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Analysis of Current Status and Regulatory Promotion for Incineration Bottom Ash Recycling in Taiwan

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Abstract: Incineration is the most important technology for treating municipal solid waste (MSW) and industrial waste in Taiwan. Currently, there are 24 large-scale MSW incineration plants operated to generate about 1.2 million metric tons of residual ash (mostly bottom ash) based on approximately 6.5 million metric tons of waste incinerated yearly. To reduce the depletion of non-renewable resources under the circular economy principle, the recycling of MSW incineration bottom ash (IBA) as recycled aggregate in concrete and construction applications has been progressed in recent years around the world. According to the official database, the trend analysis of MSW generation and treatment, electricity power and IBA generation from the MSW incineration plants over the past decade (2010–2019) was performed in this work. It showed an increased power generation, growing from 0.485 kWh/kg in 2010 to 0.530 kWh/kg in 2019. In 2019, 2738 GWh of power was sold to Taipower (one of the state-owned companies in Taiwan) for electricity grid connection, gaining income of about NT\$ 5,089,383,000 (\approx US\$ 172,520,000) at an average rate of 1.86 NT\$/kWh (0.063 US\$/kWh). On the other hand, the ratios of incineration bottom ash (IBA) generation to refuse incinerated indicated a decreasing trend due to the increased operation efficiencies of MSW incineration plants. Based on the revised regulations implemented on 18 May 2020, the regulatory measures for promoting IBA recycling in Taiwan were promulgated to valorize it for the production of recycled aggregate under rigorous requirements for prevent it from polluting the environment.

Keywords: incineration bottom ash; recycling; recycled aggregate; circular economy; regulatory promotion

1. Introduction

Besides recycling and reuse, incineration may be the most commonly used management option for the treatment of municipal solid waste (MSW) and industrial waste in developed and developing countries [1]. The combustion process is not only proved as an effective way to reduce waste volume, but also provides an electricity or superheated steam by using the heat exchange. Therefore, the waste-to-energy (WTE) or energy recovery from MSW incineration plants has been considered as one of biomass energy sources. Therefore, the emissions of greenhouse gases (GHG) from waste management have shown a string decrease due to the development of WTE and other recycling processes, especially in methane emissions from landfills [2–6]. On the other hand, MSW incineration can prevent groundwater and surface water pollution as compared to the waste disposed of in sanitary landfills. However, it should be noted that MSW incineration plants require well-operated control systems for flue gas cleaning and residual ash (i.e., bottom ash and fly ash) treatment, which can contaminate the environment if not handled appropriately and efficiently [7–11].

Over the past decades, the rapid economic and industrial development in Taiwan has caused a significant increase in the MSW and industrial waste generation. The central competent authority thus accelerated the construction of large-scale MSW incineration plants from the early 1990s. Currently, there are 24 MSW incineration plants, which have a total installed power capacity of 631.9 MW with designed treatment capacity of 24,650 metric tons per day [12]. In 2019, all of the 24 incineration plants made considerable efforts to incinerate 6.528 million metric tons of MSW and part of industrial waste. These facilities generated a total of 3.459 terawatt-hours (TWhs), of which 2.738 TWh were sold to the state-owned power company, thus gaining NT \$5.09 billion (US \$17.2 million) in revenue. Using the officially announced electricity carbon emissions factor (i.e., 0.509 kg CO₂ per kilowatt-hour) in Taiwan [13], the equivalent mitigation of CO₂ emissions from the MSW incineration plants was close to the reduction of 1.4×10^6 metric tons CO₂ equivalent. On the other hand, these MSW incineration plants in 2019 also produced a substantial amount of incombustible materials, which include 914,543 metric tons of bottom ash and 328,455 metric tons of fly ash [12]. These incinerator ash residues must be subjected to the limits of dioxins concentration and heavy metals by using the toxicity characteristic leaching procedure (TCLP) according to the Waste Management Act (also called the Waste Disposal Act) [14]. In Taiwan, fly ash has been identified to be a hazardous waste [15]. In contrast, bottom ash samples nearly qualified because they met the TCLP standards and dioxins concentration limit [16].

