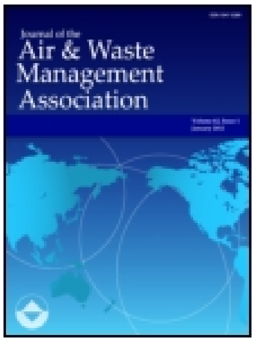

Journal of the Air & Waste Management Association

ISSN: 1096-2247 (Print) 2162-2906 (Online) Journal homepage: https://www.tandfonline.com/loi/uawm20

The study on biomass fraction estimate methodology of municipal solid waste incinerator in Korea

Seongmin Kang, Seungjin Kim, Jeongwoo Lee, Hyunki Yun, Ki-Hyun Kim & Eui-Chan Jeon

To cite this article: Seongmin Kang, Seungjin Kim, Jeongwoo Lee, Hyunki Yun, Ki-Hyun Kim & Eui-Chan Jeon (2016) The study on biomass fraction estimate methodology of municipal solid waste incinerator in Korea, Journal of the Air & Waste Management Association, 66:10, 971-977, DOI: 10.1080/10962247.2016.1185479

To link to this article: https://doi.org/10.1080/10962247.2016.1185479

Published online: 18 May 2016.

JOURNAL OF THE AIR & WASTE MANAGEMENT ASSOCIATION
2016, VOL. 66, NO. 10, 971–977
http://dx.doi.org/10.1080/10962247.2016.1185479

Taylor & Francis
Taylor & Francis Group

TECHNICAL PAPER

The study on biomass fraction estimate methodology of municipal solid waste incinerator in Korea

Seongmin Kang[a], Seungjin Kim[b], Jeongwoo Lee[c], Hyunki Yun[a], Ki-Hyun Kim[d], and Eui-Chan Jeon[a]

[a]Department of Environment & Energy, Sejong University, Seoul, Korea; [b]Cooperative Course for Climate Change, Sejong University, Seoul, Korea; [c]Department of Earth and Environmental Sciences, Sejong University, Seoul, Korea; [d]Department of Civil & Environmental Engineering at Hanyang University, Seoul, Korea

ABSTRACT

In Korea, the amount of greenhouse gases released due to waste materials was 14,800,000 t CO_2eq in 2012, which increased from 5,000,000 t CO_2eq in 2010. This included the amount released due to incineration, which has gradually increased since 2010. Incineration was found to be the biggest contributor to greenhouse gases, with 7,400,000 t CO_2eq released in 2012. Therefore, with regards to the trading of greenhouse gases emissions initiated in 2015 and the writing of the national inventory report, it is important to increase the reliability of the measurements related to the incineration of waste materials.

This research explored methods for estimating the biomass fraction at Korean MSW incinerator facilities and compared the biomass fractions obtained with the different biomass fraction estimation methods. The biomass fraction was estimated by the method using default values of fossil carbon fraction suggested by IPCC, the method using the solid waste composition, and the method using incinerator flue gas.

The highest biomass fractions in Korean municipal solid waste incinerator facilities were estimated by the IPCC Default method, followed by the MSW analysis method and the Flue gas analysis method. Therefore, the difference in the biomass fraction estimate was the greatest between the IPCC Default and the Flue gas analysis methods. The difference between the MSW analysis and the flue gas analysis methods was smaller than the difference with IPCC Default method. This suggested that the use of the IPCC default method cannot reflect the characteristics of Korean waste incinerator facilities and Korean MSW.

Implications: Incineration is one of most effective methods for disposal of municipal solid waste (MSW). This paper investigates the applicability of using biomass content to estimate the amount of CO_2 released, and compares the biomass contents determined by different methods in order to establish a method for estimating biomass in the MSW incinerator facilities of Korea. After analyzing the biomass contents of the collected solid waste samples and the flue gas samples, the results were compared with the Intergovernmental Panel on Climate Change (IPCC) method, and it seems that to calculate the biomass fraction it is better to use the flue gas analysis method than the IPCC method. It is valuable to design and operate a real new incineration power plant, especially for the estimation of greenhouse gas emissions.

PAPER HISTORY
Received February 29, 2016
Revised April 27, 2016
Accepted April 27, 2016

Introduction

Incineration is used widely to reduce the volume of waste for final disposal, as well as for generating energy. Incineration is also regarded as a sanitary method for waste disposal (Yang et al., 2012). Among the disposal methods for waste materials, landfills and incinerators are the main contributors to the release of greenhouse gases. Based on the volume of waste disposal, landfills have been decreasing since 2007, while incineration is increasing (Ministry of Environment [MOE], 2013).

