Article

Analysis of The Environmental and Economic Effect of the Co-Processing of Waste in the Cement Industry

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Abstract: Recently, the amount of waste generated has been rapidly increasing, there have been difficulties disposing of waste in Korea. As a solution to this, treating waste using a cement kiln has suggested, but the environmental and economic effects have not been specifically studied. In this study, the effects of alternative resources, and reducing the social costs(Installation and Operation) associated with waste treatment facilities were analyzed. Through a co-processing method, a reduction of approximately 53kg of CO_2 can be realized during the production of one ton of cement, and cost savings of about 3,815 milion USD. Another effect is an extension of the expiration date for landfills by 7.55 years.

Keywords: Cement; Co-process; Waste; Incineration; Landfill

1. Introduction

Growing industries will improve people's living level, though the total amount of waste generated in Korea is also increasing [1]. Moreover, it is difficult to expand recycling and disposal facilities in response to the increasing amounts of waste generated [2], with even the export of recyclable resources generated through recycling becoming difficult [3].

In 2018 witnessed a refusal to collect recyclables mainly in apartment buildings, and as the Solid refused fuel(SRF) market, as exemplified by remnants generated during the recycling process collapsed, waste disposal reached its limit. As waste that cannot be recycled is concentrated in incineration facilities and landfill facilities, treatment costs have continued to rise, and the amounts of neglected and illegally treated waste are increasing with the rise in treatment costs [4]. Meanwhile, landfill sites in the Seoul Metropolitan Area(Called Sudokwon landfill site), which processes accounting for nearly 30% of domestic waste landfills, are scheduled to cease operation in 2025, and three metropolitan areas are making various efforts to find alternative landfill sites [5].

To promote resource circulation, the "Framework Act on Resource Circulation" has been implemented since 2018, and various systems have been implemented; with the social system changed to reduce the final disposal cost, the plan was to increase the resource circulation rate. In addition, in order to curb the amount of waste generated and to eradicate difficult-to-recycle products, the "Resource Circulation Conversion Plan" contains tasks to be carried out in the stages of production, distribution, consumption, and disposal under the concept of life-cycle assessments was published in 2020 [6].

Nevertheless, as China strengthened its ban on imports of recyclable resources, reclaimed raw materials accumulated as complete recycling was impossible, and the will to install waste treatment infrastructure was stagnant due to opposition from local residents [7].

With regard to waste, sustainable waste management is required by maximizing reuse, recycling, and energy recycling [8]. As part of this initiative, an industry capable of recycling waste in large quantities is needed. Industries that can recycle and dispose of waste in large quantities in Korea include the papermaking and cement industries, as well as power plants, and it is possible to use waste as a replacement for raw materials to gain energy stored in the waste [9-10].

The treatment called "co-processing" (the use of waste as alternative raw material), in the cement industry can effectively dispose of waste and replace natural materials or energy sources [11-12]. Also, this method has been proven to be a sustainable waste management method in that it does not generate secondary waste, can reduce greenhouse gases, and is operated stably at high temperatures [13-16].

However, in Korea, there has been no study on the contribution effect of co-processing using the current status of the cement industry. For this reason, the part about the emission of dioxins, carbon monoxide, and heavy metals that can be easily measured rather than the positive effect of co-processing is being highlighted. As a result, the government is having difficulties in making policy decisions about the expansion of co-processing.

In this study, the effects of co-processing in the cement industry were analyzed in terms of the reduced use of raw materials and fuels, reductions in greenhouse gas emissions, lower installation costs for incineration and landfill facilities

2. Method

2.1. Status and Replacement Effects of Co-processing in the Cement Industry

The status of the co-processing of waste during the cement manufacturing process relied on statistical data from the Korea Cement Association(KCA). Alternative effects were analyzed in terms of environmental and economic aspects. Regarding the environmental aspects, the reduced use of natural resources and the contribution to carbon neutrality via the reduction of green-house-gas(GHG) emission were evaluated. In terms of economics, the reduced social costs of disposal due to the recycling of waste, and the reduced imports costs bituminous coal were evaluated.

