



## Article

# New Trends in Pollution Prevention and Control Technology for Healthcare and Medical Waste Disposal in China

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**Abstract:** This study explores the progression of global healthcare and medical waste (HMW) disposal technologies and emerging practices in China including the COVID-19 pandemic period through patent technology innovation analysis. Trends were identified through both the Derwent Innovation Index database and bibliometric methods. Based on the bibliometric analysis of 4128 patents issued from 2002 to 2021, the development status and research trends of HMW disposal technology were revealed. Regarding patents, China significantly advanced post-2011. However, a large number of applications are filed only in China and are more focused on domestic rather than overseas markets. As the pandemic remains a threat, and increasing amounts of medical waste are generated, new technologies are being sought in China that will be safer for humans and the environment, and will also be in line with the zero waste technology trend. Incineration and waste crushing are core methodologies in medical waste disposal. Future directions pivot towards innovations in large-scale and distributed processing equipment, automation and unmanned systems and high-temperature steam disinfection collaborative disposal methods—including the “High temperature steam–municipal solid waste incineration collaborative technology” and the “High temperature steam–thermal magnetic gasification collaborative technology”. This patent analysis enhances our understanding of the impact of COVID-19 on HMW disposal practices, guiding improved policymaking and research in the HMW sector.

**Keywords:** healthcare and medical waste (HMW); COVID-19; waste disposal; technology innovation evolution



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## 1. Introduction

Recent pandemics, including H1N1 influenza A, Ebola, and Middle East respiratory syndrome, underscored global healthcare challenges associated with the management of healthcare and medical waste (HMW). The emergence of COVID-19 in 2020 catalyzed an unparalleled strain on global medical infrastructure, accentuating the intricacies of HMW management [1–7]. Such medical waste, characterized by its infectious, toxic, and environmentally deleterious nature, poses an augmented environmental threat during pandemics [8].

Although esteemed bodies, including the WHO, UNICEF, and UNEP, have disseminated guidelines for healthcare waste management during pandemics [9–15], a comprehensive understanding of the dynamic landscape of HMW disposal and associated research trends remains nascent.

China, post-SARS, has emerged as one of the focal points in pandemic response, developing an intricate HMW management system. A series of HMW disposal technologies, e.g., rotary kilns [16], pyrolysis [16], high-temperature hot air treatment [17], high-temperature steaming [18], chemical disinfection [19], microwave [20], and technical

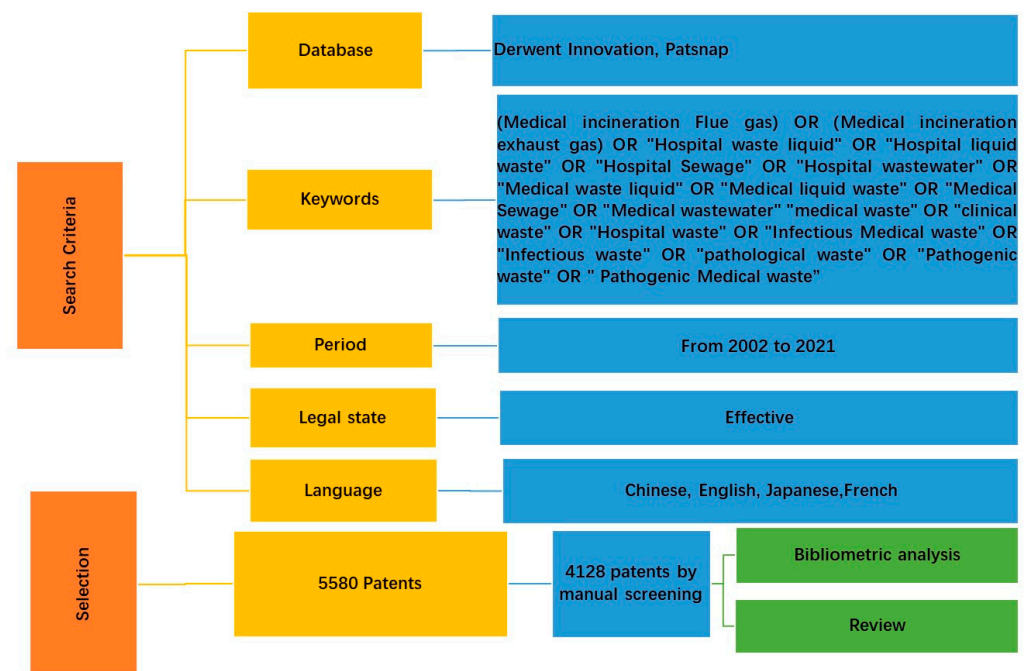
documents that permit joint management among relevant management agencies, formed a complete closed-loop medical waste management system in China. Yet, the unprecedented surge in medical waste due to COVID-19 underscored the need for agility and resilience in waste management systems. Between January and June 2020, China addressed approximately 447,000 metric tons of medical waste, ameliorating their disposal strategies and capacities [21]. Factors such as the amount of waste, costs, maintenance and types of waste, etc. should be taken into consideration when selecting appropriate disposal technologies [22]. Incineration technology could be adopted when the amount of waste is large and the investment is sufficient when disinfecting pathological or pharmaceutical waste. If the scale of the hospital is smaller and the investment is limited, chemical disinfection and high-temperature steam disinfection—which are easily maintained—are preferred. At the same time, the emergence of some combination technologies such as “high temperature steam–municipal solid waste incineration collaborative technology [23]” has also contributed to the diversification of medical waste disposal technologies due to the emergence of needs such as emergency disposal and local disposal.

Patents, pivotal for the dissemination and safeguarding of technical innovations, present a tangible metric for delineating technological trajectories in specific domains [24–27]. Harnessing repositories such as the Derwent Innovations Index (DII) and Patsnap, this study undertook a bibliometric excursion. (Patsnap is a worldwide patent search, analytics and collaboration platform (PatSnap Information Technology (Suzhou) Ltd., Suzhou, China), including patent data from 162 countries (regions) around the world, including China, the United States, Japan, South Korea, Germany, the United Kingdom, France, Australia, the European Patent Office and WIPO etc. More than 180 million patent documents are collected, covering 170 countries/regions are collected, with a time range from 1790–now. The update frequency of Patsnap is more than once a week. <https://www.zhiihuiya.com/> (accessed on 18 December 2023)). A total of 4128 patents were identified. This study was geared towards unearthing market evolution and technological categorizations in patent filings pertinent to HMW disposal. A pronounced emphasis was allocated to discerning the technological pathways in China, with attention concurrently cast to the burgeoning trends during the COVID-19 pandemic.

