FINAL REPORT

on the implementation of the Agreement:

Execution of industrial research during the implementation of the project "Influence of industrial wastewater and co-ferments on the process of sewage sludge digestion in the wastewater treatment plant in Henrykowo".

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1. Basis and scope of the study

This Final Report has been prepared according to the requirements of Agreement No. CON-U/0001/2018 of December 18, 2018, concluded between Miejskie Przedsiębiorstwo Wodociągów i Kanalizacji Sp. z o.o. in Leszno, as the Employer and Ekocentrum Sp. z o.o. with its registered office in Wrocław as the Contractor.
The above Agreement was signed in connection with the inclusion of the Employer in the implementation of the BEST Project, co-financed by the European Regional Development Fund. The study is a summary of all activities carried out by the Contractor under the aforementioned Agreement.
According to the Agreement, MPWiK Sp. z o.o. in Leszno entrusted Ekocentrum Sp. z o.o. with the following activities:

a) research of the area served by the wastewater treatment plant in Henrykowo[1] and the Functional Area of the Leszno Agglomeration (Obszar Funkcjonalny Aglomeracji Leszczyńskiej – OFAL) in terms of identification of entities producing industrial sewage,
b) research and examination of the market of potential suppliers of industrial wastewater and waste, which could potentially be used as substrates in the process of co-digestion (co-fermentation) of waste and sewage sludge produced in the wastewater treatment plant in Henrykowo,
c) intermediation and coordination together with mediation between the Employer and the selected entities being potential suppliers of wastewater and waste for the co-digestion process,
d) conducting pilot studies of the process of common digestion of sewage sludge and external waste.

2. General information about the BEST Project

The BEST Project is implemented under the Interreg Baltic Sea Region Programme. The name of the project is an acronym for the English full name: **B**etter **E**fficiency for Industrial **S**ewage **T**reatment.
The operational objective of the Project is to strengthen cooperation between local governments (boards of cities and municipalities), industry representatives and water and sewer system operators to promote best industry wastewater management practices.
The strategic objective of the Project is to reduce the inflow of the pollution load originating from wastewater to the Baltic Sea.

[1] The wastewater treatment plant in Henrykowo treats sewage coming and transported from the area of Leszno and a part of the Functional Area of the Leszno Agglomeration (OFAL).

The Project involves several entities: water and sewer system operators, water management associations, industrial companies, municipalities, regional authorities and research institutions, as well as expert and non-governmental organisations dealing with wastewater treatment and environmental management.

As part of the Project, local waterworks and wastewater treatment plants are to, among others, gain information about the sources and composition of industrial wastewater and the pre-treatment processes they apply. An important task is also to educate businesses and to transfer knowledge to businesses on the impact of wastewater produced in the facilities on the processes carried out in the municipal wastewater treatment plant. The aim is to develop partnership principles of cooperation based on the awareness of the consequences of actions and the responsibility of both parties for the state of the aquatic environment at both a local level (underground water, lakes, rivers) and a wider level, concerning the Baltic Sea.

3. General description of actions carried out under the Agreement

3.1. Research of the area served by the wastewater treatment plant in Henrykowo and analysis of the waste market

A database has been developed containing information on industrial wastewater and waste producers that can be a source of substrates introduced to the digestion process together with sewage sludge produced in the wastewater treatment plant in Henrykowo. The territorial scope of the research covered primarily the Functional Area of the Leszno Agglomeration (OFAL). Additionally, the developed database included also industrial plants located outside the OFAL area, but at a distance not exceeding 40 km. Potential suppliers of substrates were sought among companies and enterprises involved in food production: slaughterhouses, meat processing plants, vegetable processing plants, manufacturers of dairy products, confectioneries and bakeries. A list of municipal wastewater treatment plants producing sludge that could be received by the wastewater treatment plant in Henrykowo was also drawn up.

