

## ENERGY RECOVERY FROM ORGANIC WASTE

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*One of the main environmental problems of today's society is the continuously increasing production of organic waste. Food production is achieved with significant energy consumption and waste generation on relatively large quantities. The high content of organic constituents found in this type of waste, rendering those to be suitable for regenerative bio-energy process.*

*Under the frame work of "Waste to Energy" the related study from present article focus on the energy efficiency of an industrial food provider due to energy recovery from their own waste produce, which can increase the economical savings for industrial food stakeholders.*

**Keywords:** energy recovery, organic waste, anaerobic digestion, biogas

### 1. Introduction

In many countries, sustainable waste management and prevention of accumulation and reduction of waste, have become major political priorities, and represents an important contribution to common efforts to reduce pollution and emissions of greenhouse gases and mitigate global climate change [1,2]. The continuously increasing production of organic waste is linked on the agricultural and food industries, which represents an environmental issue for today's society that has to deal with.

Under Waste to Energy (WtE) concept, food waste can be used as a rich source of energy recovery as electricity and/or heat. Food production is achieved with significant energy consumption and organic waste generation resulted from these processes is relatively in large quantities. The high content of organic constituents found in this type of waste, rendering those to be suitable for regenerative bio-energy process, where the energy recovery potential is developed through anaerobic digestion process [1,3]. This process is considered to be the optimal treatment for manure and of a wide variety of organic waste, which produce renewable energy as methane production and organic sludge suitable as fertilizer for agriculture [1,4].

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Under the frame work of waste to energy the related study from present article focus on the energy efficiency of an industrial food provider due to energy recovery from their own waste produce. The methodology approached is to evaluate the energy efficiency calculated on the amounts of generated waste and the possibility to energy recovery in suitable units to mitigate the highest value of energy efficiency. For this purpose, it was subjected the case study of Smithfield Farms nearby Timișoara area.

Findings related on present papers are reflected in the quantity of the imported energy required for industrial processes developed and economical savings that can be achieved. This will be useful for stakeholders, in order to reconsider their possibility to improve global energy efficiency upon their existing facilities.

## 2. Methane gas recovery through anaerobic digestion

The energy recovery from organic wastes is strong influenced by the active elements content of the organic waste, which, through biochemical process releases the methane gas. In order to recover the maximum potential of methane gas released from biochemical process is needed an anaerobic digestion (AD) conditions to be achieved [2,3]. Fig. 1 illustrates the four stages of AD that lead to methane production.

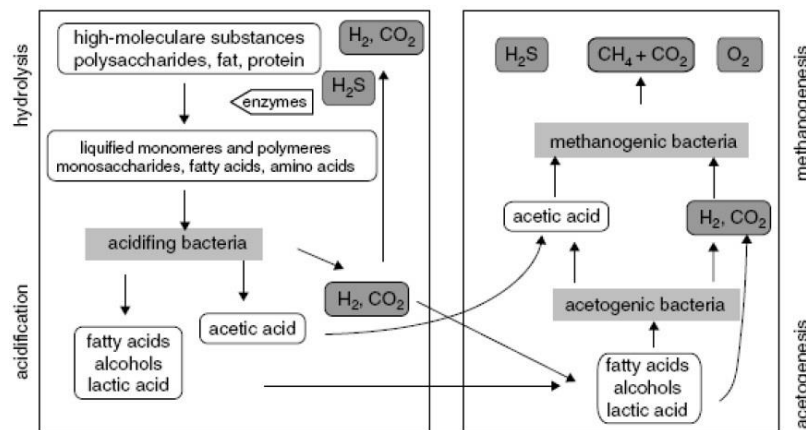


Fig.1. Methane production stages of anaerobic digestion [4]

*Hydrolysis* develops as the first stage of AD, where the organic compounds content is liquefied under enzymes influence, which transforms the carbohydrates, fats and proteins into elements like monosaccharides, fatty acids and amino acids.

This is followed by *the second stage of acidification* through metabolism influence of specific bacteria, where the preview elements are passing into short-chain saturated carboxylic acids, alcohols and carbon dioxide.