## 2. Materials and Methods

### 2.1. Data Collection

Data were obtained from searches of DII and Patsnap databases. Details were as follows: (1) ALL = ((Medical incineration Flue gas) OR (Medical incineration exhaust gas) OR “Hospital waste liquid” OR “Hospital liquid waste” OR “Hospital Sewage” OR “Hospital wastewater” OR “Medical waste liquid” OR “Medical liquid waste” OR “Medical Sewage” OR “Medical wastewater” “medical waste” OR “clinical waste” OR “Hospital waste” OR “Infectious Medical waste” OR “Infectious waste” OR “pathological waste” OR “Pathogenic waste” OR “Pathogenic Medical waste”). (2) The application year was set from 2002 to 2021, as the first patent related to HMW was collected in the database in 2002. (3) The language of the patent was set to Chinese, English, Japanese, Korean and French. (4) Numbers of patent families related to HMW disposal technology were grouped by the earliest priority year. (5) The relevant data are exported in CSV format from the DII and Patsnap databases, integrated according to the patent publication number, and a total of 5580 patents were collected. (6) In order to obtain accurate articles related to HMW disposal technology, a second round comprising manual screening of 4128 patents based on title, abstract, and content was performed (Figure 1), and the patents were imported into the Patsnap system in Excel data format for online analysis.



**Figure 1.** Document selection and flow diagram of data collection on HMW disposal technology.

## 2.2. Patent Analysis and Visualization

Bibliometric searches were conducted using the Patsnap system, i.e., application trends, patent competition layout, followed by the research hotspot analysis, i.e., keywords cluster. Here, we employed the following criteria for the bibliometric analysis:

**Application trends:** This was based on the year of patent application to reveal the trend of patent applications over time.

**Patent competition layout:** This analysis combined the dimensions of application year and priority countries. We observed the target market by counting the priority countries where all members of the patent family applied. By comparing the “earliest priority” country and the “priority countries” of family members, we performed an analysis of patent flow.

Microsoft Excel 2020 and Apache ECharts 5.3 software were used for the visualization of the above results.

**Keywords cluster:** A visual analysis of co-occurrence of keywords was prepared based on the International Patent Classification (IPC). Keywords for HMW disposal were extracted from abstracts and divided into nine clusters distributed on a 3D map using Patsnap. The white peak represents hotspots of current research, and the valley indicates blind spots. Categories are displayed in different colors.

The 3D patent map serves as a visual representation of the primary technological layout based on IPC classification. In this context, Patsnap utilizes text clustering to construct the topography, followed by an in-depth analysis of all patent texts within each cluster. From this analysis, nine groups of key terms were extracted, as illustrated in Supplementary Materials. Within this depiction, the “terrain” of the patent map reflects the quantity of patents within different technology clusters: white peaks signify areas of concentrated technological focus, while valleys signify technological blind spots. To enhance our comprehension of these technologies, the nine clusters were manually consolidated into three major categories, guided by the technical labels and IPC classification codes. These categories are visually represented on the map in distinct colors: blue, red, and yellow. Each colored point on the map corresponds to an individual patent.

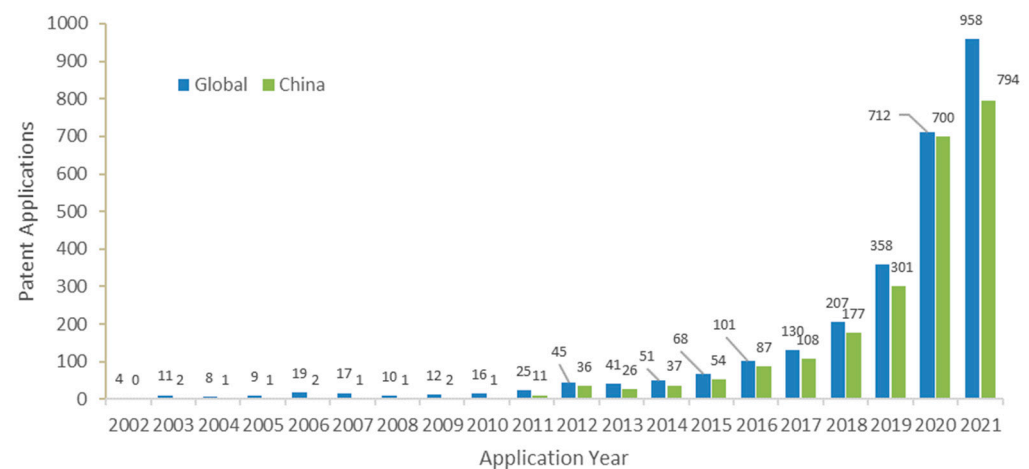
The blue category, focused on pollution prevention, includes pretreatment (IPC: B02C18), incineration/non-incineration, and landfilling (IPC: F23G5, A61L11). The red category includes pollution-control technologies of wastewater disposal (IPC: C02F9),

liquid waste disposal (IPC: C02F1), and flue gas disposal (IPC: B01D53). The yellow category introduces waste management technologies, such as management in collection and transportation (IPC: A41D13), management systems (IPC: G05B19), and special evaluation methods (IPC: G06Q50).

### 3. Results and Discussion

#### 3.1. Patent Application Activities of HMW Disposal (2002 to 2021)

An examination of China's patent application trends over the past two decades reveals that the patent application activity experienced a “slow growth period” in 2002–2010 and a “rapid development period” in 2011–2019, mirroring global trends (Figure 2). Several technical guidelines [28–35] were issued in 2003 for regulation of SARS medical waste generated by medical and health institutions in Figure 1. Between 2009 and 2010, the Response Plan on the Management of Medical Waste for Influenza A (H1N1) [36,37] was issued by the Ministry of Environmental Protection of China to ensure that medical waste was disposed of in a timely, orderly, efficient, and harmless manner. A pronounced increase in applications in China was observed with the AGR reaching 20.4% after 2011. Meanwhile, the AGR remained high at 25.0% (2015), 32.7% (2016), and 37.2% (2018), which aligns notably with the emergence of significant public health crises, such as Zika in 2015–2016 and Ebola in 2018. With an average AGR of 26.8%, there is a discernible uptick in Chinese research and development efforts. Post-2011, China rolled out a plethora of pertinent technical standards [38,39] to support the development of HMW disposal technology, including promotion of innovation and technological transformation, disposal technology selection and performance testing and further cultivating a conducive ecosystem for the evolution of HMW disposal technologies. The strengthening of government regulation in this period also affected the growth in patent submissions.



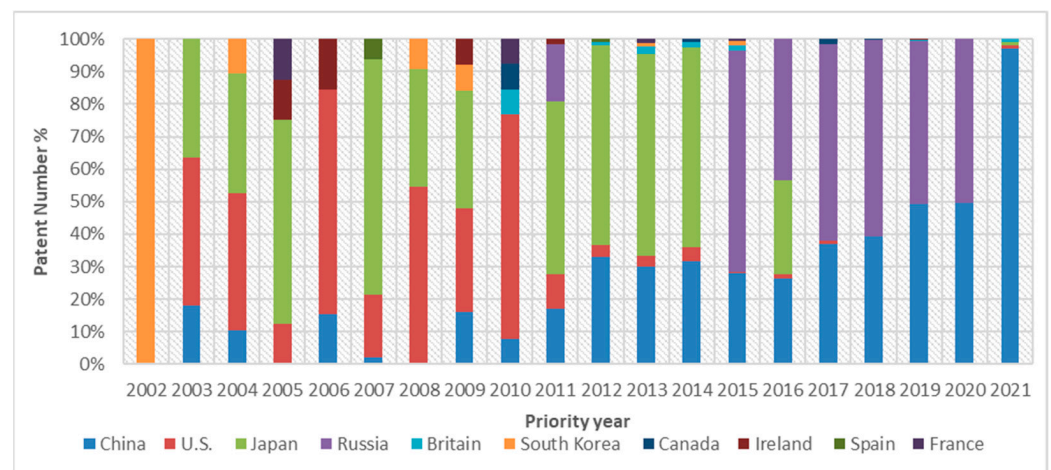
**Figure 2.** Chronological application activities of medical waste disposal technology patents. The statistics are based on publicly available documents—Patent applications are normally published 3–18 months after filing; therefore, rendering the 2021 data as provisional.

