sustainability

MDPI

Article

An Improved Strategy to Effectively Manage Healthcare Waste after COVID-19 in Republic of Korea

Min-Jung Kim [1,2], Yoon-Soo Park [1], Taesung Kim [1], Hyo-Hyun Choi [1], Young-sam Yoon [1], Tae-wan Jeon [1] and Namil Um [1,*]

[1] Resource Recirculation Research Division, National Institute of Environmental Research, Hwangyeong-ro 42, Seo-gu, Incheon 22689, Republic of Korea; minjung12@korea.kr (M.-J.K.); yunsupower@korea.kr (Y.-S.P.); kimts3@korea.kr (T.K.); kchh80@korea.kr (H.-H.C.); ysyoon3sf@korea.kr (Y.-s.Y.); jeonsa@korea.kr (T.-w.J.)

[2] Department of Environmental and Energy Engineering, Incheon National University, Academy-ro 119, Yeonsu-gu, Incheon 22012, Republic of Korea

* Correspondence: namil-um@korea.kr; Tel.: +82-32-560-7510

Abstract: During the coronavirus disease 2019 (COVID-19) pandemic, 24,289 tons of infectious waste was generated in 2021 in Korea, a 320% increase compared to that generated in 2020 (5788 tons). The disposal of other healthcare waste has been delayed because COVID-19 infectious waste must be disposed of first, leading to long-term concerns related to the lack of healthcare waste disposal capacity. To solve this problem, this study investigated healthcare waste classification systems in Korea and overseas. We analyzed the current state of healthcare waste in Korea and compared the treatment methods and healthcare waste treatment systems by country. The results showed that Korea has a strict healthcare waste management system compared to other countries, which relies on dedicated incinerators and transport. It is difficult to expand incinerators exclusively for healthcare waste due to site selection issues because they incinerate infectious waste. Therefore, to solve the healthcare waste disposal problem, Korea should improve its management system to reduce treatment amounts. This study suggests that general healthcare waste that is considered less infectious should be excluded from healthcare waste-exclusive treatment and that sterilization/grinding as an intermediate treatment method should be allowed.

Keywords: healthcare waste; status of generation; management direction; COVID-19

Citation: Kim, M.-J.; Park, Y.-S.; Kim, T.; Choi, H.-H.; Yoon, Y.-s.; Jeon, T.-w.; Um, N. An Improved Strategy to Effectively Manage Healthcare Waste after COVID-19 in Republic of Korea. *Sustainability* **2024**, *16*, 2696. https://doi.org/10.3390/su16072696

Academic Editor: Silvia Fiore

Received: 15 February 2024
Revised: 15 March 2024
Accepted: 18 March 2024
Published: 25 March 2024

1. Introduction

The first case of coronavirus disease 2019 (COVID-19), a respiratory infectious disease, was identified in December 2019; since then, the disease has affected more than 490 million people worldwide [1]. In Korea, the number of confirmed COVID-19 cases has been continuously increasing since the first confirmed case in January 2020, affecting one-third of the total population (17 million people) after the emergence of the omicron variant with high infectivity [1,2]. The global mortality rate associated with COVID-19 exceeds 3% and the use of personal protective gear such as masks and disposable gloves is essential to prevent the spread of infection; post-COVID effects are also serious. Therefore, a large amount of healthcare waste is generated during the treatment and care of infected people [3,4]. Healthcare waste related to COVID-19 is generated not only in hospitals but also in homes. Therefore, methods to reliably dispose of healthcare waste without the effects of viruses or harm to the environment are vital.

In India, it is advocated that COVID-related healthcare waste should be individually collected in hospitals and homes and various technologies such as incineration, fuel conversion, and pyrolysis should be applied [5]. In the Netherlands, healthcare waste generated from infectious diseases such as COVID-19 is considered dangerous, but most other healthcare waste is not; therefore, it was proposed to replace personal protective equipment such as masks with materials that are easily pyrolyzed and disposed of using

eco-friendly technology through proper separation and collection [6]. In this way, considering the infectiousness of healthcare waste and disposing of it in an eco-friendly manner is a very important issue.

Korea applies very strict standards to healthcare waste management, considering the risk of infection, to ensure stable disposal of healthcare waste. It has a unique healthcare waste management system that is rarely observed in other countries. Healthcare waste is discharged in dedicated containers, collected using dedicated vehicles, and incinerated at dedicated incinerators. In addition, the process from healthcare waste discharge to incineration has been monitored using Radio Frequency Identification (RFID) technology since 2018. RFID is a radio frequency recognition technology that uses an electronic chip capable of transmitting and receiving information to recognize and process all matters related to objects in real time. Due to this, Korea has identified a series of processes from the generation to the disposal of healthcare waste (Figure 1) [7]. As a result of using RFID to identify the recent amounts of healthcare waste generated, given the rapid increase in the amount of healthcare waste generated recently, it was found that the treatment capacity of the dedicated incinerators is insufficient, which raises concerns over long-term management [7,8]. Installing or expanding the dedicated incinerators is necessary for the stable treatment of healthcare waste, but this faces challenges such as NIMBYism and failure to reach social consensus [9,10].