Depending on the compositions of waste incinerated, about 15–25% of MSW input was transferred to so-called incineration bottom ash (IBA), which is composed of mineral fractions (80–85%), ferrous and non-ferrous metals (8–15%), and unburned materials (<1%) [17]. In order to address the significant amount of IBA in an environmentally friendly way, recycling this non-hazardous industrial waste for appropriate construction materials not only provides a low cost aggregate [18–21], but further reduces the need for disposal to sanitary landfills. It is noteworthy that IBA may contain significant amounts of ferrous and non-ferrous metals [22–25], thus the need for developing the state-of-the-art technologies for metal recovery in recent years [26]. In Taiwan, it was reported that the main metals in the IBA include iron (Fe), aluminum (Al), copper (Cu), zinc (Zn), chromium (Cr), and lead (Pb) [22]. To establish a legal basis for the recycling of IBA, the Taiwan Environmental Protection Administration (EPA) first announced the regulation (“Management Methods of Municipal Solid Waste Incinerator Bottom Ash”) on 11 October 2002. Referring to the practices and experiences of various developed countries (i.e., Japan, Netherlands), the EPA recently revised this regulation on 18 May 2020, which will now be based on the leaching scenarios and the control when recycled aggregate from the IBA is used in the environment.

Obviously, replacing natural aggregate materials with IBA not only reduces the mining of non-renewable resources, but also creates a circular flow for sustainable resource management and supply chain models. The main purposes of this study included the trend analysis of MSW management and bottom ash generation from MSW incineration plants, and further addressed the regulatory measures for promoting IBA recycling in Taiwan. Therefore, this paper was structured using three key issues. First, the trend analysis of MSW generation and treatment over the past decade (2010–2019) was addressed. Second, the trend analysis of electricity power from the MSW incineration plant and its bottom ash generation was further performed. Finally, the promotional measures for MSW IBA recycling regulations were compiled to be in accordance with the environmental protection standards and also to meet the circular economy policy based on joint efforts by the central governing authorities.

2. Data Mining

The statistical database, recycling methods, and regulatory measures relevant to MSW and IBA were briefly summarized below.

- Activity (statistics and status) of MSW and IBA

The updated data on the statistics and status of MSW and IBA management in Taiwan were obtained from the official yearbook [12], which was compiled by the EPA.

- Technological reuse methods

In order to highlight current IBA recycling methods in Taiwan, the official website [27], which was established by the EPA, provided the IBA recycling methods, certified IBA recycling facilities, and IBA flow inquiry.

- Regulatory measures for IBA recycling

The information about the regulatory measures for MSW/industrial waste management and IBA recycling was accessed on the official laws and regulations website [14], which was established by the Ministry of Justice (MOJ).

In addition, the measured data on the proximate analysis and elemental compositions of an IBA sample received from MSW incineration plant were incorporated into the discussion about the promotional measures for its recycling regulations.

3. Results and Discussion

3.1. Trend Analysis of MSW Generation and Treatment

According to the environmental protection regulations in Taiwan [14], the waste is basically divided into “general wastes” and “industrial waste”. The latter, including “general industrial waste” and “hazardous industrial waste”, refers to waste that is produced from industry activities (but excluding waste generated by the employees themselves). Therefore, “general wastes” refers to waste that is not “industrial waste”. The industry refers to (1) agricultural, industrial and mining plants and sites, (2) construction enterprises, (3) medical organizations (hospitals), (4) public and private waste clearance and disposal organizations (e.g., waste incineration plants), (5) laboratories of schools, agencies and groups, and (6) other enterprises designated by the EPA. In this context, the so-called general waste in Taiwan is equivalent to garbage or MSW because it is generated from all non-industrial community sources like households, businesses, and municipal services (e.g., hospitals and schools). Based on its hazardous characteristics and valuable reuse, “general wastes” is mainly categorized into three types, including general garbage (e.g., residential trash, pruned branches), kitchen (food) waste, and recyclable garbage (e.g., paper, plastics, and metal from home electrical appliances or waste, electrical, and electronic equipment) [28]. Some bulk garbage (e.g., abandoned furniture, pruned branches) may be categorized into general garbage or recyclable garbage, depending on its characteristics.