The emergence of the COVID-19 pandemic and ensuing lockdown measures profoundly impacted HMW management, thereby garnering intensified research scrutiny during this period due to the infectious nature of the SARS-CoV-2 virus. In February 2020, the Chinese government issued its Work Plan for Comprehensive Treatment of Waste in Medical Institutions, which requires all cities above the prefecture-level to build at least one centralized medical waste disposal facility by the end of 2020 and each county to build a medical waste system that consists of the collection, transfer, and disposal parts by 2022 [40]. Notwithstanding the proposal of an ambitious large-scale blueprint for medical waste disposal infrastructure, the intricacies of their execution remain paramount. By the close of 2018, HMW incineration facilities comprised 37% of the total facility count in

China. Incineration facilities are primarily pyrolysis furnaces; non-incineration facilities such as high-temperature steam treatment, microwave, chemical disinfection and other technologies are also used [41]. Prior to the advent of COVID-19, centralized disposal facilities predominantly employed unwieldy equipment, which were challenging both in terms of mobility and installation. Furthermore, these facilities exhibited rigidity, falling short of the specialized requirements for managing voluminous amounts of highly contagious materials. Movable waste disposal facilities, hazardous and municipal solid waste incineration facilities, industrial furnaces, cement rotary kilns, and other facilities can be used for emergency disposal in China [40]. Operational parameters necessitate calibration to accommodate medical waste processing [42].

### 3.2. Geography of Patent Filings in HMW Disposal (2002 to 2021)

Assessing the geographical distribution of patent filings helps to understand the activity of relevant technologies in China, as well as to identify the main countries producing technologies and their markets. Historically, key patent offices, which indicate the perceived target markets for HMW disposal technology, included Korea, the United States, Japan, Ireland, and Spain. Nevertheless, these jurisdictions have witnessed a decline in patenting activities since 2011. Concurrently, China has experienced a burgeoning trend in patent submissions (see Supplementary Materials), eclipsing those of the United States and constituting over 72.2% of the global aggregate since 2012 (Figure 3).



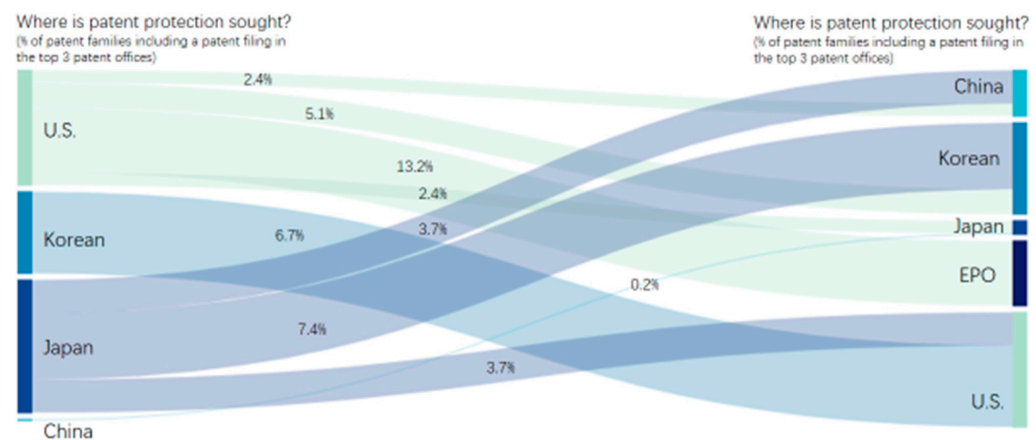
**Figure 3.** Patent filing trends related to HMW disposal technologies across primary market countries/regions by year.

In examining target markets, overall, >85.5% of the patent families in the dataset were safeguarded within a single jurisdiction, reflecting a predominant interest in a single (mostly local) market, especially in China. A mere 1% of initial patents filed in China are subsequently filed in another jurisdiction, compared with 6.7–23.1% percent being re-filed from all other offices. China trails among the five offices (China, Korean, Japan, EPO, U.S.) containing families with at least one granted patent. While myriad factors may underpin these statistics, the pronounced volume of applications exclusively filed in China suggests a Chinese proclivity for the domestic over the international market in the realm of HMW disposal. The substantial proportion of applications localized to China, juxtaposed against a relatively augmented refiling rate in the USPTO and the other three offices, may indicate that HMW disposal technologies are innately tethered to local development and operational contexts (Figure 4).

China's HMW disposal technologies, such as steam-based treatment, microwave treatment, frictional heat treatment, and other non-incineration processes, have been locally developed and refined. These technologies are notably tailored to suit China's unique



environmental conditions, offering cost-effective, operationally streamlined, and space-efficient solutions.



**Figure 4.** Patent applications in the main patent offices in terms of number of patent applications filed in 2002–2021 for HMW disposal technology.

In contrast the United States, Japan, and European nations have traditionally shared more convergent process systems distinct from those prevalent in China. Historically, these regions have represented crucial markets for one another, a trend evident in their corresponding patent activities. For example, incineration technology was extensively embraced for HMW disposal in the United States throughout the last century, driven by active promotion from the Environmental Protection Agency (USEPA). However, the ubiquity of such technologies has gradually dwindled since the late 1990s. In Japan and European countries, incineration and vacuum autoclave technologies have predominated as primary options for HMW disposal.

