January 25, 2018

Via Electronic Transmission

Ms. Madison Le
Director, Fuels Compliance Policy Center (FCPC)
Office of Transportation & Air Quality
U.S. Environmental Protection Agency
1200 Pennsylvania Ave NW
Washington, D.C. 20460

**RE: RESPONSE TO EPA REGARDING CO-DIGESTION, SYNERGISMS AND APPROACH TO SIMPLIFIED D3-D5 DIFFERENTIATION**

Dear Ms. Le:

Following up on our phone conversations over the summer, we have completed the project we discussed which we hope will create another way to allocate D3 and D5 RINs from an anaerobic digester ("AD") that uses manure and/or biosolids in addition to food waste. Our findings are included below.

We would love to meet with you to discuss how this approach could be implemented.

**Purpose:** The American Biogas Council ("ABC") has been in a dialogue with EPA's Office of Transportation and Air Quality ("OTAQ") to address uncertainties related to properly allocating D3 and D5 RINs to co-digestion systems. In a co-digestion system, multiple types of feedstocks are processed simultaneously to improve the overall health of the anaerobic digester and produce biofuel. These feedstocks can include manure, wastewater sludge food waste and/or other wastes. Under the US EPA's Renewable Fuels Standard, manure and wastewater sludge have been approved to produce cellulosic biofuel (D3) and food waste and other wastes have been approved to produce advanced biofuel (D5). AD operators and owners want to create the appropriate split of RINs in a way that is both accurate and more administratively efficient. From our previous discussions and in a continuing effort to resolve this challenge, OTAQ asked the ABC to:

1. Review biomethane potential (BMP) literature for manure and municipal primary and waste-activated solids (sludge);
2. Review literature on possible synergistic effects from co-digestion; and
3. Propose a simplified BMP-approach to allocating D3 and D5 RINs from a common process.

We have enclosed our findings on each of these topics and suggest the "Simplified BMP-Approach" described below for allocating D3 and D5 RINs. It does not require the extensive, and therefore expensive, feedstock testing otherwise currently required.

We would like to note that this Simplified BMP Approach is not intended to replace the other methods EPA currently allows such as:

1. For ADs processing ONLY feedstocks with a 75% or greater cellulosic content ("Cellulosic Feedstocks"), as recognized by EPA in its existing regulations or going forward, all renewable biofuel produced will generate 100% D3 RINs;
2. For ADs processing both Cellulosic Feedstocks and other waste feedstocks:
    a. The portion of D3 and D5 RINs generated may be determined using a combination of tests for cellulosic content and BMP of the input feedstocks to the AD.
    b. If multiple tanks are used in the AD system, Cellulosic Feedstocks can be placed into one or more tanks that will generate 100% D3 RINs from the gas produced by those tanks and in different tanks, non-Cellulosic or a mix of both Cellulosic Feedstocks and other waste feedstocks can be digested. These different tanks would produce 100% D5 RINs.

Rather, this approach is intended to take a process like the one previously described in 2a, which is currently complicated and expensive, and provide an alternate option that is still accurate and also administratively much more efficient. Some industry projects may still choose to use the methods already established, but we know that many more would prefer to use this simplified method.

**Simplified BMP-Approach**: The ABC proposes the following method of allocating D3 and D5 RINs to ADs producing cellulosic and non-cellulosic biofuels from co-digestion of D3 and D5 eligible feedstocks:

1. For ADs processing both Cellulosic Feedstocks and other waste feedstocks:
    a. D3 RINs will be recognized based on flow/mass intake and generally accepted BMP values of the Cellulosic Feedstocks;
        i. Dairy Manure: 0.243 +/- 0.060 m3 CH4 kg $VS^{-1}$ (Labatut et al., 2011)
        ii. Swine Manure: 0.210 +/- 0.040 m3 CH4 kg $VS^{-1}$ (Vedrenne et al., 2008)
        iii. Municipal Sludge: 0.31 +/-0.16 m3 CH4 kg $VS^{-1}$ (Speece, 1987)
    b. D5 RINs will be recognized using a simple subtraction of the calculated D3 fraction, as previously described, from the known total biogas fuel production.

The proposed, simplified method is supported by data on feedstock intake, AD monitoring and periodic wastewater testing to verify accuracy of the proposed cellulosic BMP values.

