial Replacement of Fine Aggregate with Waste Plastics. *Mater. Today Proc.* **2019**, *8*, 182–187. [CrossRef]
143. Hamsavathi, K.; Prakash, K.S.; Kavimani, V. Green high strength concrete containing recycled Cathode Ray Tube Panel Plastics (E-waste) as coarse aggregate in concrete beams for structural applications. *J. Build. Eng.* **2020**, *30*, 101192. [CrossRef]
144. Makri, C.; Hahladakis, J.N.; Gidarakos, E. Use and assessment of "e-plastics" as recycled aggregates in cement mortar. *J. Hazard. Mater.* **2019**, *379*, 120776. [CrossRef] [PubMed]
145. Coppola, B.; Courard, L.; Michel, F.; Incarnato, L.; Di Maio, L. Investigation on the use of foamed plastic waste as natural aggregates replacement in lightweight mortar. *Compos. Part B Eng.* **2016**, *99*, 75–83. [CrossRef]
146. Awoyera, P.O.; Adesina, A. Plastic wastes to construction products: Status, limitations and future perspective. *Case Stud. Constr. Mater.* **2020**, *12*, e00330. [CrossRef]
147. Zhang, L. Production of bricks from waste materials—A review. *Constr. Build. Mater.* **2013**, *47*, 643–655. [CrossRef]
148. Farooq, A.; MAlIk, M.A.; Tariq, T.; RIAz, M.; Haroon, W.; MAlIk, A.; Ur Rehman, M. impact on concrete properties using e-plastic waste fine aggregates and silica fume. *Gospod. Surowcami Miner.* **2019**, *35*, 103–118.
149. Hameed, A.M.; Fatah Ahmed, B.A. Employment the plastic waste to produce the light weight concrete. *Energy Procedia* **2019**, *157*, 30–38. [CrossRef]
150. Nursyamsi, N.; Indrawan, I.; Theresa, V. Effect of HDPE plastic waste towards batako properties. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *309*, 012013. [CrossRef]
151. Al-Azzawi, A.A. Mechanical properties of recycled aggregate concrete. *ARPN J. Eng. Appl. Sci.* **2016**, *11*, 11233–11238.
152. Solikin, M.; Ikhsan, N. Styrofoam as partial substitution of fine aggregate in lightweight concrete bricks. *AIP Conf. Proc.* **2018**, *1977*, 030041.
153. Srinivasan, K.; Premalatha, J.; Srigeethaa, S. A performance study on partial replacement of polymer industries waste (PIW) as fine aggregate in concrete. *Arch. Civ. Eng.* **2018**, *64*, 46–56. [CrossRef]

154. Bhogayata, A.; Arora, N. Feasibility study on usage of metalized plastic waste in concrete. In *Contemporary Issues in Geoenvironmental Engineering, Proceedings of the 1st GeoMEast International Congress and Exhibition, Sharm El-Sheikh, Egypt, 15–19 July 2017*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 328–337.
155. Al-Hadithi, A.I.; Al-Ani, M.F. Effects of Adding Waste Plastics on Some Properties of High Performance Concrete. In Proceedings of the 2018 11th International Conference on Developments in eSystems Engineering (DeSE), Cambridge, UK, 2–5 September 2018; pp. 273–279.
156. Waroonkun, T.; Puangpinyo, T.; Tongtuam, Y. The Development of a Concrete Block Containing PET Plastic Bottle Flakes. *J. Sustain. Dev.* **2017**, *10*, 186. [CrossRef]
157. Habib, M.Z.; Alom, M.M.; Hoque, M.M. Concrete production using recycled waste plastic as aggregate. *J. Civ. Eng. IEB* **2017**, *45*, 11–17.
158. Jaivignesh, B.; Sofi, A. Study on mechanical properties of concrete using plastic waste as an aggregate. In *IOP Conference Series: Earth and Environmental Science, Proceedings of the International Conference on Civil Engineering and Infrastructural Issues in Emerging Economies (ICCIEE 2017), Tirumalaisamudram, Thanjavur, India, 17–18 March 2017*; IOP Publishing: Bristol, UK, 2017; p. 012016.