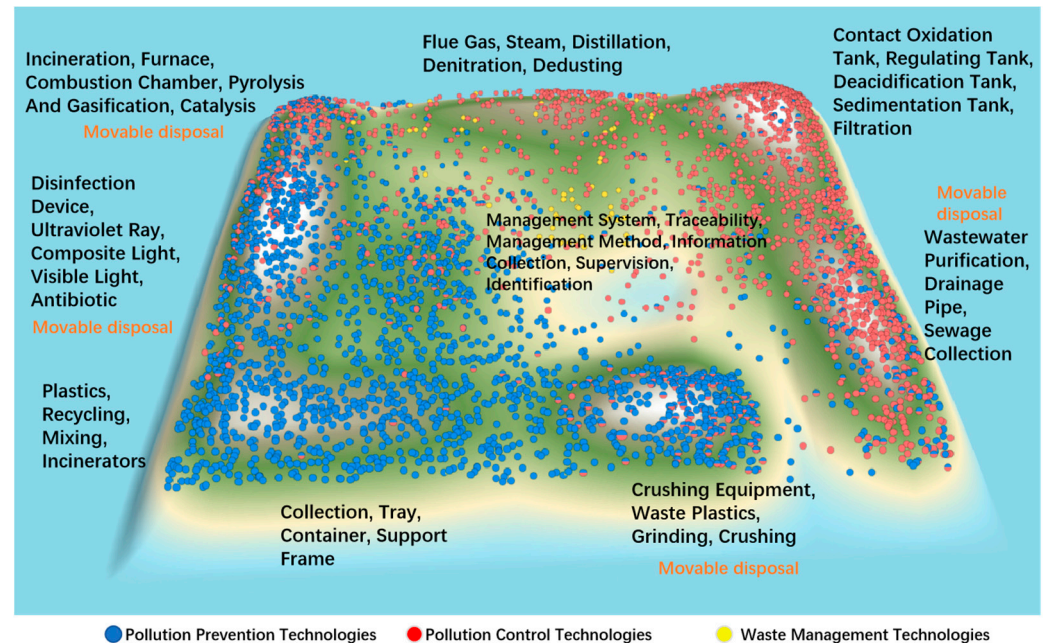
In just over a decade, China's medical waste disposal technology has gone through a process of self-disposal by hospitals, simple incineration during the SARS period, centralized incineration under national planning, and separation of planned incineration and non-incineration technologies. With the application and promotion of BAT/BEP, after nearly a decade of development, the overall level of medical waste disposal technology in China has improved, and incineration is developing towards large-scale. The scale of non-incineration treatment is constantly expanding, and the technology tends to be regional synergy and complementarity.

A noteworthy development since 2020 is the heightened international reach of Chinese patents related to HMW disposal technologies. This expansion can be attributed to adaptive enhancements in HMW disposal technologies during the COVID-19 pandemic, coupled with the burgeoning overseas application experience of Chinese patentees. This trend is anticipated to persist, with Chinese patents extending to an even wider array of overseas patent offices in the future.

### 3.3. Technical Status of HMW Disposal Process in China

Nine clusters were manually merged into three major categories created using technical labels and IPC classification codes (Figure 5). Active technical areas of waste disposal are provided with labels on the three prominent peaks: (1) Crushing equipment, waste plastics, grinding, crushing; (2) Disinfection devices, ultraviolet light, composite light, visible light, antibiotics; and (3) Plastics, recycling, mixing, incinerators. The two peaks in wastewater treatment reflect: (1) Contact oxidation, regulating, deacidification, and sedimentation tanks, and filtration; and (2) Wastewater purification, drainage pipe, sewage collection. It is worth noting that during the COVID-19 pandemic, movable disposal technology (IPC: F23G7) was also an active area of development (marked in orange). At the intersection of these categories, a conspicuous low-patent-density valley emerges. Technologies on either

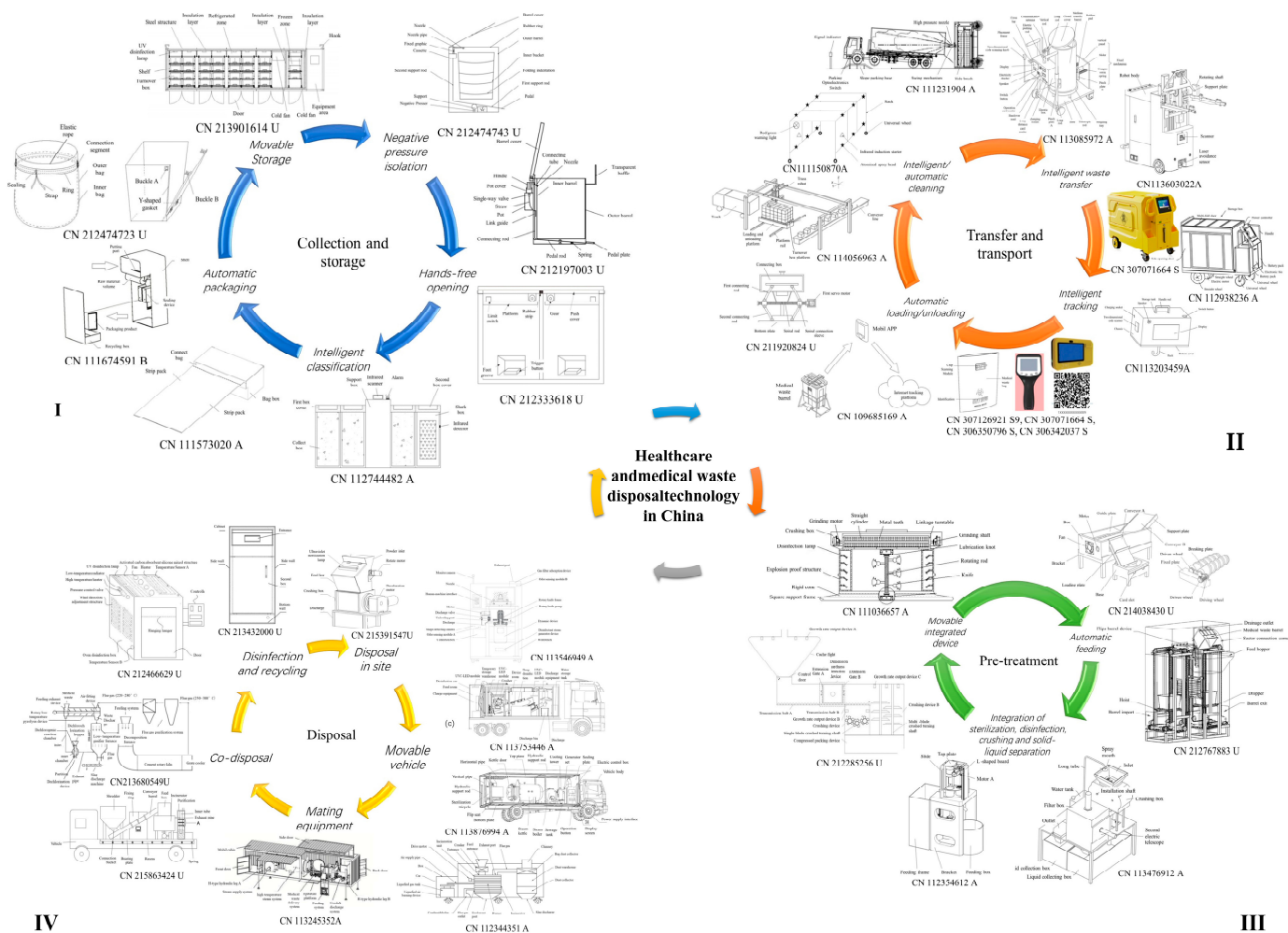
side of this valley encompass HMW pollution risk assessment methods (CN106096268B), devices for the treatment of radioactive medical waste (CN110526245A), and methods for treating carcinogens produced in medical wastewater (CN107758924A). These technologies potentially signify prospects for further advancements in these domains.