In discussing this method verbally with EPA staff we learned that some concerns existed related to a possible synergistic effect that might be created when blending multiple feedstocks. The ABC shows in this letter, based on a review of synergism studies, that:

> <u>synergisms do not likely exist with any statistical relevance</u>, and if any such synergisms were to exist, they would most likely increase biogas production from the <u>non-manure</u> or <u>non-sludge</u> fractions from co-digestion. Manure and sludge contain desired modulating factors to digestion that induce enhancements in other feedstocks as opposed to the opposite.

This Simplified BMP-Approach is based on easily accessible, well-established, well-documented, verifiable and current information. ADs already monitor feedstock volume/mass intake and biogas production data, as well as important operational parameters to allow simple implementation and reporting. The approach, set forth above for allocating D3 and D5 RINs from biogas produced using co-digestion would:

a) Provide certainty and predictability to regulated parties;
b) Be a simple metric to calculate, apply and enforce;
c) Ease the burden of administration and compliance on both producers and OTAQ; and
d) Follows the RFS's emphasis on feedstock character and volume as the defining metrics for determining RIN D-Code allocation

**LITERATURE REVIEW**

In support of the above approach ABC performed an extensive audit of peer-reviewed research and presents the following articles as support for the premise that biogas volume correlates to feedstock BMP with such consistency and precision that BMP may be used to accurately predict biogas yields for D3 and D5 feedstocks, including when co-digested.

The following is a summary of a literature review focused on:

- BMPs for manure and municipal primary and waste-activated solids (sludge); and
- Possible synergistic concerns within co-digestion.

**<u>BMPs—Bio Methane Potential Tests</u>**

International Standards Organization ("ISO") procedures define methods for determining BMPs from organic material (Holliger et al., 2016). Importantly, years of peer-reviewed BMP research is available in journals for many common anaerobic digestion substrates and establishes test methods to determine BMPs for various organic substances.

BMP models are based on a ratio of estimated bio-methane production per unit mass of volatile solids sent to the AD ($m^3$ $CH_4$ kg $VS^{-1}$), but can be adjusted to accept ratios of total solids ($m^3$ $CH_4$ kg $TS^{-1}$) or chemical oxygen demand ($m^3$ $CH_4$ wet $COD^{-1}$) intake.

The use of a ratio is valuable for this purpose. While manures and sludges can come in a variety of forms and dilutions, the biogas achieved is independent of form and dilution and instead based simply on the given amount of loaded VS, TS, or COD. As each of these parameters are relatively simple and cost effective to test in an industrial setting, the use of the BMP ratio can be applied in conjunction with TS, VS, and/or COD data to determine methane or biogas produced and therefore, D3 and D5 allocation.

With the manures and sludges of interest, the following BMP are reported, with variation within and across different references. The variation is in part due to changes in the manure and sludges from feedstock/source diet, collection/storage time (Vedrenne et al., 2008), and inherent deviations within biological process and the laboratory testing. An additional complication arises in that municipal sludge is composed of two distinct feedstocks, the primary separated sludge and the secondary waste activated sludge, with facilities treating one, the other, or both in varying ratios, while also incorporating different thickening steps in front of the digestion process.

- Dairy Manure: 0.243 +/- 0.060 $m^3$ $CH_4$ kg $VS^{-1}$ (Labatut et al., 2011)
- Swine Manure: 0.210 +/- 0.040 $m^3$ $CH_4$ kg $VS^{-1}$ (Vedrenne et al., 2008)
- Municipal Sludge: 0.31 +/-0.16 $m^3$ $CH_4$ kg $VS^{-1}$ (Speece, 1987)

An immediate question that arises from the above discussion is how to deal with the variation. Several approaches could be taken. First, particularly in the case of manures, the mean or some other agreed upon value within the BMP literature could be used as the BMP baseline. A second approach would be to perform site-specific BMP tests for that manure or sludge. Once a reliable bassline is established, testing frequency would be reduced. Importantly, the site-specific BMP testing would be verified against a literature BMP model for confirmation of accuracy.

A second concern or question that arises is whether industrial continuous flow AD processes are well represented by literature results and laboratory-based, batch BMP assessments testing. Holliger et al., (2017) studied actual continuous flow AD biogas production at wet and dry biogas plants against feedstock specific, laboratory-based, batch BMP testing. Holliger et al., (2017) show a 94 ± 6.8% and 89.3 ± 5.7% correlation to laboratory-based, batch BMP testing for the wet and dry processes, respectively over one year.