To evaluate this effect, waste not associated with the cement industry was analyzed by establishing a disposal route, as shown in Table 1, for each type. The treatment route was consulted by the person in charge of KCA. To calculate the effect of co-processing in the cement industry, it is necessary to examine the amounts that can be saved through recycling. To this end, the effects of replace natural minerals and fossil fuels were analyzed. The amounts that can be reduced by recycling natural resource, such as the limestone, clay, and siliceous raw materials currently used in the process of manufacturing cement, were calculated [17]. The basic unit of greenhouse gas emitted in the production stage of natural raw materials was referenced from related prior research [18-19]. The exchange rate is 1289.81 USD per 1 KRW. The calculation formulae are expressed here as Equations 1 and 2.

$$GHG\ reduction \left(\frac{kg}{CO_2}\right) = \sum_{i=1}^{n} (\text{alternative of Resource } x_i) X (\text{emssion GHG mining resource } x_i) \quad (1)$$

$$Raw\ material\ cost\ savings = \sum_{i=1}^{n} (\text{alternative of Resource } x_i) X (\text{price of resource } x_i) \quad (2)$$

i=1(Kaolin), 2(Silica Stone), 3(Iron ore), 4(Gypsum)

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The net calorific value of bituminous coal for fuel is 5,660 kcal/kg, while it is 8,170 kcal/kg for petroleum coke [20]. Waste-derived fuel(WDF) and SRF values were calculated by applying the corresponding minimum calorific values of 3,500 kcal/kg and 6,000 kcal/kg [21]. For the unit calorific value (kcal/kg) of waste, 6,073 kcal of waste tires, 4,500 kcal of waste synthetic resin, 4,730 kcal of waste rubber, and 3,500 kcal of waste wood were applied. using data(Average of 6 large cement companies) provided by the KCA. Bituminous coal consumption savings and fuel cost savings were calculated using Equations 3 and 4.

$$Coal\ consumtiop\ reduction\left(\frac{ton}{year}\right)$$

$$= \text{alternative fuel calorific value} \div \text{Coal calorific value (kcal/kg)} \qquad (3)$$

$$Fuel\ cost\ savings\left(\frac{ton}{year}\right)$$

$$= \text{Coal consumption reduction(tons/year)} \times \text{Coal incom price (USD/ton)} \qquad (4)$$

Table 1. This is a table show common treatment routes for wastes treated in the cement industry. the alternative resources for each waste treated in the cement industry and the general treatment route if not co-processing. (a) is types of natural resources replaced by waste. (b) is the extent to which waste is generally in demand for recycling. (c) is general treatment route, if except for co-processing.

Waste	Alternative resource[a]	Recycle Value[b]	Common disposal route[c]		
			Recycle	Landfill after incineration	Direct Landfill
Fly ash(Coal)	Clay	Low			○
Organic sludge	Clay	Low		○	
Inorganic sludge	Clay	Low			○
Slag	Iron	High	○		
Dust	Clay, Iron	Low			○
Catalyst	Clay	High	○		
Gypsum and lime	Gypsum	High	○		
Ash	Clay	Low			○
Adsorbent	Clay	Low			○
Soil	Clay	Low			○
Metal	Iron	Low			○
Foundry and sandblast	Silica	Low			○
Glass	Silica	Low			○
Ceramics	Silica	Low			○
Textile	Fuel	Low		○	
Tire	Fuel	High	○		
Synthetic resin	Fuel	Low		○	
Rubber	Fuel	Low		○	
Wood	Fuel	Low		○	

2.2. Savings associated with waste treatment facility installation and operation costs

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Co-processing not only reduces the installation cost of the waste treatment facility(WTF) but also reduces the costs operating the WTF. the costs can differ depending on the operation method, but these factors must be considered as major contributing of co-processing. the operating cost was calculated by referring to the estimated regression equation derived in previous work [22]. the dummy variable index was excluded from the review process because it is difficult to calculate this separately as it is related to incidental costs and profits and includes such processes as incineration heat recovery, power generation, and leachate treatment. the estimation formulae used to calculate the operating cost are expressed as equations 5 and 6.

The ministry of the environment(MOE) has set standard installation cost unit. for the incineration facility, the operation rate was set to 85% (310 days out of 365 days). The cost unit for installation applied here was KRW 381 million/ton, and the lifetime of the incineration facility was 20 years.