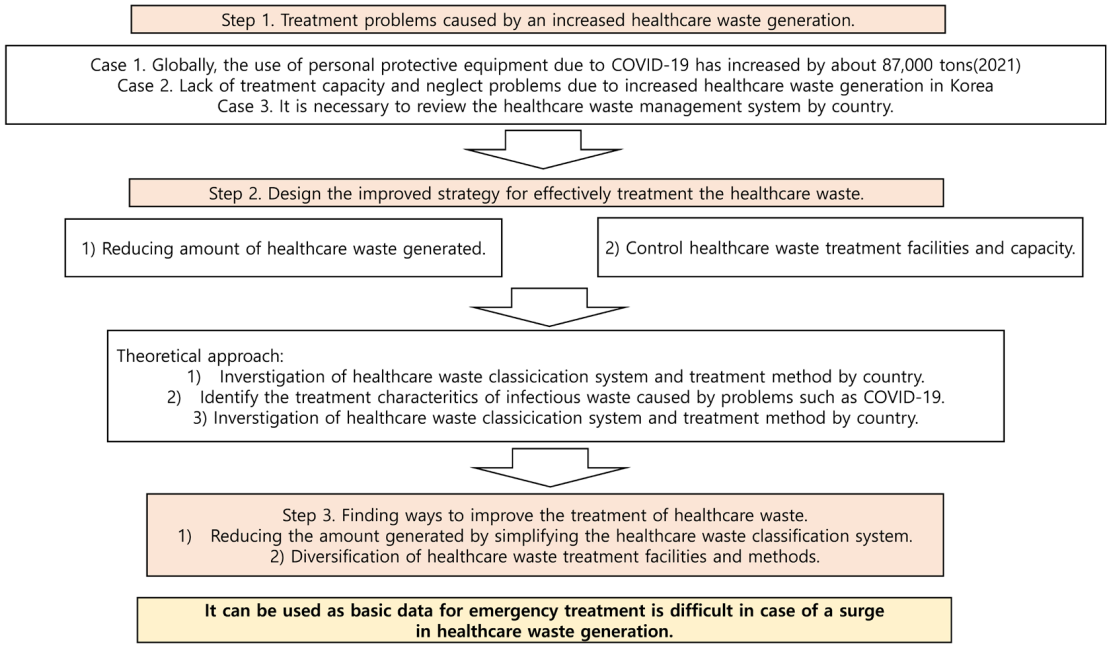

Figure 1. Approach for effective treatment steps of healthcare waste.

NIMBYism refers to a collective movement against the installation of facilities in residential areas. Environmentally, NIMBYism is a phenomenon that causes conflicts with residents when environmental facilities such as landfills, waste incinerators, recycling centers, sewage treatment plants, thermal power plants, nuclear power plants, and radioactive waste disposal sites are built around residential areas. Healthcare waste incineration facilities are among the representative NIMBY facilities in Korea.

After the outbreak of the COVID-19 pandemic, the Ministry of Environment (ME) in Korea announced and implemented same-day transport and same-day incineration standards for the safe management of COVID-19-related infectious healthcare waste [10–12]. The amount of infectious healthcare waste generated significantly increased during the extended COVID-19 pandemic and its treatment is still being prioritized. Therefore, the treatment of other types of healthcare waste, such as hazardous and general healthcare waste, is being delayed [12,13]. Furthermore, the issue of healthcare waste treatment

continues. [14] To solve this problem, it is necessary to reduce the amount of healthcare waste through a classification system that considers the risks of healthcare waste and to try various treatment methods other than incineration.

Therefore, this study analyzed the status of domestic healthcare waste generation and treatment in preparation for the increase in healthcare waste due to the spread of infectious diseases such as COVID-19 and proposed a direction for the stable management of domestic healthcare waste.

2. Methodology

A research procedure was established from recognizing the problem to suggesting improvement measures. First, we recognized the problems related to the generation and treatment of healthcare waste. Then, a research method was sought to prepare a solution to the healthcare waste. Finally, we proposed ways to improve healthcare waste treatment.

2.1. Healthcare Waste Generation and Treatment Data

Data from the Allbaro Waste Treatment System (http://www.allbaro.or.kr, accessed on 20 February 2022) and "the status of designated waste generation and treatment", which are statistical data released by the ME, were surveyed and summarized [15,16]. Data from EU countries were collected from Eurostat [17].

2.2. Confirmed Cases of COVID-19 and the Associated Damage

For confirmed cases of COVID-19, data from the WHO Coronavirus Disease Pandemic website and the Korea Disease Control and Prevention Agency were used for overseas and domestic cases, respectively (http://covid19.who.int/adgroupsurvey, WHO Coronavirus Dashboard, accessed on 20 February 2022). In addition, COVID-19 data reports from Johns Hopkins University, USA, were used for data such as human casualties [18,19].

The research process for effectively managing healthcare waste in this study was prepared as shown in Figure 1.

2.3. Comparison of Domestic and Overseas Healthcare Waste Management Systems

For related data in Korea, reports and data on the "Wastes Control Act" and guidelines were utilized [18–20]. For overseas data, data from international organizations such as the WHO and Basel Convention, and the systems and guideline data of the USA (California and Florida), the EU (Germany), the UK, and Japan were surveyed and summarized [21–28].

2.4. Management Direction

For management directions, a healthcare waste expert forum was formed, and related issues were examined through expert reviews and discussions. The healthcare waste expert forum was composed of more than 10 healthcare waste experts from related organizations such as the government, hospitals, research institutes, universities, and NGOs.

2.5. Others

OECD data were used for gross domestic product (GDP) and related data were obtained through websites and search engines such as Google and reviewed and utilized [29].

3. Results and Discussion

3.1. Generation of Healthcare Waste in Korea

The amount of healthcare waste generated in Korea was 233,825 tons in 2019, which was lower than the values in 2020 and 2021. Compared with the 169,926 tons produced in 2014, the amount in 2019 demonstrates an increase rate of approximately 38% and an average annual increase rate of approximately 7.6% (Figure 2). The latest amount of data for healthcare waste in 2022 is a total of 229,503 tons, which is constantly increasing [15].