Unsurprisingly, the continuous flow AD biogas production rates were consistently, slightly lower than the idealized BMP data, but the correlation was impressive, especially since these facilities were complex projects treating multiple, changing feedstock inputs. The correlation would likely be even stronger for manures and sludges compared to the wet system in the Holliger et al., (2017) study.

A more detailed response requires knowledge of laboratory-based BMP determination protocols. First, these BMP studies were performed under idealized laboratory conditions, including suitable inoculum to manure ratios and moderate levels of organic loading to avoid inhibition during 40-day batch digestion. To achieve or confirm results under large-scale, industrial scale, continuous flow digestion, one would need to confirm maintenance of suitable bacteria, loading rates, and retention time. Fortunately, this is quite easily done, via confirmation from known design tank volumes, known biological consortia growth rates, in-line flow meters, and regular but inexpensive testing of VS, TS, and/or COD parameters.

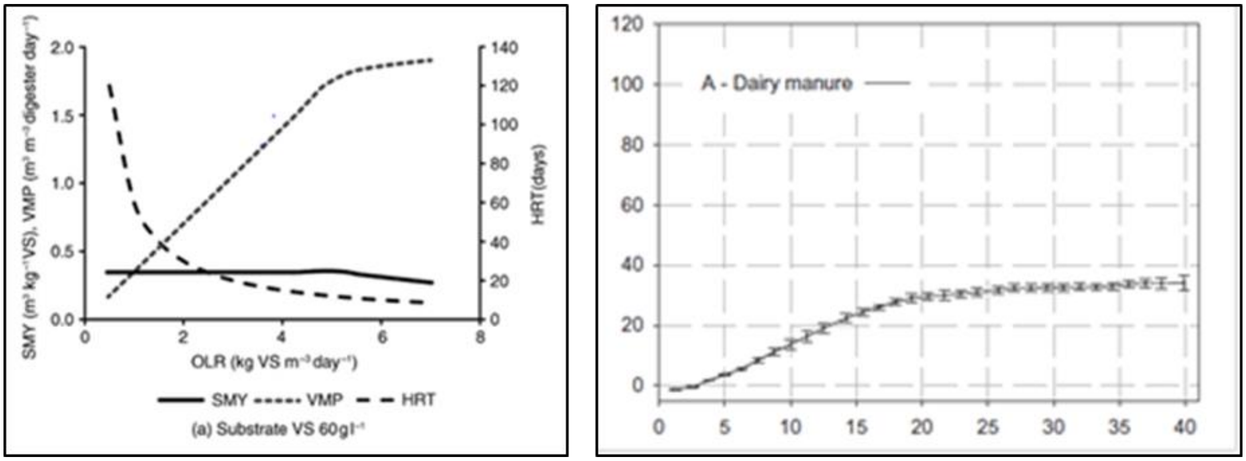


**Figure 1:** (a) Banks and Heaven (2013), showing a consistent BMP as represented by specific methane yield in the OLR range of 1-5; (b) Labatut et al (2011); biogas yield in mL against days

Two concepts to highlight, however, are the facility's choice for organic loading rate and retention time. As noted, the model BMP tests were conducted under loading conditions that would not lead to inhibition. The same needs to be true for continuous flow ADs, which Banks and Heaven (2013) confirmed for typical slurry ADs (solids retention time (SRT) = hydraulic retention time (HRT)) operating in the normal organic loading range (OLR) of 1-5 kg VS $m^{-3}$ $day^{-1}$. Put another way, Banks and Heaven (2013) show that with a generic representation of non-inhibitory feedstock (i.e. manure, bio-solids and other typical organic substrates), properly operated slurry ADs not exceeding normal range of OLR or HRT can maintain consistent BMP.

Regarding HRT, typical BMP laboratory tests are operated over 40 batch days while design retention times of most slurry ADs are 20 days. Considerable evidence with both bio-solids and dairy/swine manure is available to show that a 20 day HRT is suitable for appropriate biological growth and reaction. BMP studies confirm this by monitoring gas/methane production over a 40-day period. Gas production from bio-solids and dairy manure achieves 95% or greater of total BMP productivity by day 20 as illustrated in Figure 1 below.