*The third stage is acetogenesis*, where the carboxylic acids and alcohols are transformed by acetogenic bacteria into saturated volatile organic acids, acetic acid, hydrogen and carbon dioxide.

*Methanogenesis is the final stage* that develops under specific anaerobic bacteria influence, which assimilates the compounds arise from preview stage, and release the methane gas.

One conclude that the AD develops in certain specific conditions under influence of acetogenesis and methanogenesis bacteria [5,6,7]. Basically, the organic waste represents the “food” to this kind of bacteria, this means that a rich content of organic compounds found in the waste, leads to high quantities of methane gas production.

The organic waste used for energy recovery is generically known as substrate. The substrates composition influences the methane efficiency and specific production rate of biogas as resulted from table 1.

Table 1

**Biogas production rates of the substrates main chemical compounds [7]**

Compound	Biogas production [L/kgods*]	CH <sub>4</sub> [% vol]	CO <sub>2</sub> [% vol]	Calorific value [kWh/kgods*]
Carbohydrates	790	50	50	4,0
Fats	1250	68	32	4,9
Proteins	700	71	29	8,0

\*ODS – Organic dry substance

The values given in table 1 indicate that the presence of biodegradable organic compounds contained into substrates leads to high methane production rates. Basically, the specific methane gas production is given by the biodegradation capacity of the substrate [8,9].

Besides methane generation, as a result from AD process, a significant quantity of sludge arises, which is a nutrient-rich material with considerable reduce pathogen load that can be used as fertilizer for agriculture crops [10]. Considering the EU legislation given by the Regulation No. 1774/2002, the AD process can be seen as a treatment method for organic wastes that are rendered as hazardous for human health and environment [11]. With a proper processing of this type of waste can be easily converted into substrates suitable for biogas production in AD process, and further on into green energy.

### 3. Energy recovery from organic waste

The substrates composition plays a key role in sizing and design of an anaerobic digestion process line. In order to create optimal condition for enzymes

and bacteria activity, temperature has an important influence upon organic decomposition. Based on this fact and economic considerations, best practice of our days AD technologies uses two ranges of temperature: 35-45°C for mesophilic digestion and 55-60°C for thermophilic digestion [12]. Previous studies on related literature show that exceeding temperature over 60°C leads to drastic decreasing production of methane gas rate [13,14].

The volume percentage of methane gas from an AD process gas is around 50-85%, depending on the hydraulic retention time (HRT), digestion temperature and organic load of the waste [1,10,12]. From energy recovery point of view, the comparison of mesophilic and thermophilic digestion based on operating and controlling parameters is given in table 2.

Table 2

**Energy recovery from mesophilic and thermophilic anaerobic digestion [12]**

Parameter	Mesophilic system	Termophilic system
Optimal temperature [°C]	35-40	55-60
pH-value	7.2-8.0	7.2-8.5
Max. allowable temperature fluctuation of the system [°C]	3-5	1-2
Hydraulic retention time [days]	15-25	3-10
Max. COD* reduction [%]	65-85	85-95
Max. BOD <sub>5</sub> ** reduction [%]	60-80	80-90
Max. organic substrates reduction	45-55	55-70
Biogas production (Nm <sup>3</sup> /1000 kg <sub>ODS</sub> ***)	920-980	950-1000
Methane gas content of biogas [%]	60-70	70-85
Volatile acid [mg CH <sub>3</sub> COOH/dm <sup>3</sup> ]	1500-2500	3000-4000
Alkalinity [mg CaCO <sub>3</sub> /dm <sup>3</sup> ]	4000-6000	3000-5000
*COD – chemical oxygen demand **BOD <sub>5</sub> – five days biochemical oxygen demand ***ODS – organic dry substance		

As it results from table 2, the biogas production is slightly higher on the thermophilic compared on mesophilic one. The main advantages of thermophilic digestion is given by shorter time for hydraulic retention and by the higher organic substrates reduction, which means that for this process is needed a lower volume for digestion reactor and a lower quantities of sludge are produced.

One conclude that thermophilic digestion produce higher quantities of biogas and requires a smaller reactor volume compared with mesophilic one, for the same composition of substrates, but requires for a higher consumption of thermal energy. Nevertheless, the mesophilic systems are most common systems used in practice.