159. Jalaluddin, M. Use of plastic waste in civil constructions and innovative decorative material (eco-friendly). *MOJ Civ. Eng.* **2017**, *3*, 359–368. [CrossRef]
160. Cadere, C.A.; Barbuta, M.; Rosca, B.; Serbanoiu, A.A.; Burlacu, A.; Oancea, I. Engineering properties of concrete with polystyrene granules. *Procedia Manuf.* **2018**, *22*, 288–293. [CrossRef]
161. Bulut, H.A.; Şahin, R. A study on mechanical properties of polymer concrete containing electronic plastic waste. *Compos. Struct.* **2017**, *178*, 50–62. [CrossRef]
162. Manjunath, B.T.A. Partial Replacement of E-plastic Waste as Coarse-Aggregate in Concrete. *Procedia Environ. Sci.* **2016**, *35*, 731–739. [CrossRef]
163. Sayadi, A.A.; Tapia, J.V.; Neitzert, T.R.; Clifton, G.C. Effects of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete. *Constr. Build. Mater.* **2016**, *112*, 716–724. [CrossRef]
164. Lasiyal, N.; Pawar, L.G.; Dixit, M. Effect of Plastic Waste as Partial Replacement of Fine Aggregate in Concrete and Cost Analysis. *Int. J. Eng. Res. Technol.* **2018**, *4*, 1–4.
165. Hossain, M.; Bhowmik, P.; Shaad, K. Use of waste plastic aggregation in concrete as a constituent material. *Progress. Agric.* **2016**, *27*, 383–391. [CrossRef]
166. Kothai, P.; Malathy, R. Utilization of steel slag in concrete as a partial replacement material for fine aggregates. *Int. J. Innov. Res. Sci. Eng. Technol.* **2014**, *3*, 11585–11592.
167. Alqahtani, F.K.; Ghataora, G.; Khan, M.I.; Dirar, S.; Kioul, A.; Al-Otaibi, M. Lightweight concrete containing recycled plastic aggregates. In Proceedings of the 2015 International Conference on Electromechanical Control Technology and Transportation, Zhuhai City, China, 31 October–1 November 2015; Atlantis Press: Paris, France, 2015; pp. 13–14.
168. Mbadike, E.; Ezeokpube, G. Effect of Plastic Synthetic Aggregate in the Production of Lightweight Concrete. *J. Adv. Biotechnol.* **2014**, *2*, 83–88. [CrossRef]
169. Saikia, N.; Brito, J.D. Waste polyethylene terephthalate as an aggregate in concrete. *Mater. Res.* **2013**, *16*, 341–350. [CrossRef]
170. Rahim, N.L.; Sallehuddin, S.; Ibrahim, N.M.; Amat, R.C.; Ab Jalil, M.F. Use of plastic waste (high density polyethylene) in concrete mixture as aggregate replacement. *Adv. Mater. Res.* **2013**, *701*, 265–269. [CrossRef]
171. Rai, B.; Rushad, S.T.; Kr, B.; Duggal, S.K. Study of Waste Plastic Mix Concrete with Plasticizer. *ISRN Civ. Eng.* **2012**, *2012*, 469272. [CrossRef]
172. Xu, Y.; Jiang, L.; Xu, J.; Li, Y. Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick. *Constr. Build. Mater.* **2012**, *27*, 32–38. [CrossRef]
173. Mahzuz, H.; Tahsin, A. Use of Plastic as A Partial Replacement of Coarse Aggregate in Concrete for Brick Classifications. *Civ. Eng. Archit.* **2019**, *7*, 215–220.
