

Alavi-Borazjani, S. A.; Capela, I.; Tarelho, L. A. C.

Article

Valorization of biomass ash in biogas technology: Opportunities and challenges

Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Alavi-Borazjani, S. A.; Capela, I.; Tarelho, L. A. C. (2020) : Valorization of biomass ash in biogas technology: Opportunities and challenges, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, Iss. 1, pp. 472-476, <https://doi.org/10.1016/j.egyr.2019.09.010>

This Version is available at:

<https://hdl.handle.net/10419/243775>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

6th International Conference on Energy and Environment Research, ICEER 2019, 22–25 July,
University of Aveiro, Portugal

Valorization of biomass ash in biogas technology: Opportunities and challenges

S.A. Alavi-Borazjani^{*}, I. Capela, L.A.C. Tarelho

Department of Environment and Planning, University of Aveiro, Campus Universitario de Santiago, 3810-193 Aveiro, Portugal
Centre for Environmental and Marine Studies (CESAM), University of Aveiro, Campus Universitario de Santiago, 3810-193 Aveiro, Portugal

Received 24 July 2019; accepted 7 September 2019

Abstract

Despite the increasing global focus on replacing fossil fuels with biomass resources, handling the enormous quantity of ash from biomass thermochemical conversion processes into energy remains a serious challenge from both environmental and economic points of view. Therefore, in pursuit of the circular economy, the use of biomass-derived ash in beneficial applications can have a great contribution to address problems related to ash disposal, and at the same time to promote the valorization of wastes. This work attempts to provide a clear insight into the feasibility of the utilization of biomass ash in a valuable field, namely anaerobic digestion and biogas technology, along with a brief statement of possible opportunities and challenges.

© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of the 6th International Conference on Energy and Environment Research, ICEER 2019.

Keywords: Biogas technology; Biomass ash; Challenges; Opportunities

1. Introduction

Due to serious energy crises and environmental concerns in recent years, the replacement of a fraction of conventional fossil fuels with biomass, as a plentiful and green source of renewable energy, has attracted a lot of attention worldwide [1]. It is reported that the world's annual production of biomass with potential for conversion to energy is currently around 7 billion tons [2]. As shown in Fig. 1, biomass resources can be categorized within 6 major groups: (i) wood and woody biomass; (ii) herbaceous and agricultural biomass; (iii) animal/ human-derived biomass waste; (iv) commercial and construction biomass residues; (v) aquatic biomass; and (vi) household and industrial organic residues.

Nevertheless, the thermochemical processes (e.g., combustion, gasification, and pyrolysis) applied to convert biomass into energy vectors, generate a huge amount of residual ash. These inorganic residues are mainly buried in

^{*} Corresponding author.

E-mail address: saab@ua.pt (S.A. Alavi-Borazjani).

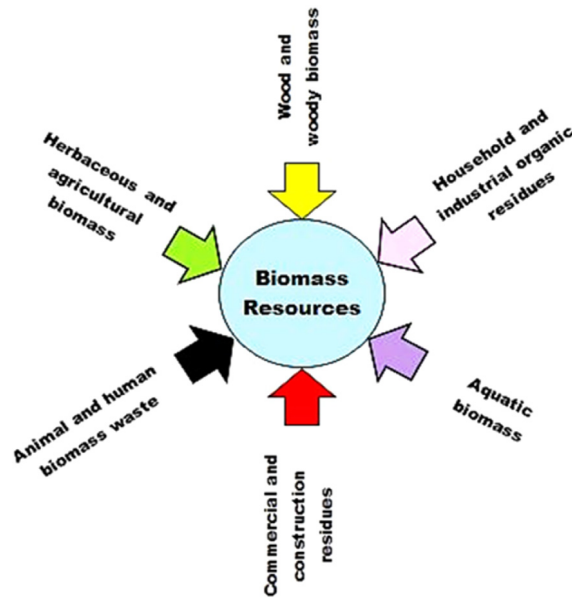


Fig. 1. Categorization of the main biomass types.
Source: Adapted from [3].

landfills, occupying a large area of applicable land and contaminating the environment [2]. Thus, a proper solution must be adopted to solve the disposal-related issues of biomass ash.