Based on the database built by the central competent authority (i.e., the EPA) [12], Table 1 listed the statistics of MSW generation and treatment over the past decade (2010–2019). It showed that the annual generation indicated a slight decline during the period of 2010–2015, but increased since 2016. This trend was consistent with the data on the amount of MSW generation per capita, ranging from 0.342 metric tons per capita in 2010 and 0.308 metric tons per capita in 2015, to 0.416 metric tons per capita in 2019. It also indicated the significant increase of MSW generation in 2018, which was due to the inclusion of waste generated by the employees themselves in the industry activities. By contrast, the amounts of recyclable garbage showed an increasing trend, which was parallel to the development of Taiwan’s resource recycling policy since 2000 [2]. Regarding the MSW treatment in Taiwan, Table 1 also listed the statistics on the treatment methods. In 2019, the percentages of MSW treatment by recycling/reuse, incineration, and sanitary landfill accounted for 57.2%, 41.9%, and 0.9%, respectively. Obviously, the data in 2019 were different from those in 2010; the 2019 percentages were 48.8% for recycling/reuse, 48.9% for incineration, and 2.3% for sanitary landfill. Herein, the MSW treatment by

incineration in Taiwan was operated by 24 large-scale facilities with a total design treatment capacity of around 8 million metric tons per year. To resolve the lack of industrial waste incineration facilities in Taiwan, the combustible portion of general industrial waste (e.g., waste wood, waste paper, waste cloth) can be incinerated together with MSW under permits provided by the local governments.

Table 1. Current status of MSW generation and treatment in Taiwan ^a.

Year	MSW Generation by Type				MSW Treatment by Method				
	Total	General Garbage	Recyclable Garbage	Food Waste	Total	Recycling/Reuse	Incineration	Landfill	Others
2010	7,957,601	4,072,603	3,115,834	769,164	7,957,601	3,884,998	3,888,641	181,771	2191
2011	7,554,589	3,610,848	3,132,541	811,199	7,554,589	3,943,740	3,468,620	142,155	74
2012	7,403,948	3,379,390	3,190,018	834,541	7,403,948	4,024,558	3,277,252	102,052	85
2013	7,332,694	3,300,151	3,237,330	795,213	7,332,694	4,032,544	3,208,721	91,355	75
2014	7,369,439	3,272,669	3,376,397	720,373	7,369,439	4,096,770	3,189,457	83,136	76
2015	7,229,290	3,236,389	3,383,195	609,706	7,229,290	3,992,901	3,143,054	91,655	1679
2016	7,461,342	3,133,582	3,751,828	575,932	7,461,342	4,327,760	2,993,435	77,940	62,206
2017	7,870,896	3,130,735	4,188,829	551,332	7,870,896	4,740,161	2,969,654	70,382	90,699
2018	9,740,671	4,317,339	4,828,340	594,992	9,613,982	5,423,332	4,103,398	87,251	–
2019	9,812,418	4,290,856	5,023,517	498,045	9,650,074	5,521,562	4,042,110	86,402	–

^a Source [12]; unit: metric tons.