174. Aslani, F.; Deghani, A.; Asif, Z. Development of lightweight rubberized geopolymer concrete by using polystyrene and recycled crumb-rubber aggregates. *J. Mater. Civ. Eng.* **2020**, *32*, 04019345. [CrossRef]
175. Almeshal, I.; Tayeh, B.A.; Alyousef, R.; Alabduljabbar, H.; Mohamed, A.M. Eco-friendly concrete containing recycled plastic as partial replacement for sand. *J. Mater. Res. Technol.* **2020**, *9*, 4631–4643. [CrossRef]
176. Sulyman, M.; Haponiuk, J.; Formela, K. Utilization of recycled polyethylene terephthalate (PET) in engineering materials: A review. *Int. J. Environ. Sci. Dev.* **2016**, *7*, 100. [CrossRef]
177. Fai Chow, M.; Khalili Rosidan, M.A. Study on The Effects of Plastic as Admixture on The Mechanical Properties of Cement-Sand Bricks. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *713*, 012016. [CrossRef]
178. González-Montijo, M.A.; Soto-Toro, H.; Rivera-Pérez, C.; Esteves-Klomsingh, S.; Suárez, O.M. Design and characterization of concrete masonry parts and structural concrete using repurposed plastics as aggregate. *J. Mech. Behav. Mater.* **2019**, *28*, 81–88. [CrossRef]
179. Bhushaiah, R.; Mohammad, S.; Rao, D.S. Study of plastic bricks Made from waste Plastic. *Int. Res. J. Eng. Technol.* **2019**, *6*, 6.
180. Nursyamsi, N.; Indrawan, I.; Ramadhan, P. The influence of the usage of Idpe plastic waste as fine aggregate in light concrete bricks. In Proceedings of the International Conference on Sustainable Civil Engineering Structures and Construction Materials (SCESCM 2018), Yogyakarta, Indonesia, 5–7 September 2018; p. 01006.
181. Lalzarliana Paihte, P.; Lalngaihawma, A.C.; Saini, G. Recycled Aggregate filled waste plastic bottles as a replacement of bricks. *Mater. Today Proc.* **2019**, *15*, 663–668. [CrossRef]

182. Kamarulzaman, N.; Adnan, S.; Sari, K.M.; Osman, M.; Jeni, M.A.; Abdullah, M.; Ern, P.A.S.; Yahya, N.; Yassin, N.; Anuar, M.W. Properties of Cement Brick Containing Expanded Polystyrene Beads (EPS) And Palm Oil Fuel Ash (POFA). *J. Sci. Technol.* **2018**, *10*, 41–46. [CrossRef]
183. Akinyele, J.O.; Toriola, I.O. The effect of crushed plastics waste on the structural properties of sandcrete blocks. *Afr. J. Sci. Technol. Innov. Dev.* **2018**, *10*, 709–713. [CrossRef]
184. Azmi, N.B.; Khalid, F.S.; Irwan, J.M.; Mazenan, P.N.; Zahir, Z.; Shahidan, S. Performance of composite sand cement brick containing recycle concrete aggregate and waste polyethylene terephthalate with different mix design ratio. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *140*, 012129. [CrossRef]
185. Yaseen, M.; Bandlekar, R.; Pruthviraj, M.; Srinivas, M. Strength Characteristics Of Ecofriendly Cement Bricks Using Solid Waste Composites. *IJSART* **2018**, *4*, 1536.
186. Ali, N.; Yusup, N.F.M.; Khalid, F.S.; Shahidan, S.; Abdullah, S.R. The Effect of Water Cement Ratio on Cement Brick Containing High Density Polyethylene (HDPE) as Sand Replacement. In Proceedings of the Malaysia Technical Universities Conference on Engineering and Technology (MUCET 2017), Penang, Malaysia, 6–7 December 2017; p. 03010.
187. Prasanth, R.; Gopalakrishnan, S.; Thanigainathan, G.; Kathiravan, A. Utilization of waste plastics in fly ash bricks. *Int. J. Pure Appl. Math.* **2018**, *119*, 1417–1424.
188. Mondal, M.K.; Bose, B.P.; Bansal, P. Recycling waste thermoplastic for energy efficient construction materials: An experimental investigation. *J. Environ. Manag.* **2019**, *240*, 119–125. [CrossRef] [PubMed]
189. Alan, S.; Sivagnanaprakash, B.; Suganya, S.; Kalaiselvam, A.; Vignesh, V. A Study on Mechanical Properties of fly ash Brick with Waste Plastic Strips. *Int. J. Appl. Eng. Res.* **2015**, *10*, 183–192.
190. Kumar, K.P.; Gomathi, M. Production of Construction Bricks by Partial Replacement of Waste Plastics. *IOSR J. Mech. Civ. Eng. (IOSR-JMCE)* **2017**, *14*, 9–12. [CrossRef]
191. Wahid, S.A.; Rawi, S.M.; Desa, N.M. Utilization of plastic bottle waste in sand bricks. *J. Basic Appl. Sci. Res.* **2015**, *5*, 35–44.
