

Editorial

# Special Issue on the Intensified Conversion of Organic Waste into Biogas

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## 1. Introduction

Anaerobic digestion is a sustainable technology used to produce renewable gas from organic wastes. There are thousands of biogas facilities in the world, but many fundamental aspects of anaerobic digestion processes are still being discovered. For example, the catalytic effect of conductive materials is undoubtedly one of the key breakthroughs in recent years, and it will improve the efficiency of every digester around the world [1]. Anaerobic digestion involves a series of syntrophic relationships where hydrogen (H)/Formate (F) electron carriers play an important role in the process of interspecies electron transfer (H/F IET) [1]. When syntrophy is compromised, conversion rates are reduced, which affects greatly the treatment efficiency.

Several strategies have been implemented to improve anaerobic digestion of organic waste [2] such as empirical modifications of process design, operational conditions [3], application of substrate pretreatments [4], and waste co-digestion [5,6]. Nevertheless, much work is needed to understand the fundamental phenomena involved in the anaerobic digestion process to accelerate the activity of anaerobic microorganisms and thus improve the self-sufficiency and sustainability of anaerobic digesters.

This Special Issue brings together a broad range of recent advances in the field of anaerobic digestion. Notably, these range from co-gasification of municipal solid waste to a spatially explicit model and the definition of the best location for a co-digestion biogas production facility. Additionally, this Special Issue presents some advancements in pretreatments and co-digestion approaches and the application of conductive materials to improve methane production. A total of eight articles were selected for publication.

## 2. Strategies to Improve Anaerobic Digestion of Organic Waste

Anaerobic digestion can be a suitable in situ solution for the treatment of agro-industry wastes, providing a source of renewable energy, which can be a supply for the processes in these industries [7]. Montes et al. [7] assessed the biomethanogenic potential of several wastes and by-products from alcoholic beverage production, indicating that the economic feasibility of anaerobic digestion technologies could depend on the capability of the industries to join forces and create consortiums [7]. Moreover, the implementation of biogas production units may include pre/post-treatments and must consider the logistics of sludge disposal [8]. Coura et al. [8] developed a spatially explicit model using an analytical hierarchy process concerning the suitable location and the pre-dimensioning of biogas units in anaerobic co-digestion systems for liquid fraction treatment and valorization of sewage sludge and dairy cattle manure. This approach will be very useful to decision-makers working towards resources optimization.

Recent advances in the anaerobic digestion field have also shown that the addition of conductive materials to anaerobic digestion processes can improve methane production rates, reducing lag phases, increase organic loading rates, and contribute to a more stable operation of the systems [1]. For example, Cavaleiro et al. [9] evaluated the effect of carbon



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nanotubes on the methanogenic activity of anaerobic sludge and river sediment. Carbon nanotubes accelerated the initial specific methane production rate from acetate, hydrogen, ethanol, and butyrate, with a more pronounced effect on the assays with acetate and butyrate, i.e., 2.1 and 2.6 times, respectively. Experiments with river sediment showed that cumulative methane production was 10.2 times higher in the assays with carbon nanotubes impregnated with iron than in the assays without carbon nanotubes [9]. The conductive particle-mediated interspecies electron transfer mechanism facilitates the electron transfer between species and has been shown to be beneficial to accelerate methane production [10].

Other strategies include substrate pretreatment to overcome the recalcitrant complex structure of some softwood species, such as Norway spruce (*Picea abies*). Ghimire et al. [11] evaluated the methane yield in thermophilic anaerobic digestion conditions from hot water extract of Norway spruce pretreated at two different pretreatment severities. A higher pretreatment severity (170 °C) yielded higher concentrations of AD inhibitors. Despite having lower sugar content, hydrolysate pretreated at the lower temperature of 140 °C had an 18% higher methane yield. This result shows that these substrates can be utilized safely in continuous-flow industrial anaerobic digestion [11].

Furthermore, other recalcitrant wastes, such as cork boiling wastewater, were assessed through a biochemical methane potential [12]. Results showed that anaerobic treatment of this wastewater is possible and that co-digestion with food waste was not an advantage. Nevertheless, the co-digestion with cow manure increased the biomethane yields, demonstrating that this strategy increases biogas production and the quality of the final digestate [12].

Different thermal hydrolysis technologies were analyzed using data from the wastewater treatment plant of Burgos (Spain) as the base scenario when operating with conventional mesophilic anaerobic digestion [13]. García-Cascallana et al. [13] showed that when hydrolysis was applied to digested sludge and sludge from the Solidstream<sup>®</sup> process, this resulted in a 35% increase in biogas available for engines and a 23% increase in electricity production. In this case, the main advantage of the hydrolysis process is the decrease in the volume of digesters and the amount of dewatered sludge needing final disposal [13].

The exposure of sewage sludge and cattle slurry to amoxicillin, oxytetracycline, sulfamethoxazole, and metronidazole resulted in differences in the composition of microbiota engaged in the anaerobic processes [14]. The number of copies of the characteristic genes of the families *Methanosarcinaceae* and *Methanosaetaceae* declined in most of the digestate samples with antimicrobial supplementation. In addition, metronidazole inhibited sewage sludge fermentation to the greatest extent (a six-fold decrease in biogas production and an over 50% decrease in methane content) [14].

Finally, an alternative strategy to the valorization of municipal solid waste was proposed by Ding et al. [15]. The addition of bituminous coal improved the gasification of municipal solid waste, and higher gasification temperatures increased the cold gas efficiency and the overall energy efficiency [15].

### 3. Perspectives on the Future of Research on the Intensified Conversion of Organic Waste into Biogas

While the work presented in this Special Issue offers concrete advancements to the study of anaerobic digestion, much work is still needed. Future research should focus on the development of sustainable pretreatment methods by achieving positive energy and economic balances. Additionally, it is clear that in order to predict the impact of pretreatment on anaerobic digestion, a more detailed understanding of the fundamental phenomena during pretreatment and its influence on sludge properties is necessary. Moreover, more lab-scale and pilot-scale continuous experiments are needed to achieve a holistic understanding of anaerobic co-digestion.

Additionally, it is essential to pursue research related to the inhibitory effect of pharmaceuticals further, including such aspects as the assessment of abundance and activity of microorganisms engaged in all steps of anaerobic digestion.

Furthermore, little is known about the effect of conductive materials on anaerobic digestion. Despite these recent advances in knowledge, more research is needed to understand the effects of conductive materials on anaerobic communities in order to improve the rate of methane production in anaerobic digestion processes. Further, control assays with non-conductive materials are essential for understanding the effect of conductive materials, but such controls have rarely been performed.

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