3.2. Trend Analysis of Electricity Power and IBA Generation from MSW Incineration Plants

In Taiwan, there are currently 24 large-scale MSW incineration plants with a total power generation of about 632 MW in terms of installed capacity [29]. Among these plants, the design capacity ranged from 300 to 1800 metric tons per day. As mentioned above, the amounts of refuse received by these plants were approximately 650 million metric tons, which included MSW (64.6–81.4%) and general industrial waste (18.6–35.4%). Table 2 summarizes their operation performances over the past decade (2010–2019) [12]. With respect to the electricity generation from MSW incineration plants listed in Table 2, some significant points were further analyzed below:

Table 2. Current status of operation performances of MSW incineration plants in Taiwan ^a.

Year	Refuse Received				Bottom Ash	Fly Ash	Power Generation (% of Power Sold)
	Total	MSW	General Industrial Waste	Refuse Incinerated			
2010	6,406,781	4,441,197	1,965,584	6,235,390	992,583	301,846	3,026,003 (76.82%)
2011	6,507,763	4,234,971	2,272,792	6,355,422	1,079,353	278,205	3,076,345 (76.87%)
2012	6,506,907	4,204,289	2,302,618	6,404,987	1,060,376	289,157	3,056,476 (76.79%)
2013	6,471,767	4,214,872	2,256,895	6,349,913	999,117	285,347	3,131,460 (77.05%)
2014	6,420,400	4,192,142	2,228,258	6,294,479	937,177	290,015	3,187,484 (77.84%)
2015	6,622,070	4,329,863	2,292,207	6,534,388	970,966	300,537	3,217,212 (78.14%)
2016	6,441,999	4,271,179	2,170,820	6,392,159	916,152	295,526	295,526 (78.21%)
2017	6,251,196	5,088,471	1,162,725	6,266,855	849,381	296,970	3,187,516 (78.32%)
2018	6,464,184	4,781,393	1,682,791	6,443,777	893,738	300,066	3,359,480 (79.11%)
2019	6,530,079	4,816,708	1,713,371	6,527,567	914,543	328,455	3,459,060 (79.15%)

^a Source [12]; units: metric tons and megawatt-hours (MWhs).

Based on the data on the electricity generation and percentage of power sold, it indicated a slight increase, growing from 3026 GWh and 76.82% in 2010 to 3459 GWh and 79.15% in 2019. This increase could be partly attributed to the revamping of MSW incineration plants for upgrading operational efficiency in recent years [29]. By dividing refuse incinerated, the overall power generation rates also showed an increasing trend from 0.485 kWh/kg in 2010 to 0.530 kWh/kg in 2019. However, the energy

efficiencies of MSW incineration plants in Taiwan were relatively low with a gross value of <20% based on the ratio of output by electricity power to input by heating value [5].

Under the authorization of the Energy Management Act, the central competent authority (i.e., Ministry of Economic Affairs) promulgated the regulation titled “Implementation Measures for Cogeneration System”. About 80% of total electricity generation from MSW incineration plants must be connected with the power grid system and sold to the Taiwan Power Company (Taipower, one of the state-owned companies, Taipei, Taiwan) [29]. In 2019, 2738 GWh of electricity power was sold to Taipower, gaining income of about NT\$ 5,089,383,000 (\approx US\$ 172,520,000) at an average rate of 1.86 NT\$/kWh (0.063 US\$/kWh). The MSW-to-power in Taiwan accounted for about 22.5% of renewable electricity generation in 2019 [13].

On the other hand, the residues generated from MSW incineration plant briefly include bottom ash that remains after combustion on the mass-burn grate and fly ash that is removed from the exhausts by particulate control devices like baghouse. Table 2 also lists the amounts of bottom ash and fly ash generated, showing that 120–130 million metric tons of residues were generated by 24 large-scale MSW incineration plants annually. It is interesting to note that about one third of the residues are fly ash, but two thirds of them are bottom ash. As shown in Figure 1 [12], the ratios of IBA generation to incinerated refuse indicated a decreasing trend during the period of 2011–2017, but slightly increased over the last two years (2018–2019). This decline could be due to the increased operation efficiencies of MSW incineration plants by waste segregation (e.g., some incombustibles were removed first) and combustion upgradation (e.g., anti-sintering on the grate, insulation materials replacement) [29].