Second, as with the laboratory BMPs, industrial scale, continuous flow ADs need to have adequate mixing and temperature control. Fortunately, facilities achieve this with simple mixing methodologies and thermal instrumentation of AD temperatures. In the case of ADs operating in thermophilic range, the same models apply, simply at different reaction rates.

While not peer-reviewed data such as given by Holliger at al., (2017), here attached is industrial data at one of our member facilities, highlighting dairy manure. The facility is a slurry-based, mixed plug-flow AD fed with dairy manure wastewater and a small percentage of off-farm substrates. The AD also operated under a manure-only mode, allowing determination of its actual BMP.

Table 1 is a summary of monitored parameters from the facility while Figure 2 shows daily flows and productions over its 5 years in operation. The manure-only operation (column 1) and predicted parameters using the literature BMP from Labatut et al., (2011). As can be seen from this data, the actual facility is producing more biogas (higher BMP) than the idealized BMP combined with ASABE (2005) data would predict, but results are close and well within the standard deviation. The higher results might be from residual substrate from operation prior to the manure-only data collection and/or additional gas inputs from bedding, spilt milk in the milking parlor.

**Table 1**. Outputs and flows for manure-only and co-digestion periods

| | Manure-Only Actual | Manure-Only BMP |
|---|---|---|
| Manure Flow (gpd) | 95,036 ± 30,596 | 32,143 (as-produced) |
| Substrate Flow (gpd) | --- | --- |
| Total Flow (gpd) | 95,036 ± 30,596 | --- |
| % Substrate (% v/v) | --- | --- |
| Biogas Production ($ft^3$/day) | 232,681 ± 28,724 | 211,911 ± 52,324 |
| HRT (days) | 17.4 | 30 |
| Performance ($m^3 CH_4$/kg VS) [a] | 0.266 ± 0.03 | 0.243 ± 0.06 |

gpd= gallons/day; % v/v= volumetric basis; HRT= hydraulic retention time; VS= volatile solids [a] performance determined using ASABE (2005) for manure-only and an estimated 1,800 wet cows, wet manure production of 150 lbs./cow/day, VS production of 17 lbs./cow/day; methane reported as 56.2% from n = 64 samples

Figure 2 shows fluctuation in biogas production during co-digestion, due in part to changing types and quantities of substrates and undesirable substrate storage/loading; however, the facility maintained constant manure intake from 1,800 cows with a readily identifiable, cellulosic BMP baseline. Figure 2 further shows that cellulosic testing of the substrates and/or repeated BMP testing of the constantly changing number of substrates, as done by Holliger et al., (2017), would be unnecessarily complex and arduous. The substrate component of the biogas production can be determined by simply subtracting from this baseline.