Estimation of the operating cost of incineration

$$= \ln(\mathrm{Co}) = 3.349 + 0.656\ln(\mathrm{Q}) + 0.416\ln(\mathrm{Cu}) - 0.181\mathrm{D} \quad (5)$$

Co: Operating cost (million KRW),

Q: Facility capacity (ton/day),

Cu: Operation rate (1% = 1),

D: Dummy variable

Estimation of the operating cost of the landfill site

$$= \ln(\mathrm{Co}) = -0.238 + 0.3056\ln(\mathrm{Al}) + 0.321\ln(\mathrm{A}) + 0.384\mathrm{D} \quad (6)$$

Co=e(ln (Co))

Co: operating cost (million KRW),

Al: annual landfill (m^3/year),

A: landfill area (m^2)

D: Dummy variable

2.3. *Effect of extending the life of the landfill*

landfill is the only final disposal method in korea, it is recommended to extend the life of currently operated landfills as much as possible due to the limited lifetimes of existing landfill sites and the difficulties involved in selecting new landfill sites. the cement industry can expand the life of landfill facilities by treating large amounts of by-products and waste.

An estimation of effect expanding life of landfills can be extended was conducted by calculating the remaining landfill capacity and annual landfill volume of current landfills. In order to estimate the lifespan extension of landfills, the remaining landfill capacities and annual landfill volumes of current landfills were calculated and investigated. The life extension effect of co-processing was also calculated using Equation 7 assuming that the load on each landfill site was reduced by the capacity calculated when applying the density and ash amount for each type of waste created in the cement industry.

$$Extending\ life\ of\ landfill$$

$$= \frac{\text{Residual capacity of industrial waste landfill facility}}{① + ②} \quad (7)$$

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$$① \ the\ Amount\ of\ Annual\ industrial\ waste\ landfill$$

$$② \ the\ Amount\ of\ waste\ that\ must\ be\ brought\ to\ landfill, if\ it\ is\ not\ treated\ by\ co - processing$$

3. Results

3.1. Status of the Co-processing of Waste in the Cement Industry

Waste can be used as a fuel and as raw materials in the cement industry. most are inorganic substances that can be sent to landfills, with fly ash accounting for 39.3% and inorganic sludge accounting for 19.6%. In addition, waste synthetic resin accounts for the largest amount of fuel at 12.6% (Table 2).

Coal ash and inorganic sludge contain chemical components (e.g., SiO2, Al2O3) that are necessary for the manufacturing of cement, using coal ash as a raw material for cement is encouraged in situations where landfilling is more difficult. The manufacturing of cement from coal ash is taking place in many countries, enabling sustainable cement production[23].

Table 2. the amounts of waste by co-processing in cement industry(2019).

Category			Ton/year	%
Resource	Fly ash	Domestic	2,227,312	39.3
		Import	951,729	
	Sludge	Organic	727,435	9.0
		Inorganic	1,587,714	19.6
	Slag		245,742	3.0
	Dust		25,515	0.3
	Catalyst		13,420	0.2
	Gypsum and lime		108,608	1.3
	Ash		16,232	0.2
	Adsorbent		9,076	0.1
	Soil		148,167	1.8
	Metal		-	-
	Foundry and sandblast		606,047	7.5
	Glass		23,764	0.3
	Ceramics		-	-
Fuel	Tire	Domestic	170,905	2.1
		Import	103,787	1.3
	Synthetic resin		1,015,799	12.6
	Rubber		75,931	0.9
	Wood		35,449	0.4
	Other		5	0.0
Total			8,092,643	100.0

A large amount of energy is required for cement curing. MSW materials are considered to be a viable choice to replace a portion of the fossil fuel use [24]. Therefore, the energy requirement can be economically met through the use of waste synthetic resin.

The amount of waste used as an alternative raw material and as a type of fuel in the cement industry amounted to 8,092,643 tons as of 2019 (Table 3). Considering that the annual amount of waste is about 181,491,870 tons/year, the corresponding amounts recycled in the cement industry are 4.5% and 5.2% of the total waste recycling amount. This is similar to a single treatment method, such as incineration or a landfill, considering that landfills account for 6.1% of national waste and 5.2% of waste that is incinerated.