192. Tapkire, G.; Patil, P.; Kumavat, H.R. Recycled Plastic Used in Concrete Paver Block. 2014. Available online: https://ijret.org/volumes/2014v03/i21/IJRET20140321009.pdf (accessed on 25 July 2022).
193. Arsod, M. A Paper on Experimental Investigation on Concrete Paver Block and Plastic Paver Block. *Int. J. Res. Appl. Sci. Eng. Technol.* **2019**, *7*, 2151–2157. [CrossRef]
194. Nivetha, C.; Rubiya, M.; Shobana, S.; Vaijayanthi, R. Production of plastic paver block from the solid waste (Quarry dust, fly ash &PET). *ARPN J. Eng. Appl. Sci.* **2006**, *11*, 1819–6608.
195. Vanitha, S.; Natarajan, V.; Praba, M. Utilisation of waste plastics as a partial replacement of coarse aggregate in concrete blocks. *Indian J. Sci. Technol.* **2015**, *8*, 1. [CrossRef]
196. Safi, B.; Saidi, M.; Aboutaleb, D.; Maallem, M. The use of plastic waste as fine aggregate in the self-compacting mortars: Effect on physical and mechanical properties. *Constr. Build. Mater.* **2013**, *43*, 436–442. [CrossRef]
197. Di Maio, L.; Coppola, B.; Courard, L.; Michel, F.; Incarnato, L.; Scarfato, P. Data on thermal conductivity, water vapour permeability and water absorption of a cementitious mortar containing end-of-waste plastic aggregates. *Data Brief* **2018**, *18*, 1057–1063. [CrossRef]
198. Záleská, M.; Pavlíková, M.; Jankovský, O.; Lojka, M.; Pivák, A.; Pavlík, Z. Experimental Analysis of MOC Composite with a Waste-Expanded Polypropylene-Based Aggregate. *Materials* **2018**, *11*, 931. [CrossRef]
199. Hita, P.R.-d.; Pérez-Gálvez, F.; Morales-Conde, M.J.; Pedreño-Rojas, M.A. Reuse of plastic waste of mixed polypropylene as aggregate in mortars for the manufacture of pieces for restoring jack arch floors with timber beams. *J. Clean. Prod.* **2018**, *198*, 1515–1525. [CrossRef]
200. Coppola, B.; Courard, L.; Michel, F.; Incarnato, L.; Scarfato, P.; Di Maio, L. Hygro-thermal and durability properties of a lightweight mortar made with foamed plastic waste aggregates. *Constr. Build. Mater.* **2018**, *170*, 200–206. [CrossRef]
201. Liguori, B.; Iucolano, F.; Capasso, I.; Lavorgna, M.; Verdolotti, L. The effect of recycled plastic aggregate on chemico-physical and functional properties of composite mortars. *Mater. Des.* **2014**, *57*, 578–584. [CrossRef]
202. da Silva, A.M.; de Brito, J.; Veiga, R. Incorporation of fine plastic aggregates in rendering mortars. *Constr. Build. Mater.* **2014**, *71*, 226–236. [CrossRef]
203. Hannawi, K.; Kamali-Bernard, S.; Prince, W. Physical and mechanical properties of mortars containing PET and PC waste aggregates. *Waste Manag.* **2010**, *30*, 2312–2320. [CrossRef] [PubMed]
204. Ohemeng, E.A.; Ekolu, S.O. Strength prediction model for cement mortar made with waste LDPE plastic as fine aggregate. *J. Sustain. Cem. -Based Mater.* **2019**, *8*, 228–243. [CrossRef]
205. Spósito, F.A.; Higuti, R.T.; Tashima, M.M.; Akasaki, J.L.; Melges, J.L.P.; Assunção, C.C.; Bortoletto, M.; Silva, R.G.; Fioriti, C.F. Incorporation of PET wastes in rendering mortars based on Portland cement/hydrated lime. *J. Build. Eng.* **2020**, *32*, 101506. [CrossRef]