**Figure 5.** 3D patent map of HWM keyword co-occurrence.

Managing wastes associated with the COVID-19 epidemic requires special attention due to viral infectivity [12]. Proper waste management procedures are crucial to maintain the safety of health workers and communities [9]. Proper pollution prevention and selection of control technology are also critical for healthcare facilities and COVID-19 treatment units [14]. Different from previous conventional technologies, the main innovations of HMW disposal technology in China during the COVID-19 epidemic are discussed below (Figure 6). WHO guidelines [43] categorize healthcare waste into eight major groups, including both hazardous and nonhazardous components. While medical waste in China is normally divided into five categories –infectious, pathological, sharps, pharmaceutical, and chemical [44]. Much waste generated by healthcare facilities during the COVID-19 pandemic was general noninfectious waste, e.g., packing, food, and disposable towels. General waste was typically segregated from infectious waste in clearly marked bins, and then bagged and disposed with general municipal waste. Infectious waste produced during patient care, including those patients with confirmed COVID-19 infections (e.g., sharps, bandages, and pathological waste) was intended for collection in clearly marked lined containers and sharps boxes [41]. Therefore, the collection of COVID-19 medical waste needs to use negative pressure isolation, hands-free opening, intelligent classification, convenient packaging, automatic packaging, and compression technology (Figure 6I) to avoid excessive contact with medical staff and waste-collection personnel. Intelligent and automatic technologies such as RFID, Scan QR code, tracking systems, etc. are widely used for the transfer, tracking, loading/unloading, and cleanup for waste transfer and transport processes (Figure 6II). Intelligent and automatic technologies are also widely used for sterilization, disinfection, crushing, solid–liquid separation, feeding, and packing waste during pretreatment (Figure 6III). Patent applications were active in waste crushing which accounts for 13.2% of the total. Disposal technologies of HMW were the dominant direction in the whole field which accounts for 39.4%, with incineration technology (Figure 6IV) accounting for 22.9%. Movable and collaborative disposal of medical wastes applications

greatly reduce risks of multiple contacts between infectious waste and workers during collection, loading, unloading, and other processes.



**Figure 6.** Active technology development for healthcare and medical waste disposal in China. (I indicate collection and storage process, II indicate transfer and transport process, III indicate pretreatment process, IV indicate disposal process).

Prior to the COVID-19 outbreak in China, centralized medical waste disposal facilities used large-scale equipment that was difficult to move and install, and lacked the flexibility to adapt to the special needs of disposing of large quantities of highly infectious medical wastes unexpectedly during an outbreak. After the outbreak of the epidemic—and in addition to research and development into centralized medical waste disposal facilities—there was more research into new methods. Mobile medical waste disposal facilities and the co-processing of medical wastes by co-disposal facilities such as hazardous waste incineration facilities (CN219346508U, incineration temperature higher than 1100 °C), municipal solid waste incineration facilities (CN110486727A, CN217732843U, incineration temperature higher than 850 °C) and industrial kilns (CN112207115B, kiln temperature higher than 850 °C)—which meet the higher demand for medical waste disposal, and also improve the non-incineration technologies—have been developed, to more rapidly eliminate or reduce the intensity of infection of medical waste during epidemics. However, incineration technology dominates in the centralized disposal of medical waste. Due to the high operating costs and the high requirements in controlling dioxin pollution of centralized incineration facilities, in the case of decentralized or mobile emergency disposal, non-incineration technologies have also undergone considerable technological innovation. Against the back-



ground of Basel Convention implementation, Chinese medical waste disposal technology also underwent a gradual transition from incineration to non-incineration methods, such as high-temperature steam, microwave, and chemical disinfection. Among them, the high-temperature steam disinfection collaborative technology will be widely applied. (The scope of application of different medical waste treatment and disposal technologies is shown in Table 1) These collaborative technologies can fully leverage the advantages of low operating cost and low pollution in the treatment process of high-temperature steam disinfection process, achieving harmless treatment of medical waste. At the same time, the range of high-temperature steam disinfection technologies can be expanded by combining other medical waste disposal technologies. The “High temperature steam–municipal solid waste incineration collaborative technology (CN215489776U)” can send the disinfected waste residue to the municipal solid waste incineration plant for incineration, solving the final problem of reducing the volume of medical waste after disinfection. The “High temperature steam–thermal magnetic gasification collaborative technology (CN218146491U)” can disposal all five types of medical waste, among which infectious, damaging, and pathological medical waste is disinfected by high-temperature steam; chemical and pharmaceutical medical waste is disposed of through thermal magnetic gasification. The measured dioxin emission value of 0.013 ngTEQ/m<sup>3</sup> of medical waste disposed by the thermal magnetic gasification disposal technology is in line with the emission standard for medical waste disposal technology in China (0.5 ngTEQ/m<sup>3</sup>) and also lower than that for medical waste disposal technology in the EU (0.1 ngTEQ/m<sup>3</sup>).

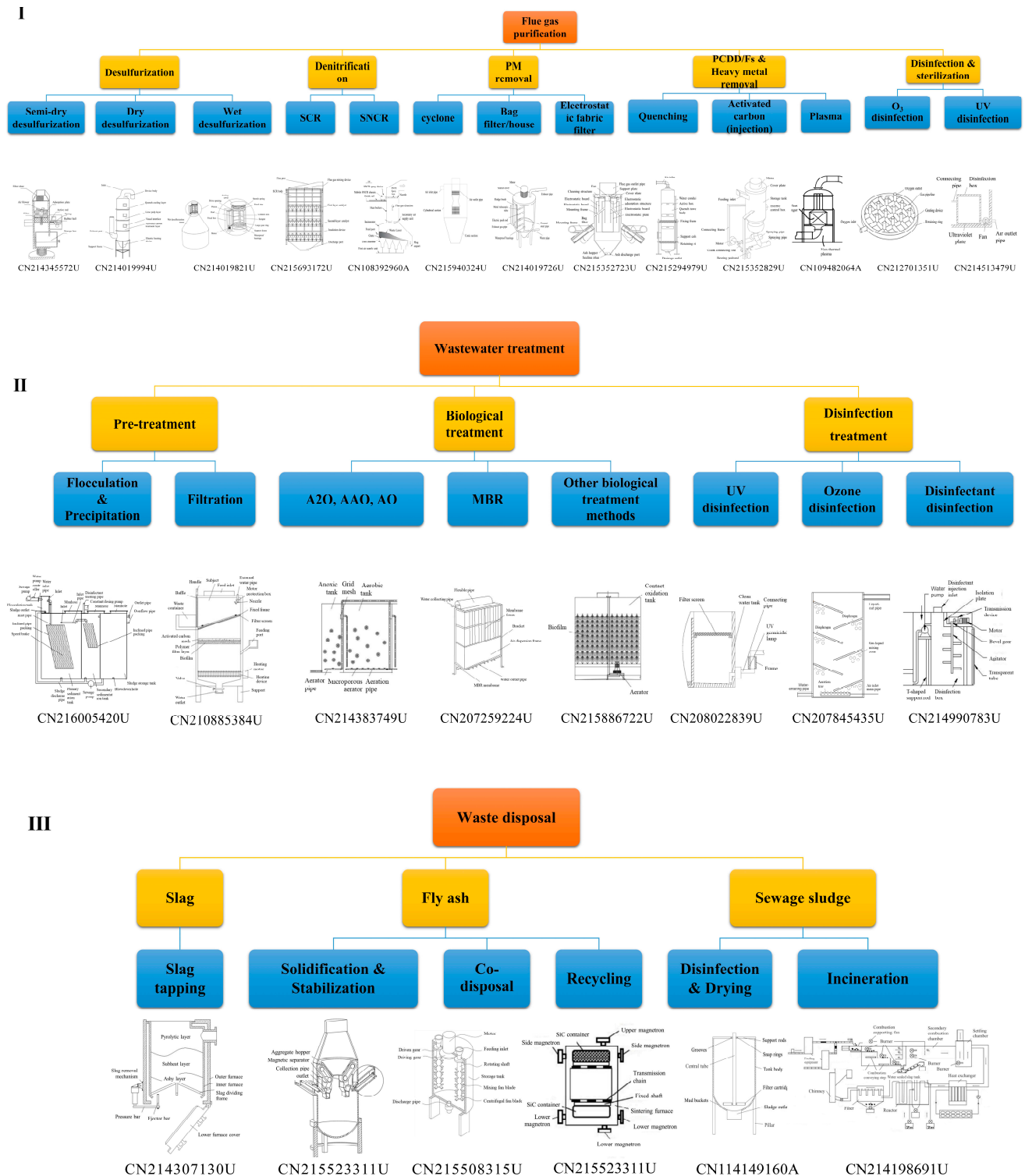
**Table 1.** Scope of application of different medical waste treatment and disposal technologies.