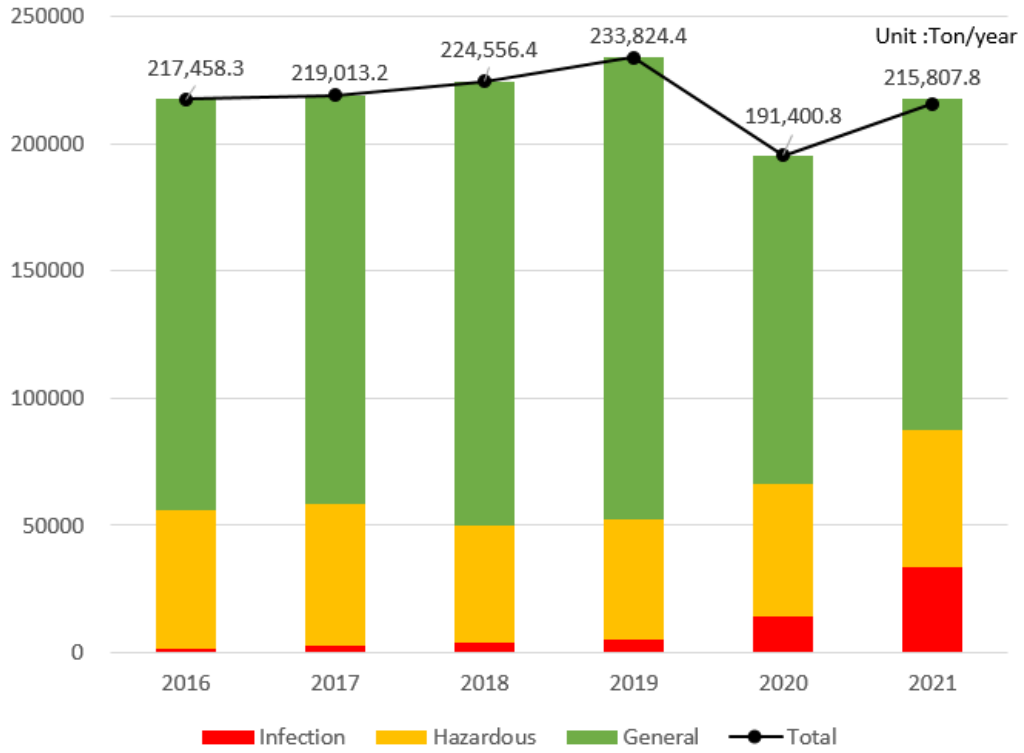

Figure 2. Generation of healthcare waste in Korea (source: Ministry of Environment of the Republic of Korea (ROK)).

Healthcare waste in Korea is classified into infectious, hazardous, and general healthcare waste. Among them, general healthcare waste accounts for the highest proportion (approximately 76%), followed by hazardous healthcare waste (approximately 23%) and infectious healthcare waste (approximately 1.1%) (Figure 2). Hazardous healthcare waste is divided into five detailed items (tissue logistics waste, pathological waste, sharp waste, bio-healthcare and chemical waste, and blood-contaminated waste) (Figure 3).

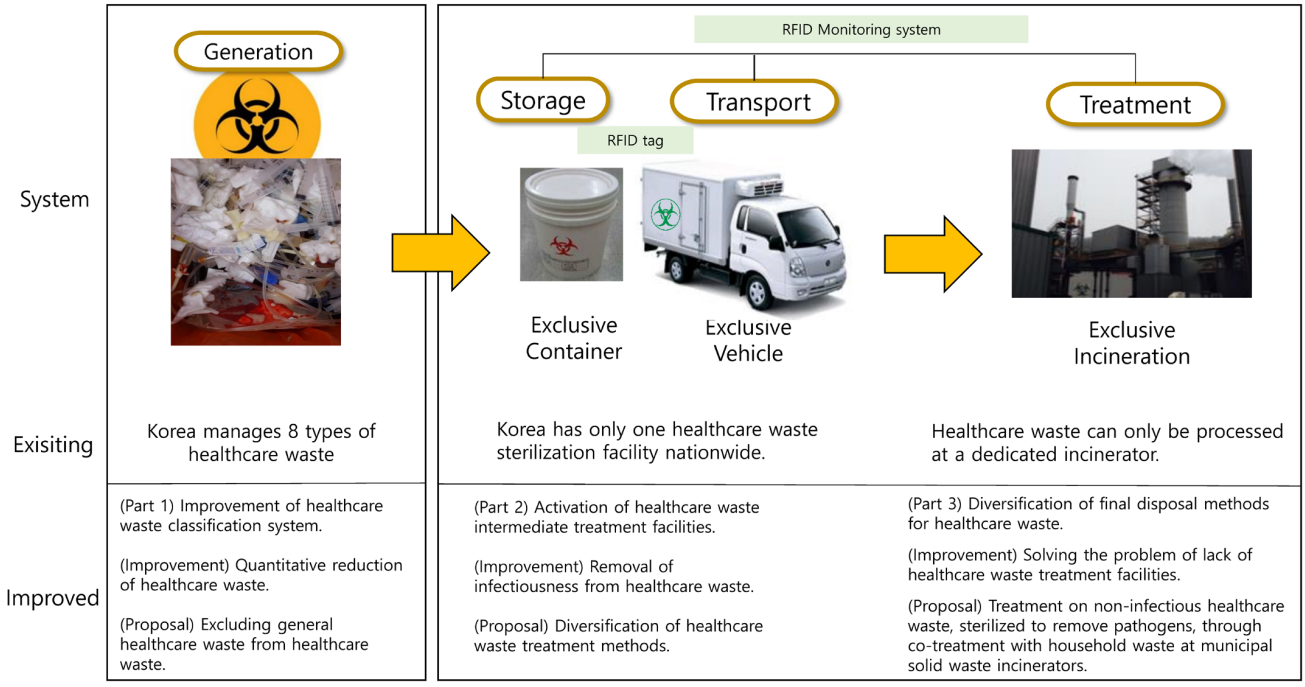

Figure 3. Suggested healthcare waste disposal guidelines.

3.2. Treatment of Healthcare Waste in Korea

In Korea, healthcare waste is treated using incineration and other methods. Healthcare waste can be treated only at dedicated incinerators in Korea, where more than 93% of healthcare waste is being treated on average (Table 1). Other methods include sterilization/pulverization, recycling, and wastewater treatment. The use of sterilization/pulverization or recycling is negligible and waste treated via wastewater treatment represents approximately 7% of healthcare waste on average (Table 1).

Table 1. Treatment of healthcare waste in Korea (source: Oh et al., 2017 [8]; Jang et al., 2006 [7]) (unit: tons/year).