206. Kaur, G.; Pavia, S. Physical properties and microstructure of plastic aggregate mortars made with acrylonitrile-butadiene-styrene (ABS), polycarbonate (PC), polyoxymethylene (POM) and ABS/PC blend waste. *J. Build. Eng.* **2020**, *31*, 101341. [CrossRef]
207. Jatoi, A.S.; Akhter, F.; Mazari, S.A.; Sabzoi, N.; Aziz, S.; Soomro, S.A.; Mubarak, N.M.; Baloch, H.; Memon, A.Q.; Ahmed, S. Advanced microbial fuel cell for waste water treatment—A review. *Environ. Sci. Pollut. Res.* **2021**, *28*, 5005–5019. [CrossRef]
208. Munoz-Cupa, C.; Hu, Y.; Xu, C.C.; Bassi, A. An overview of microbial fuel cell usage in wastewater treatment, resource recovery and energy production. *Sci. Total Environ.* **2020**, *754*, 142429. [CrossRef]

209. Jatoi, A.S.; Mazari, S.; Baloch, H.A.; Riaz, S. 256. Study to investigate the optimize blending ratio of cow dung manure with distillery waste water for power generation in microbial fuel cell. In Proceedings of the 4th International Conference on Energy, Environment and Sustainable Development, Jamshoro, Pakistan, 1–3 November 2016.
210. Wu, Z.; Li, L.; Yan, J.m.; Zhang, X.b. Materials design and system construction for conventional and new-concept supercapacitors. *Adv. Sci.* **2017**, *4*, 1600382. [CrossRef] [PubMed]
211. Kaur, R.; Singh, S.; Chhabra, V.A.; Marwaha, A.; Kim, K.-H.; Tripathi, S. A sustainable approach towards utilization of plastic waste for an efficient electrode in microbial fuel cell applications. *J. Hazard. Mater.* **2021**, *417*, 125992. [CrossRef] [PubMed]
212. Pandi, N.; Sonawane, S.H.; Gumfekar, S.P.; Kola, A.K.; Borse, P.H.; Ambade, S.B.; Guptha, S.; Ashokkumar, M. Electrochemical performance of starch-polyaniline nanocomposites synthesized by sonochemical process intensification. *J. Renew. Mater.* **2019**, *7*, 1279–1293. [CrossRef]
213. Kaur, R.; Marwaha, A.; Chhabra, V.A.; Kim, K.-H.; Tripathi, S. Recent developments on functional nanomaterial-based electrodes for microbial fuel cells. *Renew. Sustain. Energy Rev.* **2020**, *119*, 109551. [CrossRef]
214. Li, Q.; Horn, M.; Wang, Y.; MacLeod, J.; Motta, N.; Liu, J. A review of supercapacitors based on graphene and redox-active organic materials. *Materials* **2019**, *12*, 703. [CrossRef]
215. Zhong, D.; Liao, X.; Liu, Y.; Zhong, N.; Xu, Y. Enhanced electricity generation performance and dye wastewater degradation of microbial fuel cell by using a petaline NiO@ polyaniline-carbon felt anode. *Bioresour. Technol.* **2018**, *258*, 125–134. [CrossRef]
216. Prasankumar, T.; Wiston, B.R.; Gautam, C.; Ilangovan, R.; Jose, S.P. Synthesis and enhanced electrochemical performance of PANI/Fe_3O_4 nanocomposite as supercapacitor electrode. *J. Alloys Compd.* **2018**, *757*, 466–475. [CrossRef]
217. Kamavaram, V.; Veedu, V.; Kannan, A.M. Synthesis and characterization of platinum nanoparticles on in situ grown carbon nanotubes based carbon paper for proton exchange membrane fuel cell cathode. *J. Power Sources* **2009**, *188*, 51–56. [CrossRef]
218. Waje, M.M.; Wang, X.; Li, W.; Yan, Y. Deposition of platinum nanoparticles on organic functionalized carbon nanotubes grown in situ on carbon paper for fuel cells. *Nanotechnology* **2005**, *16*, S395. [CrossRef]