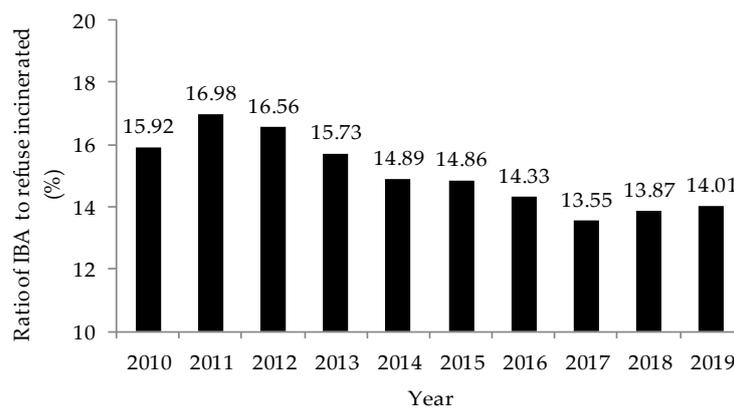


Figure 1. The variations of the ratio of incineration bottom ash (IBA) generation to refuse incinerated since 2010 [12].

3.3. Regulatory Promotion for MSW Incineration Bottom Ash Recycling

As described in Section 3.2, incineration is currently the principal method for treating MSW by 24 large-scale plants in Taiwan. About nine hundred thousand metric tons of IBA was annually produced in recent years (seen in Table 2). In general, IBA was identified as a general industrial waste because it was in accordance with the regulation entitled as the “Standards for Defining Hazardous Industrial Waste”. Table 3 listed the standards for defining hazardous industrial waste in Taiwan, which is relevant to the heavy metals based on the toxicity characteristic leaching procedure (TCLP) method. Facing so much ash, a substantial portion of sanitary landfills will be occupied when disposing of these incineration residues. In addition, IBA can be considered as a valuable resource because it is very low in heavy metals and also high in construction-grade materials like rock, stone, concrete, or glass. Regarding the elemental compositions, a preliminary measurement for IBA from the central Taiwan MSW incineration plant (Taichung City, Taiwan) was performed by using an energy dispersive X-ray (EDX) instrument (SwiftED3000, Oxford Instruments, UK). It revealed the presence of calcium (Ca) and oxygen (O) as the major elements, along with minor elements like silicon (Si), chlorine (Cl), aluminum (Al), iron (Fe), magnesium (Mg), sulfur (S), potassium (K), phosphorus (P), and sodium

(Na). The significant content of Ca in the IBA was due to the removal of acidic air pollutants (i.e., sulfur oxides and hydrogen chloride) by using slurry lime addition. After pre-treating by the methods (i.e., magnetic separation, wind sorting, and eddy current separation) to remove valuable ferrous and non-ferrous metals (e.g., aluminum) and unburned light combustibles, the resulting IBA can be further processed to produce aggregates based on the usage type. The commonly used treatment methods include waging, stabilization, and washing. The recycled aggregates have been successfully reused as substitute materials in road foundations, cement mortars, and additives in bricks, asphalt, and concrete [18–21]. Figure 2 depicts the flowchart of MSW IBA recycling treatment in Taiwan, including pretreatment and treatment processes [27]. Despite having both the technology and the capacity to recycle 100% of IBA in Taiwan, about 30% of IBA was still deposited in landfills in 2016 [30]. In fact, there are 10 different usages of recycled aggregate from IBA according to the updated regulation on 18 May 2020, which will be addressed in the next paragraph.

Table 3. Standards for defining hazardous industrial waste by toxicity characteristic leaching procedure (TCLP) relevant to toxic inorganic elements in Taiwan.