The database was created in several stages:

a) Stage I

On the basis of publicly available sources of information (websites of local governments, Provincial Environmental Protection Inspectorate, Internet databases of companies etc.), creation of the list of wastewater treatment plants and entities producing biodegradable waste in the OFAL area and its immediate vicinity.

b) Stage II

Pre-selection taking into account criteria such as the size and profile of production, selection of entities to which electronic surveys on the amounts and characteristics of generated waste have been transmitted. Following the sent surveys, there were telephone interviews carried out with the representatives of all plants.

c) Stage III

Based on the surveys and preliminary information, preparation of the list of entities ready to cooperate in terms of transferring waste and testing. Collection of waste samples for testing.

d) Stage IV

Signing letters of intent constituting a declaration of willingness to cooperate, when the sewage sludge digestion system at the premises of the wastewater treatment plant in Henrykowo is built.

Along with the identification of potential suppliers of waste for the co-digestion process, an analysis of the sources of industrial wastewater that could disrupt treatment processes was conducted. Given that such wastewater can be fed to the wastewater treatment plant through a sewer network, transported directly and discharged to the wastewater delivery station, the analysis was conducted for all economic entities discharging wastewater to the sewer system in the area served by the wastewater treatment plant Henrykowo. The above actions being parts of the analysis and research of the area served by the wastewater treatment plant and the waste market were carried out between December 18, 2018 and February 28, 2019, and ended with the elaboration and submission to the Employer of the Report on the analysis and research of the market of industrial wastewater and waste produced in the OFAL area.

3.2. Waste and co-digestion process testing

The tests were conducted to determine the effectiveness of the process of the co-digestion of sewage sludge and eight groups of waste obtained from producers potentially interested in transferring waste to the digestion system in Henrykowo in the future.

The analytical part of the tests was made by the laboratory of the Department of Environmental Engineering of the Częstochowa University of Technology. The selected research unit has adequate equipment, while the qualifications and experience of the personnel guarantees a high substantive level of the tests.

The location of the research laboratory allowed for delivering sludge and co-substrates in a manner that minimises the possible influence of the conditions of collecting and transporting them on the test results.

The tests were carried out from March to November 2019 and were completed with the development and submission to the Employer of the Report summarizing their course and results in December 2019.

4. Identification of sources of hazardous wastewater

To identify potential sources of threats to the wastewater treatment processes in the wastewater treatment plant in Henrykowo, the Employer made the following available to the Contractor:

a) a list of all economic entities discharging wastewater into the sewer system in the area served by the wastewater treatment plant in Henrykowo (data including the name of the entity/company, address, quantity of wastewater discharged to the sewer system in 2018),
b) results of analyses of wastewater discharged into the sewer system and delivered, carried out by MPWiK Sp. z o.o. in Leszno, as part of a routine monitoring of the quality of raw wastewater.

The conducted analysis indicated a group of Employer's customers who can produce waste that negatively affect the operation of the municipal wastewater treatment plant. The group was selected based on two criteria:

a) Quantity of the wastewater produced – only those entities which produce over 1 m^3 of waste as a daily average were taken into account,
b) Type of business activity / production.

In the case of the selection of wastewater in terms of the kind of the business carried out, the following wastewater was considered potentially problematic:

a) wastewater which may potentially contain excessive concentrations of biodegradable organic pollutants,
b) wastewater which may contain substances interfering with the operation of the activated sludge (undegradable substances that inhibit biological processes or that are toxic to micro-organisms of the activated sludge),
c) wastewater, the content of which may cause operational problems in the sewage system or in the mechanical part of the plant,
d) wastewater that may affect the quality of the sewage sludge produced by the treatment plant.

The category of entities that pose a potential threat to the operation of the treatment plant include:

a) service stations and fuel warehouses,
b) electroplating plants,
c) food industry plants (catering companies and restaurants, larger bakeries and confectioneries, butchers),
d) metal industry plants (foundries, production of machinery and equipment)
e) printing plants,
f) chemical plants, plastics factories, plants producing plastic products,

g) feed manufacturing plants,
h) municipal waste processing plant.

The list of entities producing potentially hazardous wastewater constitutes Appendix No. 1 to this report.