Under energy recovery consideration, quantities of 10 to 30% from thermal and electrical energy produce by AD energy recovery unit is used for its own consumption, and the rest can be sold on energy market or used for others technological processes [1].

For an efficient energy recovery, the AD facility has to assure a constant flow of biogas in order to have a continuously operation of the combined heat and power (CHP) unit. In order to achieve this, is required to assure three basic parameters as follow: (i) complete biodegradation of the substrates, (ii) a sufficient HRT and (iii) a proper size of reactor volume. In practice, for designing of AD facility has to be done a compromise between maximum biogas productivity and economic efficiency.

Under these considerations, a key role is given by the specific load that indicates the optimal quantity of substrates that can be processed in digestion reactor correlated by HRT and the reactor volume, which can be calculated as follow:

$$SL = \frac{m \cdot c}{V_R}, [1] \quad (1)$$

where: SL – specific load of substrates, [kg/day\*m<sup>3</sup>],  
 m – substrate loading mass, [kg/day],  
 c – organic load of substrates, [%],  
 V<sub>R</sub> – reactor volume, [m<sup>3</sup>].

The anaerobic digestion reactor volume needs to be sized in order to assure the HRT required for a complete biodegradation (digestion) of the substrates. Upon this consideration, the HRT is linked by reactor volume, and can be calculated as follow:

$$HRT = \frac{V_R}{V_S}, [1] \quad (2)$$

where: HRT – hydraulic retention time, [days],  
 V<sub>R</sub> – reactor volume, [m<sup>3</sup>],  
 V<sub>S</sub> – substrate loading volume, [m<sup>3</sup>/s].

The HRT value is given by the biodegradation time of the processed substrates. Most common AD facilities are using a mixture of different substrates, with different organic loads and specific biodegradation time for each one of them. One concludes that HRT value has to be establishing upon the mixture substrates processed. When total amount of substrates are known, the HRT can be set, and further on the anaerobic digestion reactor volume can be calculated.

#### 4. Smithfield Farms – Timișoara case study

In order to highlight the energy recovery from AD process, it was subjected the case study of Smithfield Farms from Bacova near located on

Timișoara city. On studied farm is handling livestock of pigs, for reproduction and animals growing for slaughter units of food industry.

Total capacity of Bacova farm is 10 000 adult livestock and between 267800 ÷ 272950 offspring per year, from which 4277 adult livestock is delivered every year to slaughter units [15]. The technological process diagram of the Bacova farm is shown in Fig. 2.

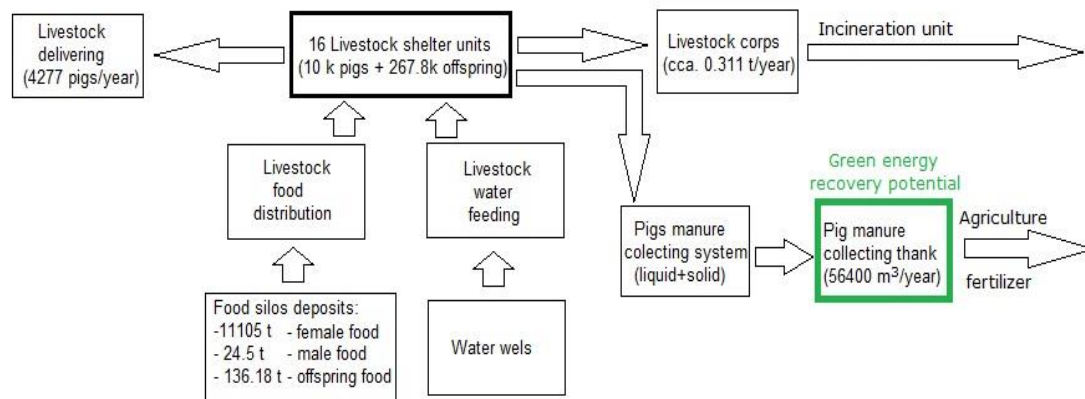


Fig.2. Smithfield Farms-Bacova Unit – process flow diagram [15]

As it results from Fig. 2 a significant quantity of pig manure is produced by farm activity, which is suitable for energy recovery through AD process. Through implementation of a unit for energy recovery based on biogas production and CHP unit, the stakeholder will gain electrical and thermal energy necessary for their own use.