	Technology	Infectious Waste	Pathological Waste	Injurious Waste	Pharmaceutical Waste	Chemical Waste
Incineration	Incineration	✓	✓	✓	✓	✓
	Pyrolysis	✓	✓	✓	✓	✓
	Grate furnace	✓	✓	✓	✓	allow part
	Plasma	✓	✓	✓	✓	✓
	High-temperature steam disinfection	✓	×	✓	×	×
Non-incineration	Microwave disinfection	✓	×	✓	×	×
	Chemistry disinfection	✓	×	✓	×	×
	High temperature dry heat disinfection	✓	×	✓	×	×
	Electronic irradiation disinfection	✓	×	✓	×	×
	High temperature steam—municipal solid waste incineration collaborative	✓	✓	✓	✓	✓
New technology	High temperature steam—thermal magnetic gasification collaborative	✓	✓	✓	✓	✓
	Friction heat treatment	✓	✓	✓	×	×

“✓” indicate that the category of medical wastes can be handled through this technology, “×” means indicate that the category of medical wastes cannot be handled through this technology.

Waste disposal processes also require terminal control capability to prevent the release of waste to the surrounding environment. Control technologies include flue gas purification, wastewater treatment, and solid waste disposal (Figure 7). Patent analysis in flue gas purification shows focus on high-temperature steam treatment, microwave and chemical disinfection process (30.4%), incineration process (64.5%), and wastewater treatment processes (5.1%). The main IPC classification number involved is B01D53. Flue gas purification technologies include desulfurization, denitrification, dust removal, dioxin and heavy metal removal, disinfection, and sterilization. Flue gas purification from incineration processes includes organic and inorganic waste gas treatment, odor abatement, flue gas control, and waste heat boiler-related processes. Medical wastewater mainly comprises liquid and wastewater contaminated with pathogens generated during the collection and disposal of medical waste. The main IPC classification number was C02F9 and mainly in pretreatment (60.3%), biological (0.7%) and disinfection processes (39.4%), which comprised 6.1% of patents in the HMW disposal field. Pretreatment mainly concerns physical treatment, such as grids, sedimentation, and air flotation. Biological treatment mainly

focuses on degradation and transformation of pollutants in sewage into sludge via micro-organism activity. Disinfection treatment examines sewage disinfection with chlorine, ultraviolet radiation, and ozone. Solid wastes generated during the HMW disposal include fly ash, slag, and sewage sludge. These materials are all managed as hazardous waste in China, and thus, technical patents primarily address slag tapping, cooling, conveying, solidification/stabilization, recycling, disinfection/drying, and incineration.



**Figure 7.** Active areas of technology for flue gas purification, wastewater treatment and solid waste disposal in the HMW disposal process (I–III).

Waste management mainly focuses on overall HMW systems. Waste management often uses decision analysis based on data obtained from sensor networks via the Internet of Things (CN104700210B), cloud platforms (CN205788259U), and intelligent networks (CN206348776U). The goal is to achieve intelligent control over production, classification, collection, storage, transportation, and disposal. Waste management often focuses on the collection and transportation processes for medical waste, including logistics of transportation positioning (CN210140185U), remote monitoring (CN203012472U), classification, screening, and collection (CN206046503U), waste weighing (CN210924622U), and collection of other data (CN207319709U). In addition, specific disposal processes may require special data collection (CN210775280U).

### 3.4. Challenges and Future Prospects

#### 3.4.1. Challenges

1. As of the end of 2022, China has issued a total of 577 hazardous waste business licences for the disposal of medical waste (including 538 separate disposal units and 39 collaborative disposal units). Except for Danzhou and Sansha in Hainan, 337 cities at or above the prefecture level have built centralized disposal facilities. In 2022, the disposal capacity of medical waste management units nationwide was 2.61 million tons per year, with an actual disposal capacity of 2.09 million tons and a disposal load rate of 80%. Among them, 800,000 tons of medical waste generated in grassroots and remote areas account for about one-third of the national medical waste production, and the composition is complex and difficult to collect and cover. During the epidemic, the production volume increased sharply: Wuhan, for example, saw a daily production volume of over 200 tons of highly infectious waste—which was 3–5 times higher than usual).
2. Medical waste disposal technology has increasingly high requirements for efficiency, cost, safety, environmental protection, and occupational health. The existing incineration and non-incineration technologies have shortcomings, and the contradiction is becoming increasingly prominent. The incineration process is prone to producing dioxins and requires complex exhaust gas treatment systems, resulting in high operating and maintenance costs; non-incineration processes do not have exhaust emissions issues, but capacity reduction is limited, and waste residue still needs to be landfilled or sent to municipal solid waste incineration plants for incineration.
3. The treatment of chemical and pharmaceutical waste will inevitably become more important in future. The difficulty in disposing of these two types of waste lies in the wide variety and varying harmfulness of chemical and pharmaceutical waste. The current situation of the collection and transportation of pharmaceutical and chemical waste in Chinese hospitals is significantly different from that in Europe and America. Meanwhile, high quality and recyclable plastics account for 40–50% of the total amount of medical waste. After being landfilled, plastic degradation takes hundreds of years or even longer. At the same time, plastic is a key source of dioxin production during incineration. Due to the constraints of China's medical waste management policies, the resource utilization of medical waste still requires joint efforts from all parties.