As part of the research of the area served by the wastewater treatment plant, also the results of tests of wastewater delivered to the treatment plant were analysed, and based on this analysis, several entities producing wastewater with the parameters significantly exceeding the permissible values resulting from the Agreement with the system operator were identified. Such excesses were noted for the following wastewater:

a) wastewater (sludge) delivered from the AGRO Rydzyna Sp. z o.o. plant Repeated testing of samples showed significant excess of such parameters as COD, BOD5, total suspended matter, nitrogen, phosphorus, ether extract. Knowing the production profile of the plant, it can be assumed that the delivered wastewater does not pose a direct threat of inhibiting the process of the activated sludge, but only causes a considerable biologically degradable load to the facility. The company is aware of the problem and shows interest in the possible future cooperation in terms of wastewater/waste delivery for the co-digestion process (signed letter of intent concerning possible future waste deliveries). Discharging highly concentrated wastewater/sludge or separated fats directly to digesters (by-passing the biological treatment line) could be beneficial for both the plant (no need for deeper wastewater treatment at the premises of the plant, avoiding any contractual penalties for discharging exceptional wastewater, lower costs of waste disposal), as well as for the operator of the treatment plant (revenues/savings due to the increased production of electricity from biogas),
b) wastewater (sludge) delivered from the plant of OSI Poland Foodworks Sp. z o.o. The tested samples show significant excess of such parameters as COD, BOD5, total suspended matter, nitrogen, phosphorus, ether extract. The wastewater is not a threat to the activated sludge process, but causes a considerable biologically degradable load to the facility. Unfortunately, the company did not express its will of cooperation in terms of future deliveries of waste to the treatment plant,
c) wastewater delivered by the MDW SA company – tests have shown that the concentrations of COD, BOD5, total suspended matter, chlorides were exceeded. The test results and the business profile of the plant (processing of waste including drilling fluids) give reasons to suspect that the wastewater may adversely affect the biological wastewater treatment processes. In the case of will to accept this wastewater to the treatment plant, it is recommended to be particularly careful and to control its parameters, and also to find out more about the plant production processes and possibly to extend the scope of the monitored parameters of the delivered wastewater,

d) wastewater from portable toilets (WC Service Sp. z o.o, TOI TOI Polska) – highly concentrated domestic sewage, no threat to biological processes, it is recommended to direct it (after mechanical pre-treatment) to the digestion process, by-passing the biological stage,

e) wastewater from meat processing plants (DANPOL Sp. z o.o., PPS Dagmara Cieślak, Zakłady Garmażeryjne SPECJAŁ, Ubojnia Sieletyccy) concentrated biodegradable wastewater, no threat to biological processes, it is recommended to direct it to the digestion process, by-passing the biological stage,

f) wastewater from the JK INTERLEATHER Jakub Derdziak company (products made of artificial and natural leathers), elevated concentrations of COD, BOD5 and chlorides were found; the threat of presence of other hazardous substances (non-monitored) characteristic to the industry of natural leather processing (chromium compounds, formaldehyde, sulphides, etc.) cannot be excluded; it is recommended to extend the wastewater testing scope.

Summary and conclusions

a) Based on the results of tests of wastewater discharged to the network and delivered wastewater, submitted by the Employer, the existence of sources of wastewater containing hazardous substances which inhibit biological treatment processes cannot be confirmed. However, it is recommended to carry out regular checks of plants indicated in Appendix No. 1, where in some cases it seems necessary to extend the scope of physical and chemical analyses conducted, adjusting them better to the business profiles of the plants. It cannot be excluded that some of the entities produce wastewater with excessive parameters in terms of indicators that are not measured as part of the monitoring studies carried out currently.

b) The problem associated with discharges of wastewater with excessive content of biodegradable substances can additionally be solved by the implementation of pre-separation of pollutants at the source by the producers and the submission of waste separately in a concentrated form (sludges, flotates) to the treatment plant in order to transfer them directly to the digestion processes – by-passing the biological treatment of wastewater using the activated sludge method. Implementation of such a system should be based on mutual benefits of the producer and the water and sewage system operator – thus, it seems necessary to use economic incentives: on the one hand, consequent checks of the quality of the discharged wastewater and increased fees if the permitted parameters are exceeded, and on the other hand, encouraging financial conditions in the case of delivering separated waste to the treatment plant that could be substrates for the co-digestion process.