According to information provided from stakeholder, the energy amount (electrical and thermal) necessary for farm production is given in table 3.

Table 3

**Energy consumption based on farms production capacity [15]**

Production		Consumed resources in order to assure production			
Livestock	Annual qty.	Energy / fuel	Quantity		Supplier
			Per year	In stock	
Pigs Offspring Pigs delivered to slaughter	216 160 4277	Electricity	2 089 178 kW	-	S.E.N
		Diesel fuel	4250 L	230 liters	ROMPETROL
		GPL	289 148 L	V1=7x5000L V2=2x5000L V3=1x4900L V4=1x2750L	GASPECO

All the consumption data are calculated according to mitigate the EU legislation given by IPPC BAT for Intensive Rearing of Poultry and Pigs [16]. As

resulted from table 3, the farm production process demands for significant energy consumption. The GPL fuel is used in order to obtain thermal energy for shelter units and as fuel for farm corps incinerator.

By implementing an AD system with energy recovery on CHP unit, thermal and electrical energy is produced, as green energy with significant overall cost reduction for imported energy that lead to substantial economic savings for the stakeholder.

### 5. Cost reduction due to energy recovery

For economic cost reduction estimation is necessary to calculate the potential of the amount of biogas that can be produced by the available substrates delivered by subjected farm, and the energy recovery into CHP unit as electrical and thermal amount. The proposed energy recovery unit is through biogas production into AD mesophilic reactor and CHP unit based on biogas fuel diesel engines.

As were previews presented, the methane production is strongly influenced by the organic composition of the substrates, organic load and HRT. The characteristics and operational parameters for most important agricultural feedstock's, suitable for AD process, can be found on previous studies on related literature as are given in table 4 [3].

Table 4

**Characteristics and operational parameters of the agricultural feedstock [3]**

Feedstock	Total Solids [%]	Volatile Solids [%]	C:N Ratio	Biogas yield <sup>a</sup> [m <sup>3</sup> /kg]	HRT [days]	CH <sub>4</sub> Content [%]
Pig slurry	3-8 <sup>b</sup>	70-80	3-10	0.25-0.50	20-40	70-80
Cow slurry	5-12 <sup>b</sup>	75-85	6-20 <sup>a</sup>	0.20-0.30	20-30	55-75
Chicken slurry	10-30 <sup>b</sup>	70-80	3-10	0.35-0.60	>30	60-80
Fruit wastes	15-20	75	35	0.25-0.50	8-20	n.a
Food remains	10	80	n.a	0.50-0.60	10-20	70-80

a – depending on drying rate; b – depending on dilution; n.a – not available

For our case study, the substrate that is used as substrate is pig manure as liquid (slurry). In order to compute the biogas estimation and energy recovery as thermal and electrical amount, we have used BioGC dedicated software [17], for accuracy and speed work.

The characteristics and operational parameters for subjected substrate were taken from table 3, and used as input data for BioGC. The resulted data are summarized in Fig. 3.