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Table 3. Effect of disposal waste in the Cement Industry. This table shows the ratio of the amount of waste recycled in the cement industry among the total amount of waste generated in Korea and the amount of recycling.

Category	Value	unit	Note
Total waste generation[a]	497,238	ton/d	
	181,491,870	ton/year	(A)
Total waste recycling[a]	430,345	ton/d	
	157,075,925	ton/year	(B)
Recycle rate	86.5	%	(C)=B/A
Amount of waste treated by the cement industry[b]	8,092,643	ton/year	(D)
	4.5	%	D/A
Rate of cement industry in recycling	5.2	%	D/B

3.2. Alternative Effects of Resources

By replacing natural raw materials with waste (Table 4), it was found that annual emissions were reduced by 304,945 tons of CO_2 per year and that the raw material cost savings was 88.0 million USD/year, with raw material savings of 130 kg per ton of cement and a reduction of greenhouse gases of 6.02 kg CO_2. The raw material cost savings were analyzed to be 2 USD/ton.

The use of alternative fuels in the cement industry amounts to 1,998,379 tons/year, which has the effect of replacing approximately 24% in terms of calories (Table 5). Compared to Germany, which replaces 68.9% of energy with waste [25], the level here amounts to a third. Co-processing can save about 62.3 million USD / year based on the import price of bituminous coal. That amount of bituminous coal translates to 123.0 million USD /ton in terms of fuel replacement savings (Table 6), and the reduction of GHG is 53.0 kg CO_2.

The reduction effect in GHG emissions is lower than 89 kg CO_2-equivalents per ton cement [26]. Considering the difference by the amount of substitution, it is judged to be an appropriate level.

Table 4. GHG Reduction Effect and Savings by Co-processing. It shows the amount of greenhouse gas emissions and resource cost savings that can be saved through the amount of resource replacement due to waste recycling in the cement industry and the amount of greenhouse gas emissions generated in the process of mining resources. (a) and (b) is GHG emissions from mining minerals. (c) is material market price(clay: 11.5 USD/ton, Silica: 9.7 USD /ton, iron: 52.5 USD /ton, Gypsum: 30.7 USD/ton)

Category	substitute (ton/year)	Emission GHG during mining ($kgCO_2$/ton)	GHG reduction ($kgCO_2$/year)	Savings raw materials cost (million USD/year)[c]
Lime	-	5.6[a]	-	-
Clay	5,706,601	50.5[a]	288,183,343	65.6
Silica	629,811	6.56[a]	4,131,561	6.1
Iron	245,742	50.5[a]	12,409,979	12.9
Gypsum	108,608	2.03[b]	220,475	3.3
Total	6,690,762	-	304,945,358	88.0
By-products from one ton of cement	0.13	-	6.022	1.7

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Table 5. Fuel Alternative Effect **by Co-processing.** The ratio of energy used in the cement industry through alternative fuels and this is expressed as the replacement amount of bituminous coal. (a),(b),(c) is the amount of fuel required to produce cement**.**

Category		Consume[a] (ton/year)	Calories (kcal/kg)	Total calories (Gcal)
Fuel	Bituminous coal	3,702,000	5,660[b]	20,953,320
	Petroleum coke	858,000	8,170[b]	7,009,860
	Total (A)	4,560,000	-	27,963,180
Alternative Fuel	Textile	3.5	3,000[c]	11
	Tire	274,692	6,073[c]	1,668,070
	Synthetic resin	1,015,799	4,500[c]	4,571,097
	Rubber	75,931	4,730[c]	359,155
	Wood	35,449	3,500[c]	124,072
	Waste Derived Fuels	587,821	3,500[c]	2,057,372
	Solid Refuse Fuel	8,683	6,000[d]	52,098
	Total (B)	1,998,379	-	8,831,874
Alternative calorie ratio (B/(A+B))X100				24%
Bituminous Coal Alternative Calorie (B÷5,660kcal/kgX1,000kg/ton)				1,560,402 ton

Table 6. Alternative Effects of Bituminous Coal by Co-processing. Represents the amount of replacement of bituminous coal due to the use of combustible waste and the reduction in import cost. (a) is total calories of combustible waste used in cement industry. (b) is the amount of calories used divided by the amount of anthracite, which is the amount of anthracite substitute