5. Results of the study of substrate supply for the co-digestion process

The following table shows a summary of the results of the research carried out concerning the availability of organic waste that could constitute substrates for the co-digestion process in the treatment plant in Henrykowo.

Specification	Yearly Mg/year	Daily average Mg/d	Dry matter content %	Daily average Mg dry matter/day
Total quantity of waste confirmed with the data from the surveys	176,249	483	-	-
- including waste with a high content of fats	2,011	5.5	15	0.83
- including waste from vegetable and fruit processing	7,800	21.4	10	2.1
- including waste from milk processing	158	0.5	12	0.06
- waste from poultry farms Woźniak	126,000	345	27	93.15
Sludges from municipal wastewater treatment plants from the OFAL area	2,017	5.8	15	0.87
TOTAL	**178,266**			

As a result of the conducted research, some producers declared preliminary readiness to transfer waste for processing in the plant of MPWiK Sp. z o.o. in Leszno. These declarations have been collected in the form of letters of intent. The following table provides a summary of the entities interested in the cooperation together with the quantities of waste produced by them.

Waste producer	Declared quantity of waste Mg/year	Waste type	Waste code
Agro-Rydzyna Sp. z o.o. ul. Kolejowa 7K Kłoda 64-130 Rydzyna	625	contents of the grease trap	19 08 09
Fermy Drobiu Woźniak Sp. z o.o.	78,000 2,600	sludge from the on-site wastewater treatment plant caged chicken manure without straw	
HIPSZ Sp. z o.o. ul. Rzeczypospolitej 9 64-130 Rydzyna	200 100	marc, sludge and other waste from the processing of plant products sludges from washing, cleaning, peeling of raw materials	02 03 80 02 03 01
Spółdzielnia Mleczarska Mlekovita Production branch in Kościan ul. Wojciecha Maya 28, Kościan	260	semi-liquid fats	
Okręgowa Spółdzielnia Mleczarska Rawicz ul. Rawicka 44 63-910 Miejska Górka,	104	grease contaminants	
Przetwórstwo Farmerskie Sery Ślubowskie Ślubów 13 56-200 Góra	72	cow milk whey	
TG NOVA Sp. z o.o. ul. Przemysłowa 6 67-410 Sława	442	post-flotation sludge	02 02 04
cattle slaughterhouse in Gola Zakład Usługowo-Handlowy Krzysztof Lubik Gola 62 63-800 Gostyń	520	chyme	
Firma Marcinkowscy Sp. z o.o. Meat Processing Company Zbęchy Pole 8 64-010 Krzywiń	650	Sludge from the on-site wastewater treatment plant	
TOTAL	**83,573**		
IN TOTAL excluding waste from poultry farms Woźniak	**2,973**		

The above summaries show a considerable disproportion between the declared quantity of the produced waste and the quantity of waste declared to be delivered to the treatment plant in Henrykowo by the producers. In the opinion of the authors of this Report, one of the reasons for this situation is the current lack of the digestion system at the premises of the treatment plant, and thus, the inability to undertake immediate cooperation in terms of transfer of wastes.

In addition, it should be noted that the vast majority of the waste available for the co-digestion is chicken manure from poultry farms Woźniak. The results of tests on the co-digestion process discussed later in this Report indicate that the use of this waste as a co-substrate is possible, but to a limited extent and after taking into account economic factors.