Toxic Inorganic Element	TCLP Standard (mg/L)	Comments
Mercury and its compounds (Total mercury)	0.2	
Cadmium and its compounds (Total cadmium)	1.0	
Selenium and its compounds (Total selenium)	1.0	
Hexavalent chromium	2.5	
Lead and its compounds (Total lead)	5.0	
Chromium and its compounds (Total chromium)	5.0	Excluding waste leather powder, dander and leather piece from the manufacture or use of animal leather
Arsenic and its arsenic (Total arsenic)	5.0	
Silver and its compounds (Total silver)	5.0	Limited to waste liquors from photographic processing and photoengraving
Copper and its compounds (Total copper)	15.0	Limited to waste catalyst, dust, waste liquor, sludge, filter material, incineration fly ash or bottom ash
Barium and its compounds (Total barium)	100.0	

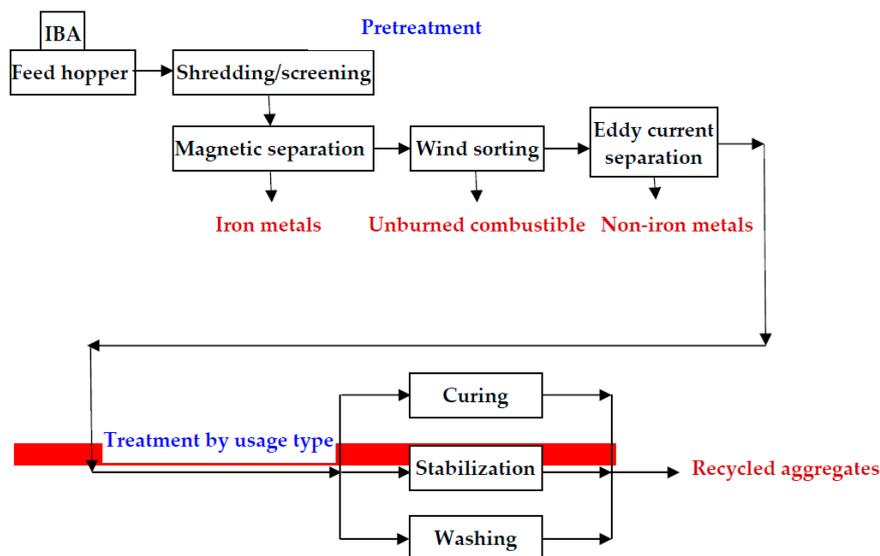


Figure 2. Flowchart of MSW incineration bottom ash (IBA) recycling treatment in Taiwan.

According to the regulation (“Methods and Facilities Standards for the Recycling, Clearance and Treatment of General Waste”), the ignition loss of IBA from large-scale MSW incineration plants should be below 5%. In this regard, a preliminary characterization of proximate analysis for IBA from the central Taiwan MSW incineration plant (Taichung City, Taiwan) was measured in triplicate, showing that the contents of moisture, combustible and ash for the as-received IBA were 19.32 ± 1.23 , 5.54 ± 0.67 , and 75.14 ± 1.85 wt%, respectively. Obviously, its combustible content (i.e., 5.54 wt% on a wet basis) is relatively high, indicating a fraction of unburned components contained in the IBA sample. In addition to recycling, IBA should be tested quarterly to check the total toxicity equivalency of dioxins (i.e., does not exceed 0.1 ng/g based on international toxicity equivalency quantity) and TCLP of heavy metals (seen in Table 3) when adopting final disposal. If the test exceeds the “Standards for Defining Hazardous Industrial Waste”, the proper remedial measures should be taken promptly and reported to the local competent authorities for reference. More notably, IBA is an industrial waste as defined in the Section 3.1. It should be tested once each half-year pursuant to the “Standards for Defining Hazardous Industrial Waste” according to the “Methods and Facilities Standards for the Storage, Clearance and Treatment of Industrial Waste”. In order to promote the reuse of IBA, the regulation (“Management Methods of Municipal Solid Waste Incinerator Bottom Ash Recycling”) was first promulgated on 11 October 2002 under the authorization of the Waste Management Act. Subsequently, it was revised several times, including the last revision on 18 May 2020. The updated regulation will take effect on January 1, 2021. In brief, this regulation was based on leaching scenarios and their control purposes when the recycled aggregate from IBA was used in the environment. In addition, the standard method NIEA R222 (“Leaching Procedure of Recycled Aggregate for Environmental Use”) and the environmental standards (“Groundwater Pollution Control Standards”) were used to restrict the location and purpose of IBA recycling clearly. Regarding the regulatory promotion and management measures of IBA recycling, the Regulation was briefly summarized as follows [14]:

Before commissioning the licensed IBA reuse facilities, MSW incineration plants should test the characteristics of IBA, which will be in accordance with the conditions (Table 4). The test results should be reported to the licensed IBA recycling facilities as a reference for the process operation and adjustment of reuse.

Table 4. Standards for recycling bottom ash from MSW incineration plants in Taiwan.

Item	Frequency	Standard
Combustible	Monthly	$\leq 2.0\%$
Dioxin concentration by I-TEQ ¹	Quarterly	≤ 1.0 ng/g
Lead ²		≤ 5 mg/L
Cadmium ²		≤ 1 mg/L
Chromium ²		≤ 5 mg/L
Selenium ²		≤ 1 mg/L
Copper ²	Quarterly	≤ 15 mg/L
Barium ²		≤ 100 mg/L
Hexavalent chromium ²		≤ 2.5 mg/L
Arsenic ²		≤ 5 mg/L
Mercury ²		≤ 0.2 mg/L

¹ I-TEQ: International Toxicity Equivalency Quantity. ² Test method by toxicity characteristic leaching procedure (TCLP).

As shown in Figure 2, the recycling processing procedure of IBA includes two stages sequentially. The pretreatment stage involves screening, shredding, sorting, and so on. The treatment stage commonly refers to curing, stabilization, or washing. The curing time within the licensed IBA recycling facility should exceed 45 days.

Before recycling recycled aggregate, the licensed IBA recycling facilities should test its characteristics to make sure every batch of such material (500 metric tons) is in accordance with the environmental standards (Table 5). If the test results exceed the previous standards, this batch of

recycled aggregate shall be not reused. The licensed IBA recycling facilities must proceed with some improvement measures until their test results meet the standards.

Table 5. Standards for recycled aggregates from the licensed IBA recycling facilities in Taiwan.

Item	Class No.1 Standards ⁴	Class No.2 Standards ⁵	Specific Purpose Standards ⁶
Dioxin concentration by I-TEQ ¹	≤0.1 ng I-TEQ/g	≤0.1 ng I-TEQ/g	≤0.1 ng I-TEQ/g
Particle size	≤19 mm	≤19 mm	≤19 mm
Impurity	Do not contain the following substances with over 20 mm by any two scales (length, width, depth): Combustibles, iron metals, non-iron metals, batteries and recognizable commercial products.	(Same as the left)	(Same as the left)
Lead ²	≤0.01 mg/L	≤0.1 mg/L	≤4.0 mg/L
Cadmium ²	≤0.005 mg/L	≤0.05 mg/L	≤0.8 mg/L
Chromium ²	≤0.05 mg/L	≤0.5 mg/L	≤4.0 mg/L
Copper ²	≤1.0 mg/L	≤10 mg/L	≤12.0 mg/L
Arsenic ²	≤0.05 mg/L	≤0.5 mg/L	≤0.4 mg/L
Mercury ²	≤0.002 mg/L	≤0.02 mg/L	≤0.016 mg/L
Nickel ²	≤0.1 mg/L	≤1 mg/L	–
Zinc ²	≤5.0 mg/L	≤50 mg/L	–
Selenium ²	– ³	–	≤0.8 mg/L
Barium ²	–	–	≤10.0 mg/L
Hexavalent chromium ²	–	–	≤0.2 mg/L