Category	Alternative calorie[a] (Gcal/year)	Bituminous coal calorie (kcal/kg)	Alternative effect[b] (ton/year)	Fuel cost savings (million USD/year)
Combustible waste	6,722,405	5,660	1,187,704	62.3
Waste per one ton of cement			0.03	123.0

3.3. Waste Treatment Facility Installation and Operation Cost Savings

The effect of reducing the installation cost of landfills and incineration facilities by recycling waste was analyzed. These values were calculated by considering recycling combustible waste in the cement industry. It was found that 1,767.2 million USD can be saved in terms of the installation cost of incineration facilities to treat waste subject to incineration. The corresponding figure is 1.7 USD for the incineration facility installation cost per ton of cement (Table 7).

Assuming that all industrial waste is treated for a fee, the unit price of landfill facilities applied to new landfill facilities is 1.6 USD/m^3, and the service lifetime of each landfill facility is 30 years. As a result of this review, incineration ash generated after the incineration of non-combustible and combustible types of waste becomes a target material, and approximately 2,046.8 million USD is saved out of the installation cost of constructing a landfill for disposal, which is equivalent to 1.4 USD/ton-cement could be saved (Table 8).

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The operating cost of a landfill was calculated and found to be 42.1 million USD /year, and an operating cost of 8.4 million USD /year was found to be necessary

Table 7. Incineration Facility Installation Cost and Savings by Co-processing**.** When waste is not treated in the cement industry, it represents the cost of installing an incineration facility required to incinerate it. (a) is waste that would have had to be incinerated if not treated in the cement industry (b) is the cost of installing an incineration facility

Category		Value	Note
Incineration target waste[a] (ton/year)	Organic sludge	727,435	
	Textile	4	
	Synthetic resin	1,015,799	
	Rubber	75,931	
	Wood	35,449	
	Total	1,854,619	(A)
Required capacity for incineration (ton/day)		5,983	(B) = (A) ÷ Operating day(310day)
Installation cost[b] (million USD/year)		1,767.2	(C) = (B) × 3.81(100million KRW/ton) ×Exchange Rate
Incineration facility depreciation (million USD/year)		88.4	(D) = (C) ÷ 20year
Savings of cement per ton (USD/year/ton)		1.7	(E) = (D)/Production of cement

Table 8. Landfill Installation Cost and Savings by co-processing. In the case where the cement industry does not treat waste, it represents the cost of installing a landfill facility required for landfill treatment. (a) is density of each type of waste (b) is In the case where the cement industry does not treat waste, it represents the cost of installing a landfill facility required for landfill treatment.

Category		landfill volume(㎥)	Note
Direct landfill waste (non-combustible waste)	Fly ash	1,484,875	Mixed waste for landfill
	Inorganic sludge	1,044,549	Industrial wastewater treatment sludge
	Ash	10,821	Mixed waste for landfill
	Adsorbent	11,345	Ion exchange resin
	Soil	92,604	Construction waste
	Foundry and sandblast	336,693	Foundry
	Glass	19,803	Glass
	Total (A)	3,000,690	
Post-Incineration landfill waste	Organic sludge	43,646	Mixed waste for landfill
	Textile	0	
	Synthetic resin	39,278	
	Rubber	1,853	
	Wood	1,394	
	Total (B)	86,171	
Total (C)		3,086,861	(A)+(B)

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Installation cost[b] (million USD/year)	2,051.3	(C)×22.2 USD/m³×30year
Landfill depreciation (million USD/year)	68.4	(D)÷30 year
Savings of cement per ton (USD/year/ton)	1.4	(E) = (D)/Production of cement

3.4. Waste Treatment Facility Installation and Operation Cost Savings

According to the Japan Cement Association, the use of waste in the cement industry can extend the lifetimes of existing landfills by 5.3 years [27]. The amount of waste expected to be disposed of in landfills is 27,114 tons/day, which is equivalent to 89% of the annual landfill amount of 30,514 tons/day [28]. As a result of this review, it was found that the lifespan of an industrial waste landfill facility, which can be extended by treating waste in the cement industry, is 7.55 years (Table 9). If not co-processed, it is considered that there is a high possibility of causing social problems due to the rapid increases in landfill volumes.