So far, extensive investigations have been done on the utilization of ashes in a wide variety of fields, including construction and ceramic industry, agricultural soil amendment, environmental remediation, and catalytic applications [3]. However, studies on the usage of biomass ash in other promising areas such as biogas technology, based on anaerobic digestion process, are scarce. This aspect provides a proper basis for further research to achieve remarkable innovations that are consistent with the circular economy concept.

Indeed, the anaerobic digestion process is a collection of sequential biochemical reactions (i.e., hydrolysis, acidogenesis, acetogenesis, and methanogenesis), in which organic substances are transformed into valuable by-products such as biogas, in an oxygen-free environment [4] (see Fig. 2).

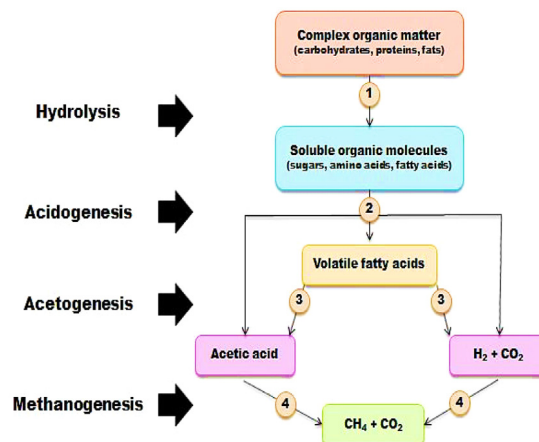


Fig. 2. Schematic diagram of anaerobic digestion process.
Source: Adapted from [4].

In the following sections are outlined the potential opportunities for the application of biomass-derived ashes in anaerobic digestion technology as well as possible challenges that may hinder the valorization of such problematic waste in the aforementioned context.

2. Opportunities

As already mentioned, biogas technology seems to be a very valuable area for the use of selected fractions of biomass ash, especially in two major applications: (i) improving the digestion process performance to enhance biogas formation and, (ii) purification of the produced biogas.

2.1. Improvement of the digestion process for increased biogas formation

Acidification problem and subsequent process instability are of major concerns in commercial biogas plants due to the presence of easily biodegradable substrates. The use of biomass ash as an additive with high buffering ability can not only increase the efficiency of the biogas production process but also significantly reduce the need for commercial alkali reagents as well as continuous regulation of pH in the anaerobic digesters [10]. The other benefit of biomass ash as a fermentation additive is the supplementation of macro- and micro-nutrients required for the activity of anaerobic microorganisms during the digestion process, leading to an overall process improvement in a cost-effective manner [11]. Despite all these advantages, little has been done so far on the study of the effect of adding biomass ash to the anaerobic digestion systems. For instance, in a series of experimental work [5–9], promising results could be achieved in the yield of methane gas from the anaerobic digestion of organic residues using distinct amounts of municipal solid waste incinerator ash. More recently, Novais et al. [10] also observed an enhanced pH buffering capacity and methane production efficiency with the addition of biomass fly ash-based geopolymer spheres to the anaerobic digesters treating high loads of cheese whey. Further details on these studies

Table 1. Effect of biomass ash addition on biogas production.

Substrate	Reactor	Temperature (°C)	Biomass ash		Maximum biogas production	Ref.
			Type	Dosage		
MSW ^a	CSTR ^b	35	MSWI BA ^c	3 and 6 (g/200 mL feed)	500 (mg/L) ^f using 6 (g MSWI BA/200 mL feed)	[5]
MSW	Four layers-arranged reactor	35	MSWI FA ^d	10 and 20 (g/L)	225 (L/kg VS) using 20 (g MSWI FA/L)	[6]
MSW	Four layers-arranged reactor	35	MSWI FA MSWI BA	10 and 20 (g/L) 100 (g/L)	222 (L/kg VS) using 20 (g MSWI FA/L)	[7]
MSW	CSTR	35	MSWI FA MSWI BA	1 and 3 (g/day) 12 and 24 (g/day)	675 (mL/g VS) using 24 (g MSWI BA/day)	[8]
MSW	Batch reactor	35	MSWI FA and MN ^e MSWI FA MSWI BA and MN MSWI BA	3, 6, 18 and 30 (g/g VS) 12, 36, 60 and 120 (g/g VS)	193 (mL/g VS) using 36 (g MN MSWI BA/g VS)	[9]
Cheese whey	Batch reactor	37	FA-based spheres	20 and 28 (g/L)	0.670 (L/g initial VSS) using 28 (g FA-based spheres/L)	[10]

^aMunicipal solid waste.