	Waste Type	Total	Proportion (%)	Infectious Waste	Tissue Logistics Waste	Pathological Waste	Sharp Waste	Bio-Healthcare and Chemical Waste	Blood-Contaminated Waste	Placenta (Recycled)	General Healthcare Waste
2021	Incineration	211,916	97.3	33,322	6869	14,800	5280	6748	16,416.	0	128,481
	Sterilization/pulverization	2178	1.0	0	0	85	129	0	58	0	1906
	Recycling	27	0.0	0	0	0	0	0	0	27	0
	Others (wastewater treatment)	3794	1.7	0	2165	420	0	1	1164	0	44
2020	Incineration	189,060	96.8	14,281	6425	13,345	5244	6412	15,369	0	127,984
	Sterilization/pulverization	1432	0.7	0	0	70	135	0	25	0	1202
	Recycling	29	0.0	0	0	0	0	0	0	29	0
	Others (wastewater treatment)	4831	2.5	0	3201	380	0	0.3	1206	0	44
2019	Incineration	219,075	92.8	4891	5220	10,658	2592	5658	13,323	0	176,733
	Sterilization/pulverization	1205	0.5	0	0	73	146	0	0	0	986
	Recycling	0	0.0	0	0	0	0	0	0	0	0
	Others (wastewater treatment)	15,675	6.6	0	2826	402	0	0	12,410	0	37
2018	Incineration	221,418	93.7	3945	6631	12,534	5039	6183	14,767	0	172,319
	Sterilization/pulverization	1.171	0.0	0	0	58	141	0	0	0	972
	Recycling	30	0.0	0	0	0	0	0	0	30	0
	Others (wastewater treatment)	14,819	6.3	0	2158	371	0	0.1	12,241	0	49
2017	Incineration	203,402	92.8	2431	5987	11,561	4573	5024	13,916	0	159,910
	Sterilization/pulverization	1061	0.5	0	0	53	127	0	0	0	881
	Recycling	28	0.0	0	0	0	0	0	0	28	0
	Others (wastewater treatment)	14,788	6.7	0	2282	351	0	0	12,104	0	51
2016	Incineration	200,618	92.0	1744	4975	11,400	4190	3795	13,301	0	161,213
	Sterilization/pulverization	959	0.4	0	0	46	113	0	0	24	776
	Recycling	0	0.0	0	0	0	0	0	0	0	0
	Others (wastewater treatment)	16,521	7.6	0	2306	454	0	3	13,711	0	47

There are 13 incinerators dedicated to healthcare waste in Korea. Among them, only three incinerators are located in the Seoul metropolitan area, and the rest are in other regions. As only approximately 30% of the waste can be handled by the three incinerators

in the Seoul metropolitan area, the remaining 70% of the waste is treated in other regions after long-distance transport (Table 2).

Table 2. Treatment capacity of incinerators dedicated to healthcare waste in Korea (unit: tons/year).

Category	Seoul Metropolitan Area	Chungcheong Region	Honam Region	Yeongnam Region	Gangwon/ Jeju	Total
Number of incinerators / Year	3	3	2	5	0	13
2015 to 2017	48,018	45,263	14,060	58,187	0	165,528
2018 to 2019	57,000	43,000	15,000	73,000	0	189,000
2020	54,575	53,524	30,222	76,811	0	215,131
2021	54,575	63,072	30,222	88,126	0	235,995

Source: Ministry of Environment of ROK.

The possibility of infection during transport and the increase in treatment cost are problems associated with the current management system. In addition, healthcare waste treatment costs have increased and cases of illegally neglecting healthcare waste over the long term have occurred because the number of treatment facilities is insufficient to deal with the amount of healthcare waste generated [29,30].

Approximately 118% of the treatment capacity was used in 2018 and the legal limit of 130% was almost reached in 2019. To solve the healthcare waste treatment problem, non-infectious disposable diapers were excluded from healthcare waste (revised Wastes Control Act in effect from January 2020) and the total treatment capacity was increased by approximately 10% by expanding two incinerators (one in 2000 and the other in 2001) despite objections from residents (Table 2).

3.3. Comparison of Healthcare Waste Generation Rates and Treatment before and after the COVID-19 Pandemic in Korea

After the outbreak of the COVID-19 pandemic in Korea, the amount of infectious healthcare waste increased by approximately 62% (3297 tons) in 2020 compared with that in 2019. The amount of COVID-19 healthcare waste was 5788 tons in 2020. The total amount of healthcare waste in 2020 was 191,400 tons, which was approximately 18.14% (42,423 tons) lower than that (233,824 tons) in 2019 (Table 3).

Table 3. Comparison of the healthcare waste generation rates before and after the COVID-19 pandemic in Korea. (unit: tons/year) (source: Ministry of Environment of ROK).

Waste Type	2019	2020	(Rate of Increase Compared to the Previous Year, %)	2021	(Rate of Increase COMPARED to the Previous Year, %)
Total	233,824.44	191,400.79	△42,423.65 (△18.14)	215,807.83	24,407.04 (12.75)
Infectious healthcare waste (Total)	5319.76	14,404.54	9084.78	35,296.54	20,892
Infectious waste	5319.76	8616.85	3297.09 (61.98)	11,007.20	2390.35 (27.74)
COVID-19 waste	-	5787.69	5787.69	24,289.34	18,501.65 (319.67)
Hazardous healthcare waste (Total)	47,278.78	47,130.51	1760.15	51,238.26	4165.97
Tissue logistics waste (excluding the placenta)	7118.11	6440.08	△678.03 (△9.53)	6973.51	533.43 (8.28)

Table 3. *Cont.*

Waste Type	2019	2020	(Rate of Increase Compared to the Previous Year, %)	2021	(Rate of Increase COMPARED to the Previous Year, %)
Pathological waste	12,786.94	13,425.89	638.95 (5.00)	14,978.81	1552.92 (11.57)
Sharp waste	5424.58	5305.35	△119.23 (△2.20)	6033.18	787.83 (13.72)
Bio-healthcare, chemical waste	6580.96	6411.52	△169.44 (△2.57)	6804.20	362.68 (6.12)
Blood-contaminated waste	15,336.89	15,490.38	153.49 (1.00)	16,418.88	928.5 (5.99)
Placenta (recycled)	31.30	30.29	△1.01 (△3.23)	29.68	△0.61 (△2.01)
General healthcare waste	181,225.90	129,892.74	△51,333.16 (△28.33)	129,273.03	△619.71 (△0.48)

Non-infectious diapers were classified as general healthcare waste before being excluded from healthcare waste, and the diapers of non-infectious patients in long-term care hospitals and large hospitals are representative cases. As shown in Table 3, the amount of general healthcare waste decreased (by approximately 28.33%, 51,333 tons) from 181,225 tons in 2019 to 129,892 tons in 2020, likely for the same reasons mentioned above.