Table 9. Extending the Life Span of Landfills for Industrial Waste by Co-processing. Represents the lifetime of landfills for industrial wastes extended by the treatment of waste in the cement industry.

Category	Value	Note
Industrial waste reclamation facility (except public) Remaining landfill capacity (A)	59,969,819	m³
Annual Industrial waste landfill (B)	3,644,089	m³
Landfill life (C)	16,46	year, B/A
Amount of landfill if not brought in from the cement industry (D)	3,086,861	m³
Remaining lifetime of landfill facility when the cement industry does not co-process waste (E)	8.91	year, A/(B+D)
Effect of extending (year)	7.55	C-E

4. Conclusions

Co-processing in the cement industry enables the calculation of benefits in the form of costs, specifically in terms of reductions of installation and operation costs of waste treatment facilities, and reductions of greenhouse gases. Large amounts of remnants (waste and by-products) that are inevitably generated from national infrastructure facilities such as those in the power generation industry and the steel industry and social infrastructure such as sewage treatment facilities and incinerators are stably and effectively recycled.

As the cement industry uses waste as an alternative fuel, the replacement effect of bituminous coal amounts to 1,187,704 tons/year, reducing the import cost of bituminous coal by 62.3 million USD/year, equaling an amount of 2,989,156 tCO_2 (annual amount of GHG reduction due to the non-mining of natural minerals: 304,945 tCO_2, and non-use of bituminous coal: 2,684,211 tCO_2).

The cost savings were estimated to be about 3,815 million USD. In addition, the strategy discussed here has the effect of extending the expiration dates of landfills at domestic industrial waste reclamation facilities by 7.55 years.

It is possible for the cement industry to play the final role of recycling the waste that is inevitably generated and inevitably incinerated and landfilled. A kiln has many advantages compared to incineration, and it is possible to contribute to zero landfill use while also serving to stabilize the treatment costs by recycling economically and stably. One problem is that it is necessary to increase the acceptance of residents by operating these facilities in an eco-friendly manner while minimizing secondary pollution in the process of bringing waste into the facility, running pre-treatment programs at the facility, and operating the heat treatment at the kiln. To this end, it is necessary to manage the imported waste strictly to minimize the import of hazardous substances and to invest continuously in sealing facilities and upgrades to air-pollution prevention facilities.