6. Summary of pilot studies

Based on the research carried out concerning the kinds and availability of waste, eight kinds of wastes were selected, and detailed tests of the co-digestion process were conducted with the use of them. The tests used the following substrates:

a) By-product of the refining of vegetable fats (waste soap) from the BEST OIL Sp. z o.o. plants in Lasocice,
b) Waste collected in the grease trap in the internal sewage system in the milk processing plant of Spółdzielnia Mleczarska MLEKOVITA (dairy cooperative) in Kościan,
c) Waste in the form of dehydrated flotate (fats) from the TG NOVA Sp. z o.o. slaughterhouse,
d) Contents of the grease trap from the meat processing plant AGRO Rydzyna Sp. z o.o. in Rydzyna,
e) Waste in the form of dehydrated excess biological sludge from the on-site wastewater treatment plant mixed with fats separated in the plants of Zakłady Przetwórstwa Mięsnego Marcinkowscy Sp. z o.o. in Zbęchy,
f) Fruit waste from vegetable and fruit freezing plant HIPSZ Sp. z o.o. in Rydzyna,
g) Chicken manure (without straw) from poultry farms Fermy Drobiu Woźniak Sp. z o.o. in Żylice
h) Dehydrated on a belt press sludge from the municipal wastewater treatment plant in Grotniki, Włoszakowice commune.

Moreover, the following sludge from the sewage treatment plant in Henrykowo was used as the basic substrate in the digestion process: initial sludge and excess sludge, and for the inoculation of the methane digestion process in the first phase of tests, the digested sludge from the WARTA S.A. wastewater treatment plant in Częstochowa was used.

The testing scope included:

a) determination of the composition of wastes (co-substrates) and sewage sludges,
b) batch tests based on which the biogas and methane performance of substrates was determined,
c) continuous co-digestion tests in the conditions imitating the parameters of digesters planned to be built at the premises of the wastewater treatment plant in Henrykowo

In the course of the tests 2 test series were conducted. In each test series, the process was carried out in a semi-continuous manner in mesophilic conditions (36°C) at the hydraulic retention time of sludge in the reactor (HRT) of 20 days and the intensity of stirring at the level of 170 rpm. The execution of the process at the HRT of 20 days made it possible to achieve the organic waste load of the reactor at the level of approx. 1.8 kg ODM/m^3·d.

The tests were carried out in two test series preceded by a preliminary period, which included the development of the digestion process using the digested sludge from the treatment plant OŚ WARTA and raw sludge from the treatment plant in Henrykowo. In each series, the period of dosing for the common digestion (waste dosing) lasted for more than 75 days.

The co-digestion process was preceded by the digestion of the sewage sludge only. At least 20 days of the semi-continuous digestion of sewage sludge was assumed (control sample) in order to stabilise the process parameters (based on the VFA/Alkalinity ratio). Only after having achieved a stable operation of the reactor, the co-digestion mixture was introduced into the reactor, in which the addition of organic waste was gradually increased: the share of waste in the co-digestion mixture increased from 2.5 to 35-30% (converted into organic dry matter).

All used organic waste may be regarded as biodegradable waste, as the ODM/DM ratio was higher than 0.6. Due to the differences in the physical and chemical properties of the used waste, the course and efficiency of anaerobic stabilisation were different.

The results of the first test series showed the best course of the co-digestion process in the case of organic waste from the plants of Mlekovita, Agrorydzyna and Bestoil. The worst results were observed for the waste from TG NOVA, where after increasing its content in the mixture to 12.5% (converted into ODM), a decrease of both daily biogas, methane production, as well as biogas production factors (YB) and methane production factors (YM) was observed.

In the case of the co-digestion of the waste from the plants of Bestoil and Agrorydzyna, the highest degree of digestion was achieved, which in the last days of stabilisation remained at the level of 55%. For the process carried out with the addition of the waste from TG NOVA, the value of this parameter was the lowest and reached the level of approximately 40%.

The organic waste load of the reactors depended on the percentage share of organic waste in the co-digestion mixture. In the case of addition of waste at the level of 35%, the highest value of the discussed parameter, at the level of 1.8 kg ODM/m^3·d was observed for the reactor with the waste from Agrorydzyna, whereas the lowest (approximately 1.6 kg ODM//m^3·d) for the waste from TG NOVA.