biogas calculator		costs	
<b>general information</b> Smithfield Farms - Bacova Unit - Case Study <b>initial data</b> total weight of the material: 56,400.00t engine type: gas engine engine power: 700kW		<b>CHP efficiency</b> electrical: 36 % thermal: 30 %	
<b>digester size and storage demand</b> <b>digester:</b> hydraulic retention time [days]: 30 required working digester volume [m³]: 4,635.62 volume load [kg org. DM/m³d]: 2.67 DM content of input mix: 6.00% <b>required storage volume:</b> total input [t/a]: 56,400.00 mass loss (1.25 kg/m³ BGP [t]): -2,105.60 balance [t/a]: 54,294.40 Volume for 6 month storage: 27,147.20 required storage volume [m³]: 27,147.20 Required area for land spreading [ha]: 0 (allowed kg/N per ha: 170, mass loss: 20%)		<b>energy production</b> <b>electrical efficiency:</b> $\eta_{el}=36\%$ total electricity production [kWh]: 4,548,096.00 electricity demand BGP [kWh] 20%: 909,619.19 electricity sales [kWh]: 4,548,096.00 <b>thermal energy:</b> $\eta_{th}=30\%$ total heat production[kWh]: 3,790,080.00 heat demand BGP[kWh] 20%: -758,016.00 Surplus heat[kWh]: 3,032,064.00	
<b>gas utilisation</b> biogas amount [m³/a]: 1,684,480.00 methane content [%]: 75.00% methane amount [m³]: 1,263,360.00 methane energy content [kW]: 12,633,600.00 continuous power output biogas [kW]: 519 resulting full load hours [h/a]: 6497 [h/d]: 18 corresponding load (CHP): 74.17%		<b>energy sales</b> <b>income from electricity sales</b> income from electricity sales: 1,167,496.25€ electricity demand BGP: -140,990.97€ total income electricity sales: 1,026,505.25€ <b>income</b> total income electricity sales: 1,026,505.25€ thermal energy: 151,603.20€ fertiliser value (10.00€/t N): 0.00€ total income: 1,178,108.50€ annual income: 890,227.50€	
		<b>selling prices</b> electricity: 25.67 ct/kWh heat: 5.00 ct/kWh fertiliser value: 10.00 €/t N <b>investment costs</b> interest rate: 6.50 % insurance: 0.50 % <b>other</b> electricity demand BGP: 20.00 % allowed kg/N per ha: 170.00 kg <b>investment costs</b> total core biogas plant: 1,400,000.00€ <b>running costs:</b> depreciation period (10 years): 140,000.00€ interest 1/2 ( 6.50% ): 45,500.00€ maintenance, repair ( 2.00% ): 28,000.00€ maintenance CHP ( 1.00ct/kWh ): 45,480.96€ insurance ( 0.50% ): 7,000.00€ labour costs (4.0h/d): 21,900.00€ substrate costs: 0.00€ costs ignition oil: 0.00€ total costst: 287,880.97€	

Fig.3. Smithfield Farms: Bacova Unit – economic issue

The economic parameters like costs, selling process and investments costs used for computation can be set for different values, depending by the country where the investments are made.

In order to find out the economic savings and the profit that can be achieved, on further calculation we will use the same values for economic parameters like the ones given in Fig. 3, as follows:

- costs with electric energy necessary for farm production process:

$$C_{el} = 0.155 \text{ €/kWh} * 2089178 \text{ kWh/year} = 323\,822.59 \text{ €/year} \quad (3)$$

- costs with thermal energy necessary for farm production process:

$$C_{GPL} = 0.659 \text{ €/L} * 289148 \text{ L/year} = 190\,548.53 \text{ €/year} \quad (4)$$

- total costs energy consumption for farm production process:

$$C_{Prod} = C_{el} + C_{GPL} = 514\,371.122 \text{ €/year} \quad (5)$$

- estimated total income after energy recovery unit investment:

$$I_{ER} = 890\,227.50 \text{ €/year} \quad (6)$$

- estimated profit that can be achieved after investment:



$$P_{ER} = I_{ER} - C_{Prod} = 375\,856.378 \text{ €/year} \quad (7)$$

By economic parameters values given in equation (3) ÷ (7), one conclude that the energy recovery from farms manure, it is a great opportunity for an investment, and very profitable for the stakeholders, which not only that will eliminate the costs with energy consumed for production process, but it will bring an profit if there are possibilities to sell the extra amount of energy produce.

## 6. Conclusions

The energy recovery from organic wastes is a useful technology that can be applied with success food industry facilities or agricultural farms, where the organic wastes are produce in large quantities.

The energy recovery on CHP units based on methane gas produced through anaerobic digestion is a reliable technology with an easier maintenance and relatively short period necessary for implementation. More than that, the EU legislation encourage and sustains the investments on this kind of units.

The study case of Smithfield Farms Bacova Unit, have shown the possibility for implementation of an energy recovery unit on their farm, that it will eliminate the energy costs for production process, and they will gain a considerable profit if they have the possibility to sell the extra amount of energy. For example, this can be sold on local to the Bacova village or to the national grid distribution.

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