References

1. Statistics research institute, Korean Social Trend, 2020.; Publisher: Statistics research institute, korea, 2020; pp. 154–196.
2. Ahn, JY. Mid-to Long-Term Development Plan to Secure the Stability of Waste Treatment Facilities. Korea Environment Institute. Sejong, korea, 2020.
3. Ministry of Environment. Available online: http://www.me.go.kr/home/web/board/read.do?boardMasterId=1&boardId=1419180&menuId=286(accessed on ay 31.12.2021).
4. Kim, HW.; Um, NI.; Kim, WI.; Lee, YK.; Kim, KH. Causes and Countermeasures on the Rejection of Household Plastic Wastes Collection. Journal of Korea Society of Waste Management 2019, Volume 36, pp. 346-353
5. Ministry of Environment. Available online: http://me.go.kr/home/web/board/read.do;jsessionid=uH3XPwbrNhxZALsL+ecy9iuf.mehome1?pagerOffset=0&maxPageItems=10&maxIndexPages=10&searchKey=&searchValue=&menuId=286&orgCd=&boardId=1464280&boardMasterId=1&boardCategoryId=&decorator= (accessed on ay 05.08.2021).
6. Ministry of Environment. Available online: http://www.me.go.kr/home/web/board/read.do?pagerOffset=30&maxPageItems=10&maxIndexPages=10&searchKey=&searchValue=&menuId=286&orgCd=&boardId=1399650&boardMasterId=1&boardCategoryId=39&decorator= (accessed on ay 17.04.2021).
7. Yi, SR. Evaluation of Resource Circulation Performance and waste treatment system suitability for sustainable waste management. Korea Environment Institute. Sejong, korea, 2020.
8. Seadon, JK. Sustainable waste management systems. Journal of Cleaner Production 2010, Volume 18, pp. 1639-1651
9. Cho, JH. Environmental Features and Actions of Pulp & Paper Indust, Journal of Korea Technical Association of The Pulp and Paper Industry 2009, Voluem 41 pp. 13-21
10. Kim, DW.; Lim, BR, Kim, JD.; Phae, CG. problems and Improvement of Domestic Solid Refuse Fuel Management. Journal of Environmental Policy and Administration 2019, Volume 27 pp. 1-10
11. Baidya, R.; Ghosha, SK.; Parlikar, UV. Co-processing of industrial waste in cement kiln – A Robust system for material and energy recovery, Procedia Environmental Sciences 2016, Volume 31, pp. 309-317
12. UNEP, Technical Guidelines on the Environmentally Sound Co-processing of Hazardous Wastes in Cement Kilns Basel Convention, 2011.
13. Hasanbeigi, A.; Lu, H.; Price, L.; Williams C. International best practices for pre-processing and co-processing municipal solid waste and sewage sludge in the cement industry, United States, 2012.
14. Kleshchov, A.; Hengevoss, D.; Terentiev, O.; Hugi, C.; Safiants A.; Vorfolomeiev A. Environmental potential analysis of co-processing waste in cement kilns. Eastern-European Journal of Enterprise Technologies 2019, Volume 4 pp. 13–21
15. Hirose, S. Waste Management Technologies in Japanese Cement Industry- from Manufacturing to Ecofactuaring TM. J. of Water and Environment Technology 2004, Voulme 2, pp. 31-36
16. Khan, MMH.; Havukainen J.; Horttanainen M. Impact of utilizing solid recovered fuel on the global warming potential of cement production and waste management system: A life cycle assessment approach. Waste Management & Research : Journal for a sustainable Circular Economy 2021, Voulme 39, pp. 561-572.
17. Yamaguchi, N.; Kawai, K.; Osako, M.; Matsuto, T. Resource Substitution and LCCO2 Evaluation by Material Flow Analysis of Incinerator Residue Recycling at a Centralized Reductive Melting Facility. Journal of the Japan Society of Material Cycles and Waste Management 2018, Volume 29, pp. 191-205
18. GtoG. The perfect loop, the path to a circular economy: aEuropean collaborative project between the recycling industry, the demolition sector and the gypsumindustry , 2015.
19. kigam. Available online: https://www.kigam.re.kr/menu.es?mid=a30101010101(accessed on ay 10.08.2020).
20. Energy Act Enforcement Rules, Available online: https://www.law.go.kr/LSW//lsBylInfoP.do?bylSeq=14197749&lsiSeq=239897&efYd=20220121(accessed on ay 01.02.2021).
21. Notification on the quality labeling method and quality class classification of solid refused fuel, Available online: https://www.law.go.kr/LSW/admRulLsInfoP.do?admRulSeq=2100000194074(accessed on ay 01.02.2021).
22. Choi, SW.; Kim, JH. A Study on the Operating Cost Prediction of Incineration Plant and Landfill Facility using MultI-Regression Analysis, Journal of Korea Society of Waste Management 2018, Volume 35, pp. 341-347
23. Argiz, C.; Sanjuán, MA.; Menéndez, E. Coal Bottom Ash for Portland Cement Production. Advances in Materials Science and Engineering 2017, pp. 1-7
24. Usón, AA.; López-Sabirón, AM.; Ferreira, G.; Sastresa, EL.; Uses of alternative fuels and raw materials in the cement industry as sustainable waste management options. Renewable and Sustainable Energy Reviews 2013, Volume 23, pp. 242-260

doi:10.20944/preprints202207.0173.v1

25. vdz. Umweltdaten der deutschen Zementindustrie Environmental Data of the German Cement Industry.; Publisher: vdz, germany, 2020
26. Boesch, Michael E.; Hellweg, Stefanie. life cycle assessment of waste co-processing in chinese cement production. Chemical, Biological and Environmental Engineering 2010, pp. 254-257
27. Japan cement association. Available online: www.jcassoc.or.jp/cement/2eng/e_01d.html(accessed on ay 10.05.2021).
28. Ministry of Environment, National Waste Generation and Disposal Status.; Publisher: Ministry of Environment, korea, 2020