^bContinuous stirred-tank reactor.

^cMunicipal solid waste incinerator bottom ash

^dMunicipal solid waste incinerator fly ash.

^eMicro-nano.

^fTotal organic carbon (TOC) concentration in the leachate.

are presented in Table 1. These achievements open an interesting route towards future research on the improvement of biogas production from organic residues. Considering the high diversity of biomass-derived ashes and their associated properties [2], distinctive potential impacts can be expected from the use of different types of these valuable wastes either on methane production or on the production of other biogas types such as hydrogen or hythane from the anaerobic digestion process.

2.2. Biogas purification

Raw biogas obtained from an anaerobic fermentation process does not have enough quality for its introduction into the gas grid or vehicles fuel use. The common solution to this barrier is the purification approach by which impurities are absorbed or scrubbed from the biogas stream. The most frequently used biogas purification technologies are water/amine scrubbing, pressure swing adsorption, cryogenic distillation, and membrane separation [12]. However, the application of these processes has several drawbacks, including biogas losses, excessive consumption of energy (e.g., electricity) and chemicals, as well as related atmospheric pollution [13]. In this context, the application of biomass ashes can be advantageous for trapping biogas contaminants, hence reducing costs and environmental impacts in comparison with commercial purification techniques [14].

In recent years, a limited set of studies [13–16] have shown the feasibility of using municipal solid waste incineration bottom ash and wood ash, as sorbents, to remove CO₂ and sulphur compounds (e.g. H₂S, dimethyl sulphide ((CH₃)₂S and methyl mercaptan (CH₃SH)) from biogas in anaerobic reactors or from landfill gas (See Table 2). Nevertheless, the application of biomass ash in the biogas-cleaning process cannot be only restricted to ash residues from incineration of municipal solid waste or wood, since ashes from other biomass resources or other thermochemical conversion processes may be more effective to reduce biogas contaminants. Even when using a specific type of biomass ash, different purification capacities may be observed depending on the effect of potential factors that contribute to the variation in the biomass composition and properties [3]. Hence, these knowledge gaps provide a good opportunity for researchers who are interested in working in this economically attractive and challenging field.

Table 2. Effect of biomass ash on biogas purification.

Biomass ash		Input gas flow rate (L/h)	Impurity		Ref.
Type	Amount (kg)		Type	Removal (kg/t ash)	
MSWI BA ^a	76.3–91.9	32–131	CO ₂	15.5–39	[16]
MSWI BA	13	895	H ₂ S	3 × 10 ⁻³	[15]
		898	CH ₃ SH ^b	44 × 10 ⁻⁶	
		898	(CH ₃) ₂ S ^c	86 × 10 ⁻⁶	
		897	CO ₂	11 × 10 ⁻³	
MSWI BA	490–1000	2300–9200	CO ₂	10.2–23	[13]
Wood ash	411–856	2600–5200	H ₂ S	0.56–1.25	[14]
			CO ₂	35–135	

^aMunicipal solid waste incinerator bottom ash.

^bMethyl mercaptan.

^cDimethyl sulphide.

3. Challenges

Although there seem to exist many potential benefits of using biomass ash in biogas industry, encountering multiple barriers is unavoidable. Some of these challenging obstacles can be summarized as follows [17]:

- Scarcity and inaccessibility of data on the key parameters necessary for the technical verification of biomass ash utilization in biogas technology such as availability of ash and its characteristics, commercial validation, user needs, and relevant specifications and standards;
- Possible economic barriers and lack of adequate financial incentives to encourage investments and, ultimately, the widespread use of ash in this valuable area;
- Lack of institutional and legal guidelines as well as insufficient or strict industry and environment legislation for the use of biomass ash in biogas technology.

4. Conclusion

The growing trend of biomass ash production on recent years, resulting from an increased biomass to energy applications, has encouraged researchers to find innovative ash applications in an economic and sustainable way. It is believed that the utilization of biomass ash in anaerobic digestion technology, either as an additive for optimizing the biogas production process or as an adsorbent for biogas purification is a promising solution to the valorization of such abundant by-product from biomass to energy applications. Thus, further research in this relatively unexplored approach is highly recommended, taking into account the potential challenges and constraints.