The amount of COVID-19 healthcare waste increased (by approximately 320%, 18,502 tons) from 5788 tons in 2020 to 24,289 tons in 2021, which was the second year of the COVID-19 pandemic. In addition, the total amount of healthcare waste increased to 215,807 tons (by approximately 12.8%) compared with that in the previous year.

The amount of healthcare waste in Korea continuously increased from 2014 to 2019 (Figure 2). Although it decreased in 2020 due to a reduction in the number of hospitalized patients and the exclusion of non-infectious disposable diapers, it showed a rising trend again as the COVID-19 pandemic continued. The difference in the amount of waste between 2020 (the first year of the COVID-19 pandemic) and 2021 (the second year of the COVID-19 pandemic) mainly resulted from the increase in COVID-19 healthcare waste, caused by the increase in the number of confirmed COVID-19 cases (Table 3).

The incineration capacity of the dedicated incinerators to handle most healthcare waste in Korea increased by approximately 25% from 189,000 tons (2019) before the COVID-19 pandemic to 235,995 tons in 2021 (Table 2). Considering the increased level of healthcare waste (Figure 2 and Table 3), the treatment limit of the incinerators is expected to be reached in the near future.

3.4. Comparisons of Healthcare Waste Management Systems between Foreign Countries and Korea

To identify measures to solve the problem of healthcare waste treatment in Korea, the status of healthcare waste management in other countries was surveyed, compared, and analyzed.

3.4.1. Classification and Generation of Healthcare Waste

In Korea, healthcare waste is classified into infectious, hazardous, and general healthcare waste. Among them, hazardous healthcare waste is divided into five detailed items [10,29]. The surveyed countries also have similar classifications for infectious and hazardous healthcare waste. These items are managed as healthcare waste, but general healthcare waste items in Korea are classified as non-hazardous waste and are mostly not managed as healthcare waste (Table 4).

General healthcare waste refers to waste generated from patient care in healthcare facilities that does not pose an infectious risk, such as gauze, paper towels, and bandages.

Table 4. Healthcare waste classification systems and general healthcare waste management by country. (Sources: Oh et al., 2017 [8], Florida Administrative Code, 2021 [24], Japanese Ministry of the Environment, 2021 [26]).

Category	Korea	USA (California and Florida)	EU	Japan
Infectious healthcare waste	All waste generated from healthcare treatment of people quarantined to protect others from infectious diseases	Isolated waste/infectious pathogens and related organism media	Waste whose collection and disposal are subject to special requirements to prevent infection	■ Place of discharge: Material discharged after being used for treatment and examination. Infectious disease-ward beds, tuberculosis-ward beds, and operating rooms. ■ Types of infectious disease: Class I, II, III, IV, and V material disposed of after being used for treatment
Hazardous healthcare waste	(Tissue logistics waste) Parts of the tissues, organs, and bodies of humans or animals; animal carcasses; and blood, pus, and blood products (serum, plasma, and blood products)	Animal waste	Body parts and organs, including blood bags and blood products	-
	(Pathological waste) Culture media, culture vessels, stored strains, waste test tubes, slides, cover glass, spent media, and gloves used for testing and inspections	Pathological waste	-	■ Form: Pathological waste (organs, tissue, and skin) from surgery. ■ Form: Material used for tests and examinations related to pathogenic microorganisms (media, laboratory)
	(Sharp waste) Injection needles, suture needles, surgical blades, acupuncture needles, dental needles, and test instruments with broken glass	Injury waste/unused injury waste	Pointed or sharp objects	■ Form: Sharp object stained with blood (including broken glass fragments)
	(Bio-healthcare and chemical waste) Waste from vaccines, anticancer drugs, and chemotherapeutic agents	Anticancer drugs/small amounts of chemically harmful substances	Chemicals/cytotoxic drugs and mitogens consisting of or containing dangerous toxic substances	-
	(Blood-contaminated waste) Blood bags and waste generated from hemodialysis; other waste that requires special management due to a blood leak	Blood		■ Form: Blood (blood, serum, plasma, and fluid)
General healthcare waste	Cotton wool, bandages, gauze, sanitary pads, disposable syringes, and infusion sets soiled with blood, body fluids, and secretions	Non-hazardous waste	Waste whose collection and disposal are not subject to special requirements to prevent infection	Non-hazardous waste
Management of general healthcare waste as healthcare waste	○	x	x	x

When the healthcare waste classification systems of Korea and other countries were compared, the major difference found was that general healthcare waste with low infectivity was managed as healthcare waste in Korea, whereas it is classified as non-hazardous waste

and managed in the same way as municipal waste or general industrial waste in the US, the EU (Germany), the UK, and Japan (Table 4).

In addition, Korea and four EU countries were compared in terms of population size and amount of healthcare waste generated (Table 5). The population of Korea is approximately 25% smaller than the average population of the four EU countries. Nevertheless, the amount of healthcare waste in Korea was approximately 250% (2.5 times) higher on average. The population of Korea is approximately 15% smaller than that of Italy, which had the most similar GDP and population size to Korea, but the amount of healthcare waste was approximately 173% (1.73 times) higher (Table 5). This is because general healthcare waste with low infectivity is classified and managed as healthcare waste in Korea and represents as much as 76% of the total healthcare waste, as shown in the results of the differences in classification systems (Figure 2).

Table 5. Comparison of Korea and four EU countries in terms of population size and amount of healthcare waste.

Category		Amount (2018) (Unit: Tons)	Population (2018) (Unit: People)	GDP (2018, USD) (Unit: Million)
Korea		238,200	51,610,000	1619,424
Four EU countries	Average	93,000	69,220,000	2,918,351
	Germany	3263	82,910,000	3,996,759
	France	55,568	67,100,000	2,777,535
	Italy	137,711	60,420,000	2,073,902
	UK	176,919	66,460,000	2,825,208

Source: Ministry of Environment of ROK, Eurostat, OECD data for GDP.