#### 3.4.2. Future Prospects

Based on the above research results, it can be concluded that some innovative technologies will be well applied in the future:

1. The large-scale and distributed processing equipment will develop in parallel. In North America, medical waste treatment operators generally use large high-temperature steam treatment equipment with a single processing capacity of over 15 tons/day, with a maximum processing capacity of up to 3 tons/h per unit. For large centralized processing plants: high-temperature cooking equipment with a daily processing capacity of over 15 tons, or incineration equipment with a single processing capacity

of over 30 tons, will become the mainstream configuration. For small and medium-sized medical waste treatment plants, a new generation of high-temperature cooking equipment with a daily processing capacity of less than 5 tons and ultra-low emission thermal magnetic gasification equipment will be vigorously developed.

2. Automation and unmanned systems that are more reliable and cost-effective will become increasingly popular. Due to the increasing cost of labor, automation equipment is crossing the critical point of cost-effectiveness, and the safety and occupational health risks of on-site workers are increasing. Reducing manual operations and pursuing zero contact between humans and medical waste are the future development trends. Real unmanned workshops and intelligent factories will be popularized in the near future.
3. The high-temperature steam disinfection collaborative technology will be widely applied. These collaborative technologies can fully leverage the advantages of low operating cost and low pollution in the treatment process of high-temperature steam disinfection process, achieving harmless treatment of medical waste. At the same time, the range of high-temperature steam disinfection technologies can be expanded by combining medical waste disposal technologies.

#### 4. Conclusions

Chinese patents will be extended to overseas patent offices more frequently in the future with the adaptive improvement of HMW disposal technologies during the COVID-19 pandemic and the increasing overseas application experience of Chinese patentees. Within the realm of HMW disposal, incineration and waste crushing emerged as core methodologies. Future directions pivot towards innovations in large-scale and distributed processing equipment, automation and unmanned systems and high-temperature steam disinfection and incineration/thermal magnetic gasification disposal methods. This patent analysis enhances our understanding of the impact of COVID-19 on HMW disposal practices, guiding improved policymaking and research in the HMW sector.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/pr12010007/s1>, Table S1: Top 10 patentees in the field of healthcare and medical waste disposal technology in China. Table S2: Details of major technologies of the IPC categories.

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#### References

1. Zhou, F.; Yu, T.; Du, R.; Fan, G.; Liu, Y.; Liu, Z.; Xiang, J.; Wang, Y.; Song, B.; Gu, X.; et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: A retrospective cohort study. *Lancet* **2020**, *395*, 1054–1062. [[CrossRef](#)] [[PubMed](#)]
2. Zhu, N.; Zhang, D.; Wang, W.; Li, X.; Yang, B.; Song, J.; Zhao, X.; Huang, B.; Shi, W.; Lu, R.; et al. A Novel Coronavirus from Patients with Pneumonia in China, 2019. *N. Engl. J. Med.* **2020**, *382*, 727–733. [[CrossRef](#)] [[PubMed](#)]



3. Yu, H.; Sun, X.; Solvang, W.D.; Zhao, X. Reverse Logistics Network Design for Effective Management of Medical Waste in Epidemic Outbreaks: Insights from the Coronavirus Disease 2019 (COVID-19) Outbreak in Wuhan (China). *Int. J. Environ. Res. Public Health* **2020**, *17*, 1770. [CrossRef] [PubMed]
4. Sadia, L.; Ranjan, S.R.; Kim, H. Disinfection technology and strategies for COVID-19 hospital and bio-medical waste management. *Sci. Total Environ.* **2020**, *749*, 141652.
5. Saadat, S.; Rawtani, D.; Hussain, C.M. Environmental perspective of COVID-19. *Sci. Total Environ.* **2020**, *728*, 138870. [CrossRef] [PubMed]
6. Zhu, Y.J.; Xie, J.G.; Huang, F.M.; Cao, L.Q. Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. *Sci. Total Environ.* **2020**, *727*, 138704. [CrossRef] [PubMed]
7. WHO. *Water, Sanitation, Hygiene and Waste Management for COVID-19*; World Health Organization: Geneva, Switzerland; United Nations Children's Fund: New York, NY, USA, 2020.
8. Mochammad, C.; Masaru, T.; Ashok, V.S. A system dynamics approach for hospital waste management. *Waste Manag.* **2008**, *28*, 442–449.
9. WHO. *Interim Guidance: Water, Sanitation, Hygiene, and Waste Management for SARS-CoV-2, the Virus that Causes COVID-19*; World Health Organization: Geneva, Switzerland, 2020. Available online: <https://www.who.int/publications/i/item/WHO-2019-nCoV-IPC-WASH-2020.4> (accessed on 13 December 2023).
10. UNEP (United Nations Environment Programme). BEP Guideline. 2019. Available online: <http://www.pops.int/Implementation/BATandBEP/Progressold/BATBEPGuidelines/tabid/377/Default.aspx> (accessed on 13 December 2023).
11. WHO. *Management of Waste from Injection Activities at the District Level: Guidelines for District Health Managers*; World Health Organization: Geneva, Switzerland, 2006. Available online: <https://apps.who.int/iris/handle/10665/43476> (accessed on 13 December 2023).
12. WHO. *Overview of Technologies for the Treatment of Infectious and Sharp Waste from Health Care Facilities*; World Health Organization: Geneva, Switzerland, 2019. Available online: <https://www.who.int/publications/i/item/9789241516228> (accessed on 13 December 2023).
13. UNICEF. *Appropriate Disposal of Immunization Waste (ADIW) Platform*; United Nations Children's Fund: New York, NY, USA, 2020. Available online: [https://www.technet-21.org/en/library/main/6388-appropriate-disposal-of-immunization-waste-\(adiw\)-platform](https://www.technet-21.org/en/library/main/6388-appropriate-disposal-of-immunization-waste-(adiw)-platform) (accessed on 13 December 2023).
14. UNICEF. *COVID-19 Emergency Preparedness and Response: WASH and Infection Prevention and Control in Health Care Facilities*; Guidance Note; United Nations Children's Fund: New York, NY, USA, 2020. Available online: <https://www.unicef.org/media/66386/file/WASH-COVID-19-infection-prevention-and-control-in-health-care-facilities-2020.pdf> (accessed on 13 December 2023).
15. UNEP/IGES (United Nations Environment Programme/Institute for Global Environmental Strategies). *Waste Management during the COVID-19 Pandemic: From Response to Recovery*; United Nations Environment Programme: Nairobi, Kenya; Institute for Global Environmental Strategies: Hayama, Japan, 2020. Available online: <https://reliefweb.int/sites/reliefweb.int/files/resources/WMC-19.pdf> (accessed on 13 December 2023).
16. MEE (Ministry of Ecology and Environment of the People's Republic of China). Technical Specifications for Centralized Incineration Facility Construction on Medical Waste (HJ/T 177). 2005. Available online: [http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/hjbhgc/200505/t20050524\\_67082.shtml](http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/hjbhgc/200505/t20050524_67082.shtml) (accessed on 13 December 2023). (In Chinese)
17. Chen, Y.; Feng, Q.Z.; Liu, L.Y.; Chen, R.Z.; Zhang, Y.H.; Bao, Z. Reform and development of medical waste disposal technology system in the new era. *Chin. J. Environ. Eng.* **2021**, *15*, 382–388.
18. MEE (Ministry of Ecology and Environment of the People's Republic of China). Technical Specifications for Steam-Based Centralized Treatment Engineering on Medical Waste (on Trial) (HJ/T 276). 2006. Available online: <http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/hjbhgc/200608/W020110127377094539894.pdf> (accessed on 13 December 2023). (In Chinese)
19. MEE (Ministry of Ecology and Environment of the People's Republic of China). Technical Specifications for Chemical Disinfection Centralized Treatment Engineering on Medical Waste (on Trial) (HJ/T 228). 2006. Available online: [http://www.mee.gov.cn/gkml/zj/gg/200910/t20091021\\_171615.htm](http://www.mee.gov.cn/gkml/zj/gg/200910/t20091021_171615.htm) (accessed on 13 December 2023). (In Chinese)
20. MEE (Ministry of Ecology and Environment of the People's Republic of China). Technical Specifications for Microwave Disinfection Centralized Treatment Engineering on Medical Waste (on Trial) (HJ/T 229). 2006. Available online: <http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/hjbhgc/200603/W020111221394894641492.pdf> (accessed on 13 December 2023). (In Chinese)
21. Liu, L.Y.; Wu, G.L.; Feng, Q.Z.; Chen, Y. Emergency disposal and management of medical waste during the COVID-19 outbreak in China. *E3S Web Conf.* **2021**, *245*, 02011. [CrossRef]
22. Wang, J.; Shen, J.; Ye, D.; Yan, X.; Zhang, Y.; Yang, W.; Li, X.; Wang, J.; Zhang, L.; Pan, L. Disinfection technology of hospital wastes and wastewater: Suggestions for disinfection strategy during coronavirus Disease 2019 (COVID-19) pandemic in China. *Environ. Pollut.* **2020**, *262*, 114665. [CrossRef] [PubMed]
23. Chen, Y.; Zhang, K.; Xu, J.Y.; Shao, Z.; Ji, R. Analysis of Cooperative disposal of Medical Waste Treatment and Municipal Solid Waste Incineration. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *295*, 012052.
24. Yoon, B.; Magee, C.L. Exploring technology opportunities by visualizing patent information based on generative topographic mapping and link prediction. *Technol. Forecast Soc. Chang.* **2018**, *132*, 105–117. [CrossRef]