219. Chaudhary, S.; Kumari, M.; Chauhan, P.; Ram Chaudhary, G. Upcycling of plastic waste into fluorescent carbon dots: An environmentally viable transformation to biocompatible C-dots with potential prospective in analytical applications. *Waste Manag.* **2021**, *120*, 675–686. [CrossRef]
220. Wang, C.; Han, H.; Wu, Y.; Astruc, D. Nanocatalyzed upcycling of the plastic wastes for a circular economy. *Coord. Chem. Rev.* **2022**, *458*, 214422. [CrossRef]
221. Jiao, X.; Zheng, K.; Chen, Q.; Li, X.; Li, Y.; Shao, W.; Xu, J.; Zhu, J.; Pan, Y.; Sun, Y. Photocatalytic conversion of waste plastics into C2 fuels under simulated natural environment conditions. *Angew. Chem. Int. Ed.* **2020**, *59*, 15497–15501. [CrossRef] [PubMed]
222. Szarka, G.; Domján, A.; Szakács, T.; Iván, B. Oil from poly (vinyl chloride): Unprecedented degradative chain scission under mild thermooxidative conditions. *Polym. Degrad. Stab.* **2012**, *97*, 1787–1793. [CrossRef]
223. Szarka, G.; Iván, B. *Degradative Transformation of Poly (Vinyl Chloride) under Mild Oxidative Conditions*; ACS Publications: Washington, DC, USA, 2009.
224. Liu, S.; Kots, P.A.; Vance, B.C.; Danielson, A.; Vlachos, D.G. Plastic waste to fuels by hydrocracking at mild conditions. *Sci. Adv.* **2021**, *7*, eabf8283. [CrossRef]
225. Adamczak, M.; Kamińska, G.; Bohdziewicz, J. Application of waste polymers as basic material for ultrafiltration membranes preparation. *Water* **2020**, *12*, 179. [CrossRef]
226. Kumari, M.; Chaudhary, G.R.; Chaudhary, S.; Umar, A. Transformation of solid plastic waste to activated carbon fibres for wastewater treatment. *Chemosphere* **2022**, *294*, 133692. [CrossRef]
227. Yuan, X.; Cho, M.-K.; Lee, J.G.; Choi, S.W.; Lee, K.B. Upcycling of waste polyethylene terephthalate plastic bottles into porous carbon for CF4 adsorption. *Environ. Pollut.* **2020**, *265*, 114868. [CrossRef]
228. Zhang, H.; Pap, S.; Taggart, M.A.; Boyd, K.G.; James, N.A.; Gibb, S.W. A review of the potential utilisation of plastic waste as adsorbent for removal of hazardous priority contaminants from aqueous environments. *Environ. Pollut.* **2020**, *258*, 113698. [CrossRef]
229. Pan, D.; Su, F.; Liu, H.; Ma, Y.; Das, R.; Hu, Q.; Liu, C.; Guo, Z. The properties and preparation methods of different boron nitride nanostructures and applications of related nanocomposites. *Chem. Rec.* **2020**, *20*, 1314–1337. [CrossRef]
230. Qin, Y.; Yu, Q.; Yin, X.; Zhou, Y.; Xu, J.; Wang, L.; Wang, H.; Chen, Z. Photo-polymerized trifunctional acrylate resin/magnesium hydroxide fluids/cotton fabric composites with enhancing mechanical and moisture barrier properties. *Adv. Compos. Hybrid Mater.* **2019**, *2*, 320–329. [CrossRef]
231. Watson, D.; Trzepacz, S.; Lander, N.; Skottfelt, S.; Kiørboe, N.; Elander, M.; Nordin, H.L. Towards 2025: Separate collection and treatment of textiles in six EU countries. *Environ. Proj.* **2020**, 1–102. Available online: https://www2.mst.dk/Udgiv/publications/2020/06/978-87-7038-202-1.pdf (accessed on 25 July 2022).
232. Kim, H.T.; Kim, J.K.; Cha, H.G.; Kang, M.J.; Lee, H.S.; Khang, T.U.; Yun, E.J.; Lee, D.-H.; Song, B.K.; Park, S.J. Biological valorization of poly (ethylene terephthalate) monomers for upcycling waste PET. *ACS Sustain. Chem. Eng.* **2019**, *7*, 19396–19406. [CrossRef]