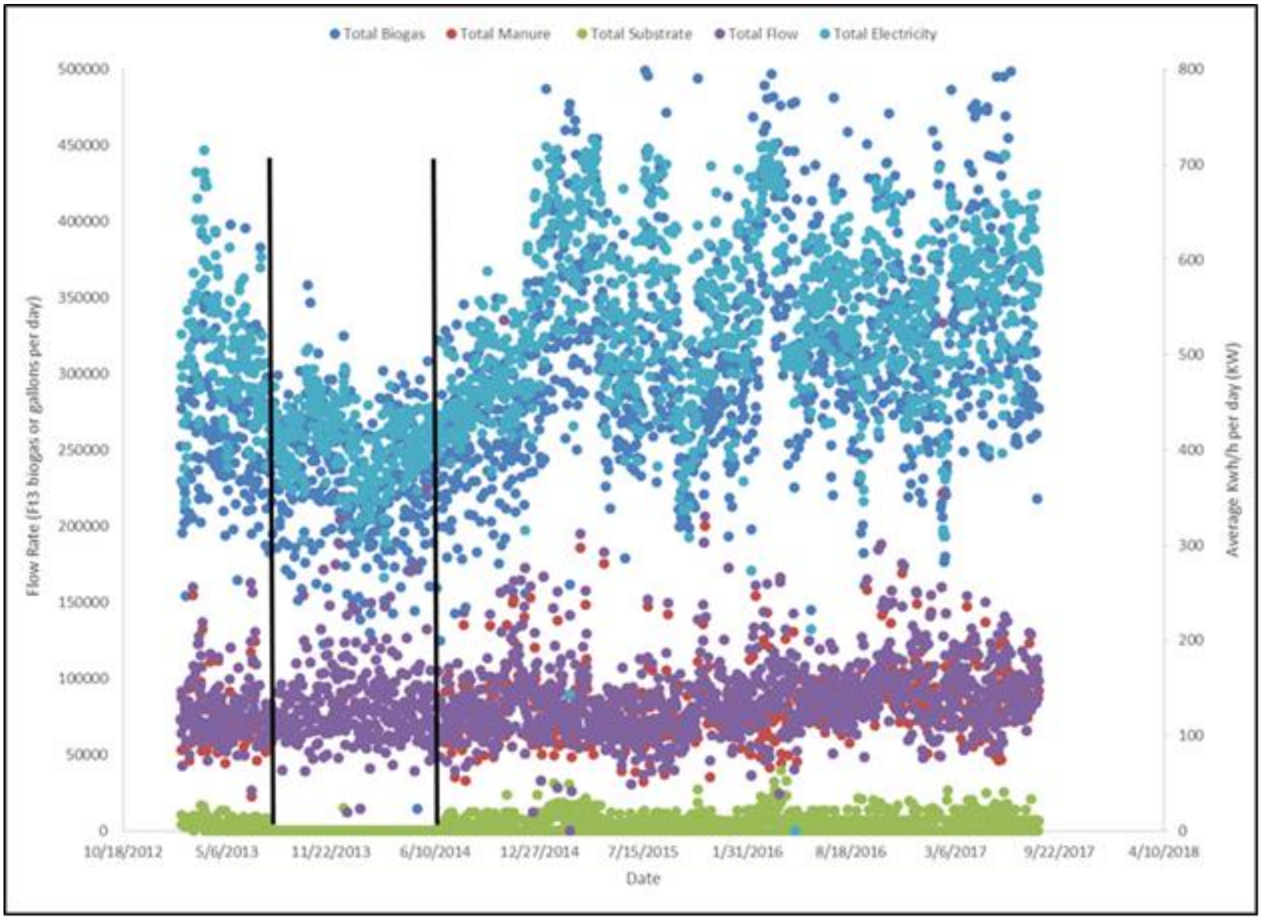


**Figure 2.** Facility flows and biogas production start-up to date (Regenis, Edaleen Dairy, Lynden WA)

**Synergisms**

Co-digestion, is a common practice within anaerobic digesters for its enhanced:

- process stability;
- remediation of inhibitory agents via dilution;
- nutrient, pH alkalinity/buffer capacity, and carbon/nitrogen (C/N) ratios;
- desired solids and/or organic loading rates;
- microbial diversity;
- project economics; and
- overall biogas production (Hagos et al., 2017).

In this section, we explore the positive or negative synergism from co-digestion (i.e., whether the biogas yield from co-digestion differs from combined single feedstock stream digestion).

Reports exist for both positive (Li et al., 2009; Li et al., 2009b; Kaparaju et al., 2005; Mata-Alvarez et al., 2000; Angelidaki and Ahring, 1997) and negative synergisms. Positive synergisms are primarily related to improved nutrient levels, pH maintenance, alkalinity/buffer capacity, and C/N ratios from co-digested feedstocks (Mata-Alvarez et al., 2011; Khalid et al., 2011). Negative synergisms, while notably less likely, occur primarily from inhibitory agents within one of the feedstocks (Chen et al., 2008).

Multiple references identify more probable neutral or non-synergistic effects. While demonstrating differences in gas production, many studies have deviations that show no statistically significant differences (Ebner et al., 2016; Jensen et al., 2014; Labatut et al., 2011). In fact, Holliger et al., (2017) state 'although synergistic effects can occur in specific cases, co-digestion most often follows the additivity principle, meaning that as much methane is produced as the sum of the methane production with the individual substrates.'

*Neutral Synergism*

For example, Labatut et al., (2011) evaluated 13 different manure co-digestion samples, and found 9 demonstrated lower biogas production, 3 were higher and 1 sample did not show statistically significant change.