The addition of organic waste to the input introduced to bio-reactors had no statistically significant effect on the methane content in the biogas generated in the co-digestion process, which ranged from 65-67%. Hydrogen sulphide was detected only in the biogas from control reactors (fed with raw sludge only without the addition of waste) and in the reactor, where the addition was the waste from the Agrorydzyna plant. Ammonia was present only in the biogas generated in the reactor fed with the waste from the Agrorydzyna plant.

The biogas production factors achieved were at the level:

a) 0.6-0.7 dm^3/kg ODM in the case of reactors fed with sludge and waste from Agrorydzyna, Bestoil, Mlekovita.

b) 0.4-0.5 dm^3/kg ODM in the case of the reactor fed with sludge and waste from TG Nova and control reactors (fed with sludge only).

The above factors relate to the co-digestion mixture of sludge and waste. The calculation indicators of biogas production in relation to pure substrate are determined in the table below:

Calculations of the biogas production converted into g ODM of waste – series 1				
Waste type	**Share of waste in the co-digestion mixture % ODM**	**Observed biogas production factor of the co-digestion mixture l/g ODM of mixture**	**Observed biogas production factor in control reactors l/g ODM of sludge**	**Computational biogas production factor of waste l/g ODM of waste**
Mlekovita	35	0.590	0.411	0.924
Agrorydzyna	35	0.645		1.079
TG Nova	35	0.406		0.398
Bestoil	35	0.679		1.178

Throughout the series there were no disruptions of the digestion process recorded, which is confirmed by the following factors:

a) the ratio of volatile fatty acids to alkalinity VFA/Alkalinity was below 0.3,

b) pH ranged between 7.5 and 8.0,

c) the level of ammonia nitrogen in the sedimentary water has never exceeded 1,000 mg/dm^3.

The results of the second test series generally showed a lower efficiency of the co-digestion of waste than in the first series. This was manifested by a lower biogas production and a lower degree of digestion. At 40% share of waste in the mixture fed into the reactor, the highest values of the daily production of biogas and methane as well as biogas and methane production factors were obtained for the process carried out with the addition of chicken manure, whereas the lowest – for the co-digestion of aerobically stabilised sludge. During the co-digestion of chicken manure with municipal sewage sludge, also the highest degree of digestion was achieved (about 45%). There was also a negative effect noted of the addition of the chicken manure and waste from HIPSZ on the content of methane in biogas, which decreased together with the increase in the addition of the discussed waste in the co-digestion mixture, and was around 61%.

The biogas production factors obtained ranged from 0.35 to 0.5 dm3/kg ODM.

The above factors relate to the co-digestion mixture of sludge and waste. The calculation indicators of biogas production in relation to pure substrate are determined in the table below:

Calculations of the biogas production converted into g ODM of waste - series 2				
Waste type	**Share of waste in the co-digestion mixture % ODM**	**Observed biogas production factor of the co-digestion mixture l/g ODM of mixture**	**Observed biogas production factor in control reactors l/g ODM of sludge**	**Computational biogas production factor of waste l/g ODM of waste**
Marcinkowscy	40	0.427	0.441	0.375
Aerobically stabilised sludge	40	0.410		0.333
HIPSZ	40	0.455		0.445
Chicken manure	40	0.449		0.431

Throughout the series there were no disruptions of the digestion process recorded: the ratio of volatile fatty acids to alkalinity VFA/Alkalinity was below 0.3, and pH ranged between 7.6 and 7.8. Significantly higher values of ammonia nitrogen level in sedimentary water were recorded: from about 1,000 mg/dm^3 to almost 1,500 mg/dm^3 (in the case of 40% share of chicken manure).

The BMP tests showed the highest methane production factor Y_M values, at the level of 0.8 l/g ODM for the wastes from Mlekovita and Agrorydzyna, whereas the lowest – for the waste from TG NOVA and aerobically stabilised sludge, for which the methane potential value did not exceed 0.2 l/g ODM.