3.4.2. Sterilization Treatments of Healthcare Waste

As shown in Table 1, the proportion of waste subjected to sterilization in the treatment of healthcare waste in Korea was approximately 0.5% in 2019, which is negligible. In Korea, sterilized and pulverized residues are excluded from healthcare waste but cannot be recycled and can be incinerated at municipal waste incinerators instead of incinerators dedicated to healthcare waste [10,31]. This means that the treatment burden on incinerators dedicated to healthcare waste can be reduced.

When the healthcare waste sterilization treatment systems of Korea and other countries were examined, we found that only heat treatment methods are allowed in Korea and that other methods, such as chemical treatment and melting, are not legally permitted. On the contrary, diverse methods are allowed for healthcare waste sterilization by international organizations, such as the WHO and Basel, and in countries such as the US, Japan, and the UK (Table 6).

In addition, concerning heat treatment methods, only large-capacity treatment facilities that can handle more than 100 kg/h are allowed in Korea, while small sterilization pulverization facilities are not permitted [10].

3.4.3. Healthcare Waste Treatment Systems Components including Incinerators and Transport Vehicles

We confirmed that the healthcare waste treatment system in Korea is highly strict compared with that in other countries. First, healthcare waste must be treated in dedicated incinerators. This means that healthcare waste cannot be mixed with other hazardous waste, and the healthcare waste discharged in containers must be added into incinerators without damaging the containers. Among the countries surveyed, only Korea had incinerators dedicated to healthcare waste, while other countries mixed healthcare waste with other hazardous waste in incinerators. Second, dedicated vehicles must be used in Korea for transport. Such vehicles must maintain a temperature of 4 °C or less during sealing and transport. However, in the other countries surveyed, healthcare waste is transported along with hazardous waste, and only specific sealing conditions are required [31]. Third,

healthcare waste subjected to sterilization must be incinerated again in general incinerators in Korea. However, in other countries, recycling or landfilling could be employed after sterilization.

Table 6. Comparison of domestic and overseas standards for sterilization. (Source: California Department of Public Health, 2020 [23]; Florida Administrative Code, 2021 [24]; Government of the United Kingdom, 2020 [25]; Japanese Ministry of the Environment, 2021 [26].)

Country \ Category		Heat Treatment	Chemical Treatment	Other Treatments
	Korea	Steam, microwave, and dry heat	Not allowed	Not allowed
	WHO	Steam, microwave, and dry heat	Disinfectants and alkaline hydrolysis	Radiation, biological, and mechanical treatments
	Basel	Steam and dry heat	Chemical agents	Microwave, radiation, and encapsulation
USA	California	Steam	Available under the approval of the department in charge or in case of equivalent performance (Results in the destruction of pathogenic microorganisms)	
	Florida	Steam	Allowed	Allowed
	Japan	Steam and dry heat	Allowed	-
	UK	Steam, microwave, and dry heat	Allowed	Direct landfilling is allowed in case of no infectivity

3.5. Suggestions and Future Challenges for the Healthcare Waste Management System

The amount of healthcare waste generated is increasing in Korea, but the treatment method is limited to incineration (Table 1) [5,29]. As the installation or expansion of incinerators dedicated to healthcare waste will be difficult in the future, the amount of healthcare waste must be reduced by improving the waste classification system for the stable management of healthcare waste in Korea. To this end, healthcare waste with low infectivity needs to be identified and excluded from healthcare waste (e.g., exclusion of non-infectious diapers from 2000) over the short term and the classification system needs to be reorganized to focus on infectious waste over the long term. This will lead to the exclusion of general healthcare waste with low infectivity, which is managed as healthcare waste in the current classification system, from healthcare waste. Measures for excluding general healthcare waste with low infectivity from healthcare waste over the long term are needed because general healthcare waste represents approximately 76% of the total healthcare waste (Figure 2) and Korea is the only country among the examined countries which manages this waste as healthcare waste (Table 4).

To exclude general healthcare waste, sufficient scientific evidence for the low infectivity of general healthcare waste needs to be secured through surveys and efforts to improve understanding and gain the empathy of people must be made to avoid objections from people due to increased concerns over infectious diseases.

Second, the sterilization treatment method must be diversified and the installation of sterilization/pulverization facilities must be allowed. In Korea, only heat treatment methods (microwave sanitation, steam sterilization, and dry heat disinfection) are allowed for sterilization (Table 6). Other methods such as chemical disinfection and melting must be allowed and, in addition to large-capacity equipment handling more than 100 kg/h waste, small treatment facilities should be permitted. Before diversifying the sterilization treatment method, the effect and safety of sterilization must be sufficiently inspected.

In this regard, safety testing should consider the microorganisms verified in overseas sterilization facility management. Additionally, it is important to consider non-eradicated microbial species, referencing research results similar to the conditions of the sterilization facilities being introduced in South Korea.

In the current COVID-19 pandemic situation, the ME has implemented same-day transport and same-day incineration guidelines for COVID-19-related waste [10]. For such prioritized incineration of COVID-19 waste, experts suggest that on-site treatment of health-

care waste with low infectivity through sterilization is a good alternative to preventing the reproduction of infectious microorganisms during the long-distance transport of healthcare waste or delayed incineration [18]. If sterilization/pulverization facilities are installed in large hospitals generating a large amount of healthcare waste, the treatment burden on dedicated incinerators will be reduced.

Finally, the classification systems must be improved to ensure that healthcare waste can also be mixed and treated in hazardous waste incinerators. The current Wastes Control Act allows healthcare waste with low infectivity to be treated in hazardous waste incinerators under emergency situations (Article 25-4 of the Wastes Control Act, Special Cases for Healthcare Waste Treatment). However, the classification systems must be improved to ensure that healthcare waste with low infectivity (i.e., general healthcare waste) can always be treated in incinerators. To this end, an additional dedicated inlet for healthcare waste must be allowed in hazardous waste incinerators as in incinerators dedicated to healthcare waste to prevent the infectivity of healthcare waste. Moreover, the installation of a facility that automatically adds healthcare waste from dedicated containers into an incinerator with no damage to the containers, a separate storage warehouse for healthcare waste, and RFID readers must also be considered. Additionally, microbial sterilization testing should be considered to confirm the stability of the sterilization facility. The healthcare waste disposal guidelines proposed in this paper are shown in Figure 4.