Similarly, Ebner et al., (2016) reported 9 of their 13 commercial-food waste and dairy manure co-digested samples showed a slight synergistic effect, while 4 indicated a negative synergism effect. All but 3 of the samples did not show a statistically significant deviation from the weighted average of the individual substrates. Of the three statistical significant deviations, events, two were manure/food blends which led to positive synergism while the non-manure, or food/food blend, led to a negative synergism.

Jensen et al., (2014) saw no statistical difference in gas production from municipal sludge, comparing co-digestion of municipal sludge and waste glycerol to their individual weighted averages. Koch et al., (2015) demonstrated a linear relationship between methane production and degree of co-digestion with municipal sewage sludge and food waste, attributed primarily to increasing volatile solids and methane potential of the food waste. Koch et al. did not determine synergistic effects.

In these studies, BMP tests and mass balances with chemical oxygen demand (COD), and hydrolysis constant determination were used as indicators of the presence or absence of synergisms (Hagos et al., 2017). Notably, though, these studies and models cannot determine feedstock from which or to which the BMP gains can be attributed. For example, Li et al., (2009) and Li et al., (2009b), determined positive synergisms in respective digestions of manure/corn straw and manure/food waste, but could not conclusively state if manure, corn straw, and/or food waste increased biogas production and therefore increased biological degradation or if increases were attributable to an individual feedstock. Put another way, the co-digestion sample, with co-mingled data and chemical mixing, does not determine whether one or both feedstocks achieve enhanced biogas production and degradation.

In the case of manures and municipal bio-solids, synergistic effects can be determined. Both feedstocks are known for nutrient presence, near neutral pH, high natural alkalinities with numerous complex buffering agents, and moderate C/N ratios (Mata-Alvarez et al., 2011; Chen et al., 2008). Conversely, common co-digestion feedstocks such as food scraps, fats/oil/greases (FOG), and field residues have low content in these parameters as well as inhibitory agents in need of modulation.

Food scraps are of low pH, have low nutrient levels and contain FOG with inhibitory long-chain fatty acids (LCFA). Crop residues have high C/N ratios. Thus, as Mata-Alvarez et al., (2011) point out, manures and bio-solids are particularly desired as co-digestion base inputs because they contain many or most of the parameters desired for balanced digestion and/or modulation of inhibitory agents.

As manures and bio-solids provide the needed balance to other feedstocks, it is the gas productivity of these other feedstocks that is most likely to improve if in fact positive synergism is noted, not the converse. Unfortunately, as noted, existing tools and data analysis do not allow for a means to fully answer this question, or preclude the fact that the manure and/or bio-solids may in fact show some level of increased biogas production.

**In Conclusion**

ABC has proposed a simplified, workable methodology to allow AD operators to secure appropriate RIN allocations for their feedstocks. This Simplified BMP-Approach is based on easily accessible, well-established, well-documented, verifiable and current information. ADs already monitor feedstock volume/mass intake and biogas production data, as well as important operational parameters to allow simple implementation and reporting. The existing scientific literature supports the allocation approach outlined above and shows that is no significant risk that the allocation methodology will result in the misallocation of RINs. Rather, a practical approach to the allocation of RINs for ADs will ensure the continued growth of this important program.

We look forward to meeting with you in the near future to discuss this paper,

Patrick Serfass
Executive Director
American Biogas Council

CC:
Byron Bunker, bunker.byron@epa.gov
Christopher Grundler, grundler.christopher@epa.gov
Jay Bassett, Bassett.Jay@epa.gov
Melissa Pennington, Pennington.melissa@epa.gov
Karl Simon, simon.karl@epa.gov
Cheryl Coleman, Coleman.Cheryl@epa.gov
Paul Argyropoulous, argyropoulos.paul@epa.gov
Dallas Burkholder, burkholder.dallas@epa.gov

Greg Kester, CASA
Chris Hornback, NACWA
David Cox, Coalition for Renewable Natural Gas

## References

Angelidaki, I., & Ahring, B. K. (1997). Codigestion of olive oil mill wastewaters with manure, household waste or sewage sludge. *Biodegradation*, *8*(4), 221-226.

ASABE (2005). Manure production and characteristics. American Society of Agricultural and Biological Engineers, ASAE D384.2 MAR2005.

Banks, C.J. and Heaven, S. (2013). Optimization of biogas yields form anaerobic digestion by feedstock type, in the Biogas Handbook: Science, production and applications, Eds. Wellinger, A., Murphy, J. and Baxter D., Chapter 6, p. 131-165.