Summary and conclusions

1. Almost all tested wastes demonstrated susceptibility to degradation under anaerobic conditions and their addition did not interfere with the sludge digestion process. The exception was the waste from the TG Nova plant, for which a decrease in the biogas production was observed while increasing the dose of that waste above 12.5%.
2. During the tests, with a gradual increase of the load of waste, a stable course of the process with the share of co-substrates at the level of 35-40% (converted into organic dry matter) was achieved.
3. Definitely the best results were obtained in the first test series in the case of the co-digestion of wastes containing mainly fats and its derivatives (Agrorydzyna, Bestoil, Mlekovita). In the case of those wastes, a marked increase in the biogas production factor was observed (in relation to control reactors) with no adverse side effects: a high degree of digestion, low level of ammonia nitrogen in sedimentary water were maintained. The process did not show a tendency to acidification.
4. Among the tested substrates, definitely the worst results were obtained in the case of dosing the waste from the TG Nova plant and aerobically stabilised sludge: low rates of digestion and biogas production.
5. The test results obtained in the case of the co-digestion of chicken manure showed a high degree of digestion with the simultaneous highly variable biogas production factor. In this case, also an increase in the concentration of ammonia nitrogen in sedimentary water was noted. The process of the co-digestion of chicken manure should be assessed also as the least stable.

6. Recommended types and dosages of co-substrates

The test results showed that it is possible to maintain a stable digestion process with co-substrates at the level of 35-40% converted into organic dry matter. The process was carried out under laboratory conditions and each time only one substrate was co-digested in a given reactor. The co-substrate load was increased gradually, allowing the bacteria to adapt to the new environmental conditions.

Technically, it is not possible to maintain such conditions of operation of digesters: there is a greater volatility of sludge and waste loads (quantity and type); moreover, a mixture of substrates will be co-digested.

Therefore, assuming the safety margin, it is recommended to assume a maximum safe dosage of co-substrates at the level of 25% ODM fed to the digesters.

The following table shows the target balance of sludge (without co-digestion) for the wastewater treatment plant in Henrykowo[2].

Sludge type	Daily quantity of sludge kg DM/d	Content of organic fraction [3] %	Daily quantity of organic fraction of sludge kg ODM/d
Primary sludge	4,000	75	3,000
Excess sludge	4,250	67	2,848
In total	8,250	-	5,848

Assuming 25% share of co-substrates in the digestion mixture, the computational amount of dosed external substrates is 1,460 kg ODM/d.

Adopting the following averaged parameters of the wastes delivered:

- the content of dry matter in the delivered waste at the level of 15%,
- the content of organic fraction in waste at the level of 80%,

the obtained daily amount of wastes received by the treatment plant is at the level of approx. 12 Mg/d.

When comparing the above value with the results of the waste availability research, it can be seen that providing a waste stream of this size is feasible. According to the declarations obtained, about half of the demand could be covered by the supply of waste showing the highest efficiency in the co-digestion process (waste with a high fat content, dairy waste). The number of animal processing plants within the radius of up to 50 km from Leszno is large, but not all companies showed interest in the possible cooperation and responded to the sent surveys. It should be assumed that if the digestion plant is built and there is a real willingness on the part of the Employer to accept waste, there would be a greater interest in the delivery of waste from industrial plants.

In summary of the above considerations, it is proposed to make the following assumptions about the quantities and types of waste accepted into the system:

a) The digestion plant on the premises of the wastewater treatment plant in Henrykowo should be able to provide supplies with its own sludge in the amount of about 5,850 kg DM/d and additionally with

[2] Source: Multi-variant concept of modernisation and expansion of the wastewater treatment plant in Henrykowo author: Biuro Projektów Budownictwa Komunalnego we Wrocławiu Sp. z o.o.
[3] Average value of the results of analyses conducted in the course of the co-digestion process tests.

the external waste in the amount of up to 1,500 kg DM/d (about 12 Mg/d of waste with 15% DM and an organic fraction of 80%),

b) It is recommended to accept, first of all, waste with a high fat content for the co-digestion process (waste from cleaning grease traps in animal processing plants, milk processing plants, separators from bakeries, confectioneries etc.). Such waste gives the largest increase in the biogas production, shows a high degree of digestion (which results in the smallest increase in the weight of the digested sludge), does not burden the treatment plant with a secondary biogen load. The biogas produced from them has a high content of methane and is not polluted with hydrogen sulphide.