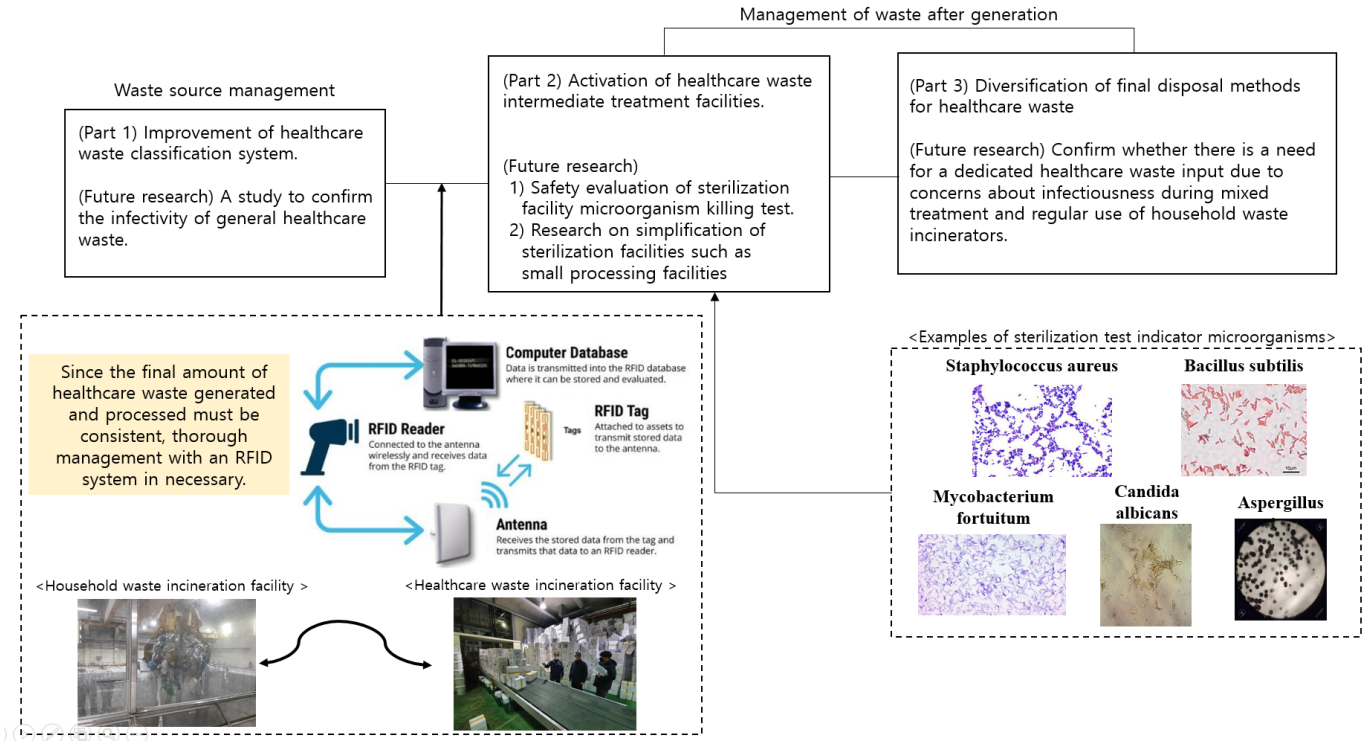

Figure 4. Healthcare waste treatment proposals.

4. Conclusions

A stable management plan for healthcare waste is required as the amount of infectious healthcare waste has increased due to the spread of COVID-19 in Korea. For stable management of healthcare waste in the future, the healthcare waste classification system must be improved to classify waste that is not expected to be infectious and exclude it from healthcare waste to reduce its amount. In the long term, low-infectivity general healthcare waste should be excluded from healthcare waste and infectious waste management should be improved. However, it is difficult to expand healthcare waste incinerators due to opposition from citizens. To solve the problem of concentrated incineration of healthcare waste, methods for infectious microorganisms should be diversified and small-scale sterilization

facilities and grinding facilities should be permitted. As a result, healthcare waste can be processed at the source in small-scale sterilization and transported to reduce the risk of infection by reducing the travel distance of infectious waste. Finally, if the operation of an intermediate treatment facility is permitted in Korea, the infectivity of some healthcare waste before final treatment is expected to decrease. Due to the NIMBY phenomenon, it is difficult to expand healthcare waste treatment facilities. Therefore, ensuring sufficient stability in sterilization facilities is important to gain the trust of citizens.

Author Contributions: The authors confirm their contributions to the paper as follows: data curation, data collection, and basic investigation: M.-J.K. and Y.-S.P.; project administration: T.K. and Y.-s.Y.; draft manuscript preparation and writing: M.-J.K. and H.-H.C.; analysis, interpretation of results, writing—review, and editing: N.U. and T.-w.J. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the National Institute of Environmental Research R&D Foundation, Ministry of Environment, Republic of Korea [grant number NIER-2021-01-01-083].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data will be made available on request from the corresponding author.

Acknowledgments: The authors acknowledge the research support provided by the Ministry of Environment (MOE) of the Republic of Korea.