Bolzonella, D., Pavan, P., Battistoni, P., & Cecchi, F. (2005). Mesophilic anaerobic digestion of waste activated sludge: influence of the solid retention time in the wastewater treatment process. *Process biochemistry*, *40*(3), 1453-1460.

Cabbai, V., Ballico, M., Aneggi, E., & Goi, D. (2013). BMP tests of source selected OFMSW to evaluate anaerobic codigestion with sewage sludge. *Waste management*, *33*(7), 1626-1632.

Chen, Y., Cheng, J. J., & Creamer, K. S. (2008). Inhibition of anaerobic digestion process: a review. *Bioresource technology*, *99*(10), 4044-4064.

Ebner, J. H., Labatut, R. A., Lodge, J. S., Williamson, A. A., & Trabold, T. A. (2016). Anaerobic co-digestion of commercial food waste and dairy manure: characterizing biochemical parameters and synergistic effects. Waste Management, 52, 286-294.

Hagos, K., Zong, J., Li, D., Liu, C., & Lu, X. (2017). Anaerobic co-digestion process for biogas production: progress, challenges and perspectives. Renewable and Sustainable Energy Reviews, 76, 1485-1496.

Hills, D. J. (1980). Biogas from a high solids combination of dairy manure and barley straw. *Transactions of the ASAE*, *23*(6), 1500-1504.

Holliger, C., Fruteau de Laclos, H., & Hack, G. (2017). Methane production of full-scale anaerobic digestion plants calculated from substrate's biomethane potentials compares well with the one measured on-site. *Frontiers in Energy Research*, *5*, 12.

Holliger C., Alves M., Andrade D., Angelidaki I., Astals S., Baier U., Ebertseder F. et al (2016). Towards a standardization of biomethane potential tests. *Water Science and Technology*, *74*(11), 2515-2522.

Jensen, P. D., Astals, S., Lu, Y., Devadas, M., & Batstone, D. J. (2014). Anaerobic co-digestion of sewage sludge and glycerol, focusing on process kinetics, microbial dynamics and sludge de-waterability. Water research, 67, 355-366.

Kaparaju, P., & Rintala, J. (2005). Anaerobic co-digestion of potato tuber and its industrial by-products with pig manure. *Resources, Conservation and Recycling*, *43*(2), 175-188.

Khalid, A., Arshad, M., Anjum, M., Mahmood, T., & Dawson, L. (2011). The anaerobic digestion of solid organic waste. *Waste management*, *31*(8), 1737-1744.

Koch, K., Helmreich, B., & Drewes, J. E. (2015). Co-digestion of food waste in municipal wastewater treatment plants: effect of different mixtures on methane yield and hydrolysis rate constant. *Applied Energy*, *137*, 250-255.

Labatut, R. A., Angenent, L. T., & Scott, N. R. (2011). Biochemical methane potential and biodegradability of complex organic substrates. *Bioresource technology*, *102*(3), 2255-2264.

Li, X., Li, L., Zheng, M., Fu, G., & Lar, J. S. (2009). Anaerobic co-digestion of cattle manure with corn stover pretreated by sodium hydroxide for efficient biogas production. Energy & Fuels, 23(9), 4635-4639.

Li, R., Chen, S., Li, X., Saifullah Lar, J., He, Y., & Zhu, B. (2009). Anaerobic co-digestion of kitchen waste with cattle manure for biogas production. *Energy & Fuels*, *23*(4), 2225-2228.

Mata-Alvarez, J., Mace, S., & Llabres, P. (2000). Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource technology*, *74*(1), 3-16.

Mata-Alvarez, J., Dosta, J., Macé, S., Astals, S., (2011). Codigestion of solid wastes: a review of its uses and perspectives including modeling. Crit. Rev. Biotechnol. 31 (2), 99–111.

Speece, R. E. (1988). A survey of municipal anaerobic sludge ADs and diagnostic activity assays. *Water Research*, *22*(3), 365-372.

Vedrenne, F., Béline, F., Dabert, P., & Bernet, N. (2008). The effect of incubation conditions on the laboratory measurement of the methane producing capacity of livestock wastes. *Bioresource technology*, *99*(1), 146-155.