Acknowledgements

Thanks are due for the financial support to CESAM, Portugal (UID/AMB/50017/2019), to FCT/MCTES, Portugal through national funds, and the co-funding by the FEDER, European Union, within the PT2020 Partnership Agreement and Compete 2020. Thanks are also due to FCT, Portugal for the doctoral scholarship No. SFRH/BD/137904/2018.

References

- [1] Wang P, Guo Y, Zhao C, Yan J, Lu P. Biomass derived wood ash with amine modification for post-combustion CO₂ capture. *Appl Energy* 2017;201:34–44.
- [2] Vassilev SV, Vassileva CG, Song Y, Li W, Feng J. Ash contents and ash-forming elements of biomass and their significance for solid biofuel combustion. *Fuel* 2017;208:377–409.
- [3] Belviso C. State-of-the-art applications of fly ash from coal and biomass: A focus on zeolite synthesis processes and issues. *Prog Energy Combust Sci* 2018;65:109–35.
- [4] Mao C, Feng Y, Wang X, Ren G. Review on research achievements of biogas from anaerobic digestion. *Renew Sustain Energy Rev* 2015;45:540–55.
- [5] Banks CJ, Lo H-M. Assessing the effects of municipal solid waste incinerator bottom ash on the decomposition of biodegradable waste using a completely mixed anaerobic reactor. *Waste Manag Res* 2003;21:225–34.
- [6] Lo HM, et al. Biostabilization assessment of MSW co-disposed with MSWI fly ash in anaerobic bioreactors. *J Hazard Mater* 2009;162:1233–42.
- [7] Lo HM, et al. Modeling biogas production from organic fraction of MSW co-digested with MSWI ashes in anaerobic bioreactors. *Bioresour Technol* 2010;101:6329–35.
- [8] Lo HM, Chiu HY, Lo SW, Lo FC. Effects of different SRT on anaerobic digestion of MSW dosed with various MSWI ashes. *Bioresour Technol* 2012;125:233–8.
- [9] Lo HM, Chiu HY, Lo SW, Lo FC. Effects of micro-nano and non micro-nano MSWI ashes addition on MSW anaerobic digestion. *Bioresour Technol* 2012;114:90–4.
- [10] Novais RM, et al. High pH buffer capacity biomass fly ash-based geopolymer spheres to boost methane yield in anaerobic digestion. *J Clean Prod* 2018;178:258–67.
- [11] Podmirseg SM, Seewald MSA, Knapp BA, Biderre-petit C, Peyret P, Insam H. Wood ash amendment to biogas reactors as an alternative to landfilling? A preliminary study on changes in process chemistry and biology. *Waste Manag Res* 2016;31(8):829–42.
- [12] Sarperi L, Surbrenat A, Kerihuel A, Chazarenc F. The use of an industrial by-product as a sorbent to remove CO₂ and H₂S from biogas. *J Environ Chem Eng* 2014;2(2):1207–13.
- [13] Mostbauer P, Lombardi L, Olivieri T, Lenz S. Pilot scale evaluation of the BABIU process – upgrading of landfill gas or biogas with the use of MSWI bottom ash. *Waste Manag* 2014;34(1):125–33.
- [14] Juárez MF, et al. Biogas purification with biomass ash. *Waste Manag* 2018;71:224–32.
- [15] Ducom G, Radu-timoveanu D, Pascual C, Benadda B, Germain P. Biogas – Municipal solid waste incinerator bottom ash interactions: Sulphur compounds removal. *J Hazard Mater J* 2009;166:1102–8.
- [16] Mostbauer P, Lenz S, Lechner P. MSWI bottom ash for upgrading of biogas and landfill gas. *Environ Technol* 2008;29(7):757–64.
- [17] Niu Y, Tan H, Hui S. Ash-related issues during biomass combustion: Alkali-induced slagging, silicate melt-induced slagging (ash fusion), agglomeration, corrosion, ash utilization, and related countermeasures. *Prog Energy Combust Sci* 2016;52:1–61.