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

References

1. Corona Board. COVID-19 Dashboard. Available online: https://coronaboard.com/ (accessed on 7 April 2022).
2. The Korea Herald. Global Maps of COVID-19 Cases. 2020. Available online: http://www.koreaherald.com/coronavirus/index.php#btnTexta (accessed on 7 January 2022).
3. Asian Development Bank (ADB). Managing Infectious Medical Waste during the COVID-19 Pandemic. 2020. Available online: https://www.adb.org/publications/managing-medical-waste-covid19 (accessed on 2 December 2021).
4. Rhee, S.W. Management of used personal protective equipment and wastes related to COVID-19 in South Korea. *Waste Manag. Res.* **2020**, *38*, 820–824. [CrossRef] [PubMed]
5. Manoj, K.L.; Santosh, K.S. Medical waste management during COVID-19 situation in India: Perspective towards safe environment. *Waste Manag. Bull.* **2023**, *1*, 1–3.
6. Mustafa, A.; Amira, E.; Dilruba, A.; Eldon, R.R. A Review on Medical Waste Managment: Treatment, Recycling, and Disposal Options. *Environments* **2022**, *9*, 146.
7. Jang, Y.C.; Lee, C.; Yoon, O.S.; Kim, H. Medical waste management in Korea. *J. Environ. Manag.* **2006**, *80*, 107–115. [CrossRef] [PubMed]
8. Oh, S.-E.; Ji, K.-H.; Park, S.; Kim, P.; Lee, K.-M. International comparisons of management systems for medical waste and suggestions for future direction of medical waste management system in Korea. *J. Environ. Health Sci.* **2017**, *43*, 532–544. [CrossRef]
9. Residents of Gijang-Gun "Frustrated" by the Plan to Expand Healthcare Waste Incinerators. *Financial News*, 9 May 2021. Available online: www.fnnews.com/print/202105091938284756(accessed on 2 December 2021).
10. Shin, S.-C.; Byun, H.; Kim, S. A Study on the Application of the Short-Range Principle for Treatment of COVID-19 Medical Waste in Korea. Korean Environment Institute (KEI). 2020. Available online: https://www.kei.re.kr/search/search.jsp (accessed on 11 May 2021).
11. ESCAP. The Safe Waste Treatment for COVID-19: Lessons from the Republic of Korea. 2020. Available online: https://www.unescap.org/kp/2020/safe-waste-treatment-covid-19-lessons-republic-korea (accessed on 7 April 2022).
12. Ministry of Environment (MOE). 3rd Special Measures for Safety Management of Wastes Related to COVID-19. South Korea, 2020b. Available online: http://eng.me.go.kr/eng/web/board/read.do;jsessionid=fA1DysRKcQJ2ioLZzTmWCSvY.mehome1?paperOffset=150&maxPageItems=10&maxIndexPages=10&searchKey=&searchValue=&menuId=461&orgCd=&boardId=1374270&boardMasterId=522&boardCategoryId=&decorator= (accessed on 14 March 2022).
13. The Ministry of Environment Can Handle Too Many COVID-19 Wastes. *Financial News*, 7 April 2020. Available online: https://www.fnnews.com/news/202004071722241372(accessed on 25 March 2022).
14. "Against Medical Waste Association"... Urging City Council Participation. *Nocutnews*, 16 January 2024. Available online: https://www.nocutnews.co.kr/news/6079894(accessed on 15 March 2024).

15. Korea Environment Corporation. Allbaro System. 2019. Available online: https://www.allbaro.or.kr/02_wss/wss_ManyPeople.vm (accessed on 6 May 2020).
16. Korea Environment Corporation. Designated Waste Occurrence and Treatment, 2014–2019. Available online: https://www.recyclinginfo.or.kr/rrs/stat/envStatDetail.do?menuNo=M13020202&pageIndex=1&bbsId=BBSMSTR_000000000002&s_nttSj=KEC006&nttId=1011&searchBgnDe=&searchEndDe (accessed on 23 April 2020).
17. Eurostat. Generation of Waste by Waste Category (Hazardousness and NACE Rev.2 Activity). 2018. Available online: https://ec.europa.eu/eurostat/web/waste/data/database (accessed on 11 March 2022).
18. Johns Hopkins University. COVID-19 Data Repository by the Center for System Science and Engineering. 2022. Available online: https://coronavirus.jhu.edu/map.html (accessed on 24 January 2022).
19. National Institute of Environmental Research (NIER). *Survey on Final Disposal Minimization through Waste Streams Analysis (II)*; National Institute of Environmental Research (NIER): Incheon, Republic of Korea, 2020.
20. National Institute of Environmental Research (NIER). *Survey on Final Disposal Minimization through Waste Streams Analysis (III)*; National Institute of Environmental Research (NIER): Incheon, Republic of Korea, 2021.
21. Oh, S.-E.; Lee, J.; Ahn, H.; Kim, K.-Y.; Park, S.; Ji, K.-H.; Kim, P.; Lee, K.-M. A Study on the Spatial Distribution of Medical Waste Generation and Treatment in Korea. *J. Environ. Health Sci.* **2015**, *41*, 449–457. [CrossRef]
22. Basel Convention. Technical Guidelines on the Environmentally Sound Management of Biomedical and Healthcare Wastes (Y1;Y3). 2003. Available online: https://digitallibrary.un.org/record/475506?ln=en (accessed on 7 April 2022).
23. California Department of Public Health. 2020. Available online: http://www.cdph.ca.gov (accessed on 22 April 2022).
24. Florida Administrative Code. Florida Administrative Act Chapter 64E-16. 2021. Available online: https://www.flrules.org/gateway/ChapterHome.asp?Chapter=64e-16 (accessed on 3 December 2022).
25. Government of the United Kingdom. 2020. Available online: http://www.gov.uk (accessed on 3 December 2022).
26. Japanese Ministry of the Environment. *Waste Management and Public Cleaning Law*; Japanese Ministry of the Environment: Tokyo, Japan, 2021.
27. LAGA (Germany). Guidelines on the Treatment of Healthcare Waste. Ministry of Environment (MOE), 2020a. Waste Management Act (In Korean). 2015. Available online: https://www.law.go.kr/LSW//lsInfoP.do?lsiSeq=228137&ancYd=20210105&ancNo=17851&efYd=20210706&nwJoYnInfo=N&efGubun=Y&chrClsCd=010202&ancYnChk=0#0000%5C (accessed on 14 March 2022).
28. World Health Organization (WHO). Safe Management of Wastes from Health-Care Activities. 2014. Available online: https://www.who.int/publications-detail-redirect/9789241548564 (accessed on 10 May 2022).
29. OECD DATA. Gross Domestic Product (GDP). 2018. Available online: https://data.oecd.org/gdp/gross-domestic-product-gdp.htm (accessed on 13 January 2022).
30. Yoon, C.-W.; Kim, M.-J.; Park, Y.-S.; Jeon, T.-W.; Lee, M.-Y. A review of medical waste management systems in the Republic of Korea for hospital and medical waste generated from the COVID-19 pandemic. *Sustainability* **2022**, *14*, 3678. [CrossRef]
31. Hernan, G.; Mazzei, S.S.; Manoj, J.K. Latest insights on technologies for the treatment of solid medical waste: A review. *J. Environ. Chem. Eng.* **2023**, *11*, 109309.