¹ I-TEQ: International Toxicity Equivalency Quantity. ² Tests for recycled aggregated by leaching procedure methods NIEA R222 and NIEA R201 for the Class No.1 and 2 standards and the specific purpose standard, respectively. ³ Not applicable. ⁴ The Class No.1 standards are applied to the announced location restrictions for IBA reuse in the usage item No.4–8 (Note: Controlled low-strength backfill materials used in ditches and pipes are to be kept out of the protected areas for water quality and water quantity). ⁵ The Class No.2 standards are applied to the non-announced location restrictions for IBA recycling in the usage item No.1–8. ⁶ The Class No.2 standards are applied to the unrestricted locations for IBA reuse in the usage item No.9 and 10.

The usage items of IBA recycling include as follows: (1) base filling, (2) embankment filling, (3) road-grade granule bottom layer and base layer, (4) controlled low-strength backfill material, (5) low-density recycled permeable concrete, (6) asphalt concrete, (7) bricks, (8) cement products for New Jersey guardrail and edge stone, (9) raw material for cement, and (10) sanitary landfill construction materials that are not in contact with steel, and cover materials in sanitary landfill (not used in the final cover).

The location restrictions for IBA recycling include the environmentally sensitive areas, including (1) drinking water source water quality protection zone, reservoir watershed zone, water quality/quantity protection zone for water supply; (2) nature reserve, wildlife protection area, or major wildlife habitat; (3) agricultural area (farmland, forestry land, and aquaculture land), homeland security land, water use land, and other protected areas under the regulation; (4) national park; and (5) the recycled aggregate should be over one meter higher than the groundwater level on site when it is used on land. However, the IBA recycling for the usage item No.5–10 is not restricted by the proceeding locations.

The IBA recycling should comply with the construction specifications of public works, national standards, international standards or usage regulations. In Taiwan, the most important norm is based on the National Standards (CNS), administrated by the Ministry of Economic Affairs.

4. Conclusions and Prospects

Under the authorization of the waste management act, the bottom ash derived from 24 large-scale MSW incineration plants with total design treatment capacity of around 8 million metric tons per

year has been considered as one of “mandatory” recyclables by the Taiwan EPA for the production of recycled aggregate in the concrete and construction applications. Regarding the trend analysis of operation performances for Taiwan’s MSW incineration plants over the past decade (2010–2019), it indicated an increased power generation, growing from 0.485 kWh/kg in 2010 to 0.530 kWh/kg in 2019. In 2019, 2738 GWh of power was sold to Taipower for electricity grid connection, gaining the income of about NT\$ 5,089,383,000 (\approx US\$ 172,520,000) at an average rate of 1.86 NT\$/kWh (0.063 US\$/kWh). On the other hand, the ratios of IBA generation to incinerated refuse decreased from 17% to 14%. This can be attributed to the increased operation efficiencies of MSW incineration plants due to waste segregation, combustion upgradation, and heat recovery revamping.

On 18 May 2020, the Taiwan EPA announced the revised regulation (“Management Methods of Municipal Solid Waste Incinerator Bottom Ash Recycling”), which was based on leaching scenarios and their control purposes when the recycled aggregate from IBA was used in the environment. This approach involving replacing natural mineral resources with recycled aggregate from IBA will gain both benefits by reducing the mining of non-renewable resources and saving the space of sanitary landfills. More importantly, the regulation on IBA recycling will promote the supply chains of sustainable building materials, thus forming a special material flow under the circular economy policy in Taiwan. However, the price of recycled aggregate from IBA is higher than for unsustainably sourced raw materials in Taiwan. We recommend that the government provide subsidies for deflating the price of recycled aggregate, so that its true value can be reflected in its price. In addition, the government must take care to not only review the legislation, but to also conduct more stringent audits for IBA recycling treatment facilities.

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