25. Wang, J.; Chen, Y.J. A novelty detection patent mining approach for analyzing technological opportunities. *Adv. Eng. Inform.* **2019**, *42*, 100941. [\[CrossRef\]](#)
26. Park, Y.; Yoon, J. Application technology opportunity discovery from technology portfolios: Use of patent classification and collaborative filtering. *Technol. Forecast Soc. Chang.* **2017**, *118*, 170–183. [\[CrossRef\]](#)
27. Lukas, J.A.; Jens, L.; Chie, H.S. Analysis of technological knowledge stock and prediction of its future development potential: The case of lithium-ion batteries. *J. Clean. Prod.* **2019**, *223*, 301–311.
28. Michele, G.; Livio, C.; Martina, D.G.; Francesco, R. The patent portfolio value analysis: A new framework to leverage patent information for strategic technology planning. *Technol. Forecast Soc. Chang.* **2015**, *94*, 286–302.
29. Fischer, T.; Leidinger, J. Testing patent value indicators on directly observed patent value: An empirical analysis of Ocean Tomo patent auctions. *Res. Policy* **2014**, *43*, 519–529. [\[CrossRef\]](#)
30. SC (State Council of the People's Republic of China). *Regulations on the Administration of Medical Waste*; State Council of the People's Republic of China: Beijing, China, 2003; Volume 380.
31. NHC (Nation Health Commission of the People's Republic of China). *Administrative Measures of Medical Waste in Medical Institutions*; Nation Health Commission of the People's Republic of China: Beijing, China, 2003.
32. MEP (Ministry of the Environment Protection of the People's Republic of China). *Technical Specification on Centralized Disposal of Medical Waste (Trial)*; Ministry of Environment Protection of the People's Republic of China: Beijing, China, 2003.
33. MOH (Ministry of Health of the People's Republic of China). *Classification Catalogue of Medical Waste*; Ministry of Health of the People's Republic of China: Beijing, China, 2003; Volume 287.
34. GB19217-2003; Technical Standard for Medical Waste Transport Vehicle. SEPA (State Environmental Protection Administration): Beijing, China, 2003.
35. GB19218-2003; Technical Standard for Medical Waste Incinerator. SEPA (State Environmental Protection Administration): Beijing, China, 2003.
36. MEP (Ministry of the Environment protection of the People's Republic of China). *Response Plan on the Management of Medical Waste for Influenza A (H1N1)*; Ministry of Environment Protection of the People's Republic of China: Beijing, China, 2009.
37. MEP (Ministry of the Environment protection of the People's Republic of China). *Technical Specification of Performance Testing for Facilities of Hazardous Waste (Including Medical Waste) Incineration*; Ministry of the Environment protection of the People's Republic of China: Beijing, China, 2010.
38. HJ-BAT-008; Guidelines on Best Available Technologies of Pollution Prevention and Control for Medical Waste Treatment and Disposal (on Trial). MEP (Ministry of the Environment protection of the People's Republic of China): Beijing, China, 2012.
39. MEP (Ministry of the Environment protection of the People's Republic of China). *Environmental Protection Technical Specification for Co-Processing of Solid Wastes in Cement Kiln*; Ministry of the Environment Protection of the People's Republic of China: Beijing, China, 2013.
40. MEE (Ministry of Ecology and Environment of the People's Republic of China). *Management and Technical Guidelines for Emergency Disposal of Medical Waste during the COVID-19 Epidemic (on Trial)*; Ministry of the Environment Protection of the People's Republic of China: Beijing, China, 2020. (In Chinese)
41. DB31/768-2013; Emission Standard of Air Pollution for Municipal Solid Waste Incineration. SEPB (Shanghai Environmental Protection Bureau): Shanghai, China, 2013.
42. MEE (Ministry of Ecology and Environment of the People's Republic of China). Annual Report on the Prevention and Control of Environmental Pollution by Solid Wastes in Large and Medium Sized Cities [Z/OL]. 2019. Available online: <https://www.mee.gov.cn/ywgz/gtfwyhxpj/gtfw/201912/P020191231360445518365.pdf> (accessed on 13 December 2023).
43. WHO. *Safe Management of Wastes from Healthcare Activities*, 2nd ed.; World Health Organization: Geneva, Switzerland, 2014.
44. Zhao, H.L.; Liu, H.Q.; Wei, G.X.; Zhang, N.; Qiao, H.Y.; Gong, Y.Y.; Yu, X.N.; Zhou, J.H.; Wu, Y.H. A review on emergency disposal and management of medical waste during the COVID-19 pandemic in China. *Sci. Total Environ.* **2022**, *810*, 152302. [\[CrossRef\]](#) [\[PubMed\]](#)

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