c) If it is not possible to cover the entire demand for the above waste, accepting the following to the co-digestion plant should be considered in the second place:

- sludge from on-site wastewater treatment plants from meat processing; such sludge usually contains a mixture of biological sludge and separated fats. Care must be taken to ensure that the received waste does not contain category 1 or 2 waste materials (which require special treatment in the processing operations), while category 3 materials (animal by-products originating from animals which do not show any disease symptoms) may be accepted,
- waste from the processing of fruit and vegetables – the problem here may be the campaign nature of the production of this waste and the inability to ensure a constant stream of supply with a stable quality,
- waste from milk processing (waste whey, products not meeting quality standards, etc.).

d) The waste which is also worth considering if there are technological reserves of the digestion plant include:

- by-products from the refining of vegetable oils of the Best Oil plants. This substrate showed a very high efficiency of the biogas production and no adverse side effects. However, the purchase price of the substrate may be a problem in this case because, according to the verbal information obtained from plant representatives, the by-product used in the research is eagerly purchased by agricultural biogas plants. The decision to use this substrate should be made after a thorough economic viability analysis, in which the purchase price of the substrate is given as the basic data,
- caged chicken manure (without straw): also, in this case, the necessity to bear costs of purchase must be expected, as this waste is eagerly bought by farmers as a valuable fertiliser. In addition, the digestion of chicken manure introduces large amounts of biogens into sedimentary water, which cause a secondary burden to the sewage line of the treatment plant. The unquestionable advantage of this substrate is that it is easily available: it can be obtained from poultry farms in constant and

virtually unlimited quantities. However, it is not recommended for this substrate to constitute more than a few percent of the total weight of co-substrates.

e) It is not recommended to accept sewage sludge from other wastewater treatment plants for the co-digestion process. Such a substrate was initially considered by the Employer and one of the objectives of the research was to verify the effects obtained with its use. Available literature data and operational experience of other operators indicated rather small effects in the form of an increased biogas production. The tests carried out under the Agreement have fully confirmed this: biological excess sludge (usually aerobically stabilised in small wastewater treatment plants) is an inefficient source for the biogas production, a small degree of digestion is obtained. Such waste is basically a ballast for the digester and it is not reasonable to introduce it in its raw form. The effects of the digestion could be increased by using the process of disintegration of the excess sludge – both for the sludge produced in Henrykowo and delivered from external sources. The application of such a process would entail high investment costs, including associated costs for pre-treatment facilities (in particular nitrogen removal) of leachate generated while dewatering the digested sludge.

7. Technical analysis of the waste reception capacity

Currently, the wastewater treatment plant in Henrykowo does not have a plant for anaerobic waste stabilization with the possibility of using the generated biogas. The sludge treatment process is limited to pre-thickening, digestion in an open digester and final dewatering. The dewatered sludge is temporarily stored on the premises of the treatment plant and then driven out of the facility for its final disposal.

However, the Employer plans to expand and modernise the facility, which will include the construction of Closed Separate Digesters (WKF) and facilities for the collection, storage and treatment of biogas. The resulting biogas will be used to supply co-generation units producing electricity and heat.

In order to enable the reception of external waste into the co-digestion process, it is necessary to build an additional, dedicated technical infrastructure and to design sludge and gas management facilities taking into account the increased quantities of sludge and biogas.

Additional facilities to be designed for the external waste reception:

a) Waste collection point

A facility consisting of a bunker/charging hopper equipped with a safety grid and screw conveyors installed at the bottom to transport waste to the buffer tank. The charging hopper should have an active capacity to accommodate the entire single waste transport. It is assumed that a capacity of 10-15 m^3 would be sufficient for this purpose. In order to reduce odour nuisance, the tank should be

closed with an airtight cover that can only be opened for the time of the discharge of waste. The gas space of the tank should be ventilated and the ventilation air should be discharged to the biofilter.

b) Waste buffer tank

This tank would receive the waste from the