In Korea, the amount of greenhouse gases released due to waste materials was 14,800,000 t CO_2eq in 2012, which increased from 5,000,000 t CO_2eq in 2010. This included the amount released due to incineration, which has gradually increased since 2010. Incineration was found to be the biggest contributor to greenhouse gases, with 7,400,000 t CO_2eq released in 2012 (Greenhouse Gas Inventory & Research Center of Korea [GIR], 2013). Therefore, with regard to the trading of greenhouse gases emissions initiated in 2015 and the writing of the national inventory report, it is important to increase the reliability of the measurements related to the incineration of waste materials.

The IPCC rules exclude the amount of CO_2 originating from biomass from the total amount of CO_2 released

CONTACT Eui-Chan Jeon ecjeon@sejong.ac.kr Department of Environment & Energy, Sejong University, 98 Gunja-dong, Gwangjin-gu, Seoul 143-747, Korea.

during incineration of waste materials and require that it be reported separately (Intergovernmental Panel on Climate Change [IPCC], 2006). Incineration facilities for municipal solid waste (MSW) incinerate many different kinds of waste materials. Therefore, when calculating the amount of greenhouse gases released, the fraction of biomass contained in the different kinds of waste materials can greatly influence the amount of CO_2 being produced. When calculating the amount of greenhouse gases released from MSW, Korea utilizes the fossil-fuel-based carbon content method suggested by the IPCC to estimate the amount of CO_2 released (Ryu, 2010; Jang et al., 2008). However, this estimation does not consider the potentially unique characteristics of the waste produced in Korea.

Therefore, this research investigates the applicability of using biomass content to estimate the amount of CO_2 released. It compares the biomass contents determined by different methods in order to establish a method for estimating biomass in the MSW incinerator facilities of Korea.

Methods

This research selected two facilities for comparison of the methods for the estimation of the biomass content. The selected incinerator facilities were visited to classify the MSW according to their composition. Afterward, the collection of flue gases (greenhouse gases) was done at the same time as the collection of solid waste samples. After analyzing the biomass contents of the collected solid waste samples and the flue gas samples, the results were compared with the IPCC method.

Selection of objective facilities

Five sets of samples for biomass fraction analysis were collected during the summer and the fall of 2013, July–September and during the winter of 2015, January–March. Two municipal solid waste incinerator facilities that incinerate more than 150 tons on average daily were selected from those in the Gyung-gi-do province that produced the most waste materials in 2011. The selected facilities use the stoker method, the most commonly used method in Korean waste incinerator facilities. The present operating conditions of the facilities are presented in Table 1.

Estimate of the biomass fraction

Three methods were used to estimate the biomass fraction at the selected facilities. The methods used the fossil carbon fraction (FCF) default value suggested by the IPCC (IPCC default), the analysis of the biomass fraction using actual waste materials collected from the solid waste incinerator facilities (MSW analysis), and the analysis of the biomass fraction using collected flue gas (flue gas analysis).

Table 1. Characteristics of the investigated MSW incinerators.

Classification	Capacity (tons/day)	Monthly Average of Incineration Amount (tons)
A	150	43,419
B	300	74,615

In particular, in the case of the method that used IPCC basic values, since IPCC presents fossil carbon content values and dry contents by the property and state of wastes (paper, textiles, food waste, etc.), the values were used to calculate biomass contents. Fossil carbon contents in wastes refer to the contents of carbon that originated in fossils, excluding the contents of carbon that originated in biomass in wastes. Therefore, biomass contents were used determined using the foregoing inversely, that is, by excluding fossil carbon contents from entire carbon contents. The method of calculating biomass contents using IPCC basic values is shown by eq 1:

$$\text{Biomass fraction}_{IPCC} = \text{MSW} \times \sum_i \left(\text{WF}_i \times \text{Dm}_{\text{IPCC},i} \times (100\% - \text{FCF}_{\text{IPCC},i}\right) \quad (1)$$

where Biomass $\text{fraction}_{\text{IPCC}}$ is the biomass fraction calculated by IPCC default value (%), MSW is the amount incinerated for household waste of the targeted resource recovery facilities (t/day), WF_i is the characteristic ratio of i within MSW, $Dm_{IPCC,\ i}$ is the IPCC dry substance content of i within MSW, and $FCF_{IPCC,\ i}$ is the ^{12}C fraction of the IPCC guidelines of i within MSW (Table 2).

Solid waste composition classification for biomass fraction analysis and production of samples for analysis

The composition of the MSW samples was classified for each incinerator facility to estimate the biomass fraction in the MSW. The IPCC classifies solid wastes into a total of 12 different categories: paper/cardboard, textiles, food

Table 2. The estimation method for the biomass fraction.

Classification	Description
IPCC default	Using the IPCC fossil carbon fraction default value
MSW analysis	Analysis of the municipal solid waste composition classification sample
Flue gas analysis	Analysis of the flue gas of waste incineration sample

waste, wood, garden and park waste, nappies (diapers), rubber and leather, plastic, metal, glass, other, and inactive waste. In Korea, the Ministry of Environment conducts statistical investigations of MSW every 5 years, and a separate investigation of MSW is done by the Association of Resource Recovery every year. However, while the Ministry of Environment classifies MSW into six categories—paper, rubber and leather, food and vegetables, wood, plastic, and others—the Association of Resource Recovery classifies waste into seven categories: paper, textiles and leather, food waste, wood and straw, vinyl and plastic, incombustibles, and others. This research used the more comprehensive 2006 IPCC G/L classification system, which is a global comparison standard, to classify and determine the biomass fraction at the Korean solid waste incinerator facilities (Table 3).

A solid waste analysis sample was produced by analysing the composition of the MSW at each incinerator facility. The accelerator mass spectrometry (AMS) analysis used by this research needed a 10-g sample. Therefore, the solid sample used for analysis was produced by mixing an amount of each waste material according to its proportion in the total waste to obtain 10 g of one mixed sample.

Sampling of waste incineration gas

The characteristics of incinerator flue gas change according to the composition and the input of the waste being incinerated. The United States, Europe, Australia, Japan, and other countries suggest and advise the use of a continuous measurement procedure when measuring greenhouse gases at waste incinerator facilities to reflect these changing characteristics (EPA, 2011; European Commission, 2012; Department of the Environment [DOE], 2012). Therefore, at MSW facilities, the sample collection time and the analysis cycle of the incinerator flue gas must be carefully determined for greenhouse gas analysis, considering carefully the characteristics of the incinerator flue gas emissions. The American greenhouse gas mandatory reporting rule (MRR) mentions that at waste incinerator facilities, a sufficient sample of incineration gas must be obtained to satisfy the requirements for continuous 24-hr monitoring or for ASTM D6866-08 for the biomass fraction analysis. Considering these requirements for this research, greenhouse gas samples were obtained continuously for 24 hr according to the sample collection methods of ASTM D 6866-08. In Korea, the air pollutants are analyzed and monitored in real time using STACK TMS. The sampling of incineration gas was conducted using an in-house incinerator gas sampler at the back of the telemonitoring system (TMS) that analyzes air pollutants in real time. A schematic of the incinerator gas sampling system is shown in Figure 1. The components of the incinerator gas sampler are a dehydrator (ALPHA, Korea) that rapidly cools down the high temperature gas released to 3°C, a drain pump (ALPHA, Korea) that releases cooled moisture, an electronic mass flowmeter (Alicat Scientific, USA) that collects the incinerator gas at constant rates, and a pump (KNJ, Korea) that enables the incinerator flue gas to be efficiently collected for 24 hr.

Table 3. Comparison of municipal solid waste composition classification systems.

Classification	2006 IPCC G/L	Ministry of Environment (2012)	Association of Resource Recovery Facility for Municipal Waste (2012)
Waste composition	Paper	Paper	Paper
	Textiles	Textiles, leather	Textiles, leather
	Food waste	Food waste	Food waste
	Wood	Wood	Wood, straw
	Garden and park waste		
	Nappies (diapers)	—	—
	Rubber and leather	-	
	Plastic	Plastic	Vinyl, plastic
	Metal	—	Incombustibles
	Glass	—	
	Other	Other	Other

Analysis of the biomass fraction

The methods commonly used to estimate the biomass fraction of the solid waste are the ^{14}C method, the selective dissolution method, and the balance method. Related standard test methods are used for the analysis

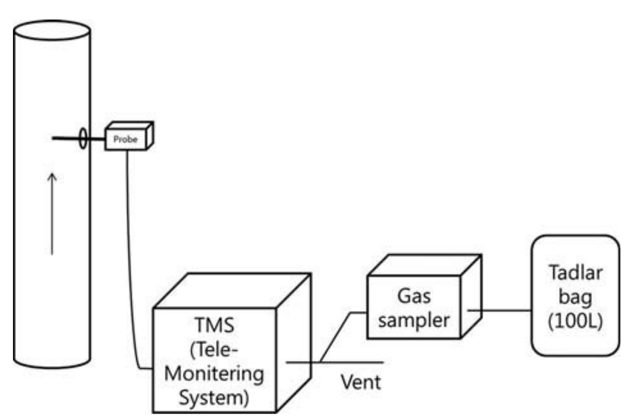

Figure 1. Schematic of the field setup for incineration gas sampling.

(Jones et al., 2013; Staber et al., 2008; DS/CEN/TS 15440, 2011; CEN/TR 15591, 2011; ASTM International, 2007). Moreover, many researchers are conducting active research at incinerator facilities regarding these methods to estimate the CO_2 produced from biomass compared to the total amount of CO_2 (Hamalainen, 2007; Larsen et al., 2013; Mohn et al., 2008; Mohn et al., 2012; Levin et al., 2003; Palstra and Meijer, 2010). In the MRR of the European Union (EU: European Commission, 2012), either the ^{14}C method or the selective dissolution method is recommended for determining the biomass fraction for emission trading. In the related standard test method ASTM D6866 (2007), it is advised to estimate ^{14}C, an isotope of carbon, using the biological carbon fraction ratio. Therefore in this research, the ^{14}C method was chosen to calculate the biomass fraction of the solid waste. ASTM D6866 identifies the liquid scintillation counting (LSC), AMS, and the isotope-ratio mass spectrometry (IRMS) analysis methods for the ^{14}C analysis methods. With radiocarbon dating, AMS can analyze even a small sample (1 g) and has the advantage that it is 105 times more precise than a standard mass spectrometer (Ruff, 2008). Therefore, this research was conducted using the AMS analysis method to estimate the biomass fraction of the waste material.

The AMS analysis method is a spectroscopic technique to accurately measure the number of isotopes in atomic nuclei such as ^{14}C by ionizing and accelerating atoms in samples and analyzing the energy, momentum, and state of charge. When the biomass contents of samples should be calculated using a ^{14}C method like the AMS analysis method, 1950 is used as the reference year in terms of "fractions of modern carbon" (f_M) as shown in the following, and biomass contents are calculated by comparing the ratios of radioactive carbon isotopes $^{14}C/^{12}C$ existing in the standard sample and the analysis sample:

$$f_{M,Sample} = \frac{\left(\frac{^{14}C}{^{12}C}\right)_{sample}}{\left(\frac{^{14}C}{^{12}C}\right)_{AD1950}} \tag{2}$$

Although $f_{M,Sample}$ is the promptly measured parameter, the fraction of biogenic or fossil carbon (%Bio C, %Fos C) has more substantive relevance:

$$\%\text{Bio C} = 100\% - \%\text{Fos C} = \left(\frac{f_{M,sample}}{f_{M,bio}}\right) \times 100\% \tag{3}$$

Since ^{14}C in fossil matter is completely decayed, the content of biogenic carbon (%Bio C) is directly proportional to the ^{14}C fraction in the emitted CO_2.

Results and discussion

Composition of municipal solid waste (MSW)

In this research, the composition of the MSW was determined while the incinerator flue gas was being collected, and then a sample for analysis (IPCC default) was collected. The results of the composition classification revealed that although there are differences between the incineration facilities, paper, plastic, food waste, and nappies (diapers) comprised the largest proportions. The waste at Facility A contained larger amounts of wood, yard, and park waste than that at Facility B. The differences in the compositions of MSW between the incineration facilities are suspected to be due to errors made during the sampling process. Even though the classification of the composition was done during the incinerator gas sampling, there are differences in the composition of the solid wastes brought into the facility. Errors are also suspected to have occurred during the process of using a crane to separate the solid wastes in the facility into those that were being combusted in the incinerator (Table 4).

Biomass fraction of municipal solid waste (MSW)

The biomass fraction of the MSW was determined using the classified compositions from the MSW incinerator facilities. The results show that the biomass content at Facility A ranged from 35 to 70%, and the biomass content at Facility B ranged from 52 to 64% (Table 5). The average biomass content was 50% for Facility A and 56% for Facility B, giving a 6 percentage point difference.

Biomass fraction of waste incineration gas

The biomass fraction of the flue gas was found by collecting and analyzing the flue gas at the MSW incinerator facilities. The result of the analysis reveal small differences depending on the time of sample collection, but unlike the analysis of the solid wastes, the analyses from Facility A and Facility B have ranges that span less than 10 percentage points. The biomass content was 55 to 58% for Facility A and 54 to 62% for Facility B (Table 6). The average biomass content was 57% for both Facility A and Facility B.

Comparison of biomass fraction by biomass estimation method

In this research, three estimation methods were used: the IPCC standard value (IPCC default), the municipal solid waste (MSW) sample method to estimate biomass

Table 4. Waste composition in target incinerators.

Classification	Paper (%)	Textiles (%)	Plastics (%)	Woods (%)	Garden and Park Waste (%)	Nappies (diapers) (%)	Rubber and Leather (%)	Food Waste (%)	Other (%)
A incinerator	29.7	8.2	21.9	8.3	1.4	12.4	0.2	15.7	2.2
B incinerator	29.0	7.0	27.6	1.6	0.5	11.2	3.4	16.0	3.9

Table 5. The result of biomass fraction analysis of MSW at target incinerators.

Classification	A Incinerator (%)	B Incinerator (%)
1	53	53
2	35	59
3	70	64
4	40	52
5	50	52
Mean	50	56

Table 6. The result of biomass fraction analysis of flue gas from target incinerators.

Classification	A Incinerator (%)	B Incinerator (%)
1	55	62
2	56	59
3	58	56
4	58	54
5	57	55
Mean	57	57

(MSW analysis), and the flue gas analysis method that collects and analyses incinerator flue gas for the estimate. The estimated values were compared (see Figure 2).

According to the estimation using the biomass fraction method (IPCC default), the biomass fraction was found to be higher for Facility A than for Facility B. It is suggested that this is due to the higher wood, garden, and park waste percentages in Facility A found during the composition classification. The biomass fraction was found to be the highest for the IPCC default method, followed by the MSW analysis and the flue gas analysis. Therefore, the difference in the estimate of the biomass fraction was the greatest between the IPCC default method and the flue gas analysis method. The difference between the MSW analysis method and the flue gas analysis method was smaller than the difference with IPCC default method. Therefore, it is suggested that the characteristics of Korean waste incinerator facilities and/or Korean MSW are not properly reflected when the IPCC default value is utilized.

The IPCC default method gave the highest level of biomass for Facility A at 73%. This was a large level compared to that determined by the MSW analysis method (50%) and the flue gas analysis method (43%). On the other hand, the difference between the MSW analysis and the flue gas analysis methods is approximately 7 percentage points. This difference is likely generated when producing analysis samples for the fossil carbon fraction of solid wastes (IPCC default). The compositional sample ratio has to be applied to obtain only a small amount sample, 10 g.

In the case of Facility B, the IPCC default value was shown to be the highest at 62%, showing a big difference from the MSW analysis method (44%) and the flue gas analysis method (43%). For Facility B there was only 1 percentage point difference between biomass fractions determined using the MSW analysis and flue gas analysis methods, a minute difference.

Conclusions

This research explored methods for estimating the biomass fraction at Korean MSW incinerator facilities and compared the biomass fractions obtained with the different biomass fraction estimation methods. The

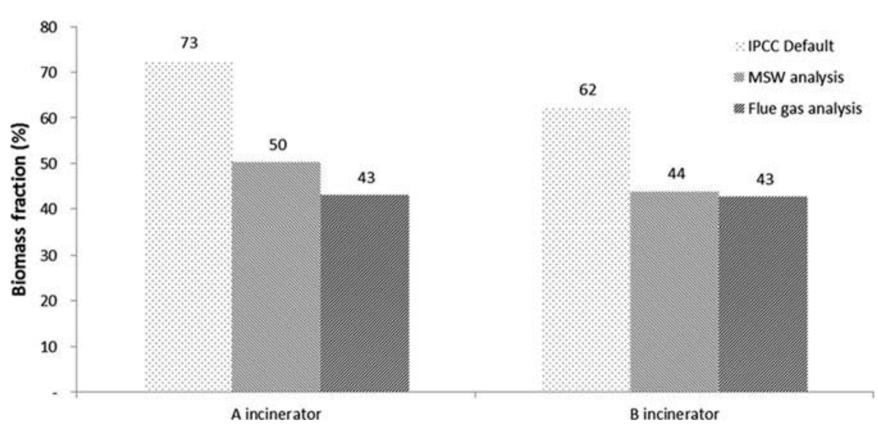

Figure 2. Comparison of estimation methods for the biomass fraction at target incinerator facilities.

biomass fraction was estimated by a method using default values of fossil carbon fraction suggested by IPCC (IPCC default), a method using the solid waste composition (MSW analysis), and a method using incinerator flue gas (flue gas analysis). The biomass fractions were determined using the AMS analysis method.

In order to analyze biomass fractions, solid waste was sampled and classified according to its composition, and samples of incinerator flue gas were collected by sampling small amounts of incinerator flue gas for 24 hr.

The highest biomass fractions in Korean municipal solid waste incinerator facilities were estimated by the IPCC default method, followed by the MSW analysis method and the flue gas analysis method. Therefore, the difference in the biomass fraction estimate was the greatest between the IPCC default and the flue gas analysis methods. The difference between the MSW analysis and the flue gas analysis methods was smaller than the difference with the IPCC default method. This suggested that the use of the IPCC default method cannot reflect the characteristics of Korean waste incinerator facilities and Korean MSW.

In Korea, most waste incinerator facilities utilize the method provided by IPCC that estimates the emissions through analysis of the solid waste (IPCC default). The default values provided by the IPCC are used for the analysis value without the waste composition being considered. They use the carbon fraction, the dried substance fraction, or the fossil carbon fraction. Among the methods evaluated in this research, a large difference (more than 18 percentage points) was found in the estimation of biomass content with the IPCC default (fossil carbon content analysis) method compared to that found by analyzing MSW from the Korean incinerator facilities. Therefore, it is suggested that the MSW analysis method is the best to use when estimating greenhouse gas emissions from the solid waste at incinerator facilities.

However, Korea is enforcing the use of gas analysis management systems and emission trading. Therefore, an incinerator company will be required to self-estimate the greenhouse gas emissions and report them to the responsible government agency. Especially for the estimation of greenhouse gas emissions, the Korean government provides guidelines for the calculation of emissions. The guidelines should suggest that estimates of greenhouse gas emissions be determined through continuous measurement of incinerator flue gas. This method is more reliable than the method of using the IPCC default value. Moreover, EPA MRR (EPA, 2011), California AB32 Mandatory GHG Emissions Reporting (2006), and EU ETS (European Commission, 2012) advise that greenhouse gas emissions be calculated using continuous measuring techniques to increase the reliability of the calculation. A method such as this can be applied to the analysis of incineration gas; therefore, it is suggested that it is best to use the flue gas analysis method to calculate the biomass fraction. A more reliable greenhouse gas inventory can be created if more related research regarding the biomass fraction of incinerator flue gas and the biomass fraction of MSW is conducted.

Funding

This work is financially supported by the Korea Ministry of Environment (MOE) as "Graduate School specialized in Climate Change."

About the authors

Seongmin Kang is affiliated with the Department of Environment and Energy, Sejong University Researcher, Seoul, Korea.

Seungjin Kim is affiliated with the Cooperate Course for Climate Change, Sejong University Researcher, Seoul, Korea.

Jeongwoo Lee is affiliated with the Department of Earth and Environmental Sciences, Sejong University Researcher, Seoul, Korea.

Hyunki Yun is affiliated with the Department of Environment and Energy, Sejong University Researcher, Seoul, Korea.

Ki-Hyun Kim is affiliated with the Department of Civil and Environmental Engineering, Hanyang University Professor, Seoul, Korea.

Eui-Chan Jeon is affiliated with the Department of Environment and Energy, Sejong University Professor, Seoul, Korea.

References

Association of Resource Recovery Facility for Municipal Waste. 2012. 2012 Current condition of operation on resource recovery facility for municipal waste in Korea. http://www.k-inc.co.kr/board/pds1.php

ASTM International. 2007. ASTM D6866. Standard test methods for determining the bio based content of solid, liquid, and gaseous samples using radiocarbon analysis. https://www.astm.org/Standards/D6866.htm

California AB32. 2006. Mandatory GHG emissions reporting. http://www.arb.ca.gov/cc/ab32/ab32.htm

CEN/TR 15591. 2007. Solid recovered fuels. Determination of the biomass content based on the ^{14}C method. http://shop.bsigroup.com/ProductDetail/?pid=000000000030155843

Department of the Environment. 2012. Technical guidelines for the estimation of greenhouse gas emissions by facilities in Australia. http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/nger-technical-guidelines-2012

DS/CEN/TS 15440. 2011. Solid recovered fuels— Methods for the determination of biomass content. http://infostore.saiglobal.com/store/details.aspx?ProductID=1666599

Environmental Protection Agency. 2011. 40 CFR Part 98 mandatory reporting of greenhouse gases. https://www.law.cornell.edu/cfr/text/40/98.40

European Commission. 2012. Biomass issues in the EU ETS. MRR Guidance document 17(3). http://ec.europa.eu/clima/policies/ets/monitoring/docs/gd3_biomass_issues_en.pdfhttp://ec.europa.eu/clima/policies/ets/monitoring/docs/gd3_biomass_issues_en.pdf

Greenhouse Gas Inventory & Research Center of Korea. 2012. National inventory report in Korea. http://www.gir.go.kr/home/index.do?menuId=36

Hamalainen, K.M. 2007. Measurment of biocarbon in flue gases using C14. *Radiocarbon* 49:325–39.

Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Jang, Y.-K., K. Jung, and K. Kwan. 2008. Variation of greenhouse gas (CO_2) emission factors and emissions by waste incineration. *J. Korean Soc. Environ. Eng*. 30(3): 243–49.

Jones, F.C., E.W. Blomqvist, M. Bisaillon, D.K. Lindberg, and M. Hupa. 2013. Determination of fossil carbon content in Swedish waste fuel by four different methods. *Waste Manage. Res*. 10:1052–61. doi:10.1177/0734242X13490985

Larsen, A.W., K. Fuglsang, N.H. Pedersen, J. Fellner, H. Rechberger and T. Astrup. 2013. Biogenic carbon in combustible waste: Waste composition, variability and measurement uncertainty. *Waste Manage. Res*. 31(10): 56–66. doi:10.1177/0734242X13502387

Levin, I., B. Kromer, M. Schmidt, and H. Sartorius. 2003. A novel approach for independent budgeting of fossil fuel CO_2 over Europe by $^{14}CO_2$ observations. *Geophys. Res. Lett*. 30(23): 2194. doi:10.1029/2003GL018477

Ministry of Environment. 2013. Statistics survey of 4th national waste in Korea (2011–2012). http://webbook.me.go.kr/DLi-File/091/018/005/5552489.pdf

Mohn, J., S. Szidat, J. Fellner, H. Rechberger, R. Quartier, B.Buchmann, and L. Emmenegger. 2008. Determination of biogenic and fossil CO_2 emitted by waste incineration based on $^{14}CO_2$ and mass balances. *Bioresource Technol*. 99(14): 6471–79. doi:10.1016/j.biortech.2007.11.042

Mohn, J., S. Szidat, K. Zeyer, and L. Emmenegger. 2012. Fossil and biogenic CO_2 from waste incineration based on a yearlong radiocarbon study. *Waste Manage*. 32(8): 1516–20. doi:10.1016/j.wasman.2012.04.002

Ruff, M. 2008. Radiocarbon measurement of micro-scale samples—A carbon dioxide inlet system for AMS. Philosophisch-naturwissenschaftlichen, Fakulttp der Universiter Bern, Bern, Germany.

Palstra, S.W.L., and H.A.J. Meijer. 2010. Carbon-14 based determination of the biogenic fraction of industrial CO_2 emissions. Application and validation. *Bioresource Technol*. 101(10): 3702–10. doi:10.1016/j.biortech.2009.12.004

Ryu, C. 2010. Potential of municipal solid waste for renewable energy production and reduction of greenhouse gas emissions in South Korea. *J. Air Waste Manage. Assoc*. 60:176–83. doi:10.3155/1047-3289.60.2.176

Staber, W., S. Flamme, and J. Fellner. 2008. Methods for determining the biomass content of waste. *Waste Manage. Res*. 26:78–87. doi:10.1177/0734242X07087313

Yang, N., H. Zhang, M. Chen, L.-M. Shao, and P.-J. He. 2012. Greenhouse gas emissions from MSW incineration in China: Impacts of waste characteristics and energy recovery. *Waste Manage*. 32:2552. doi:10.1016/j.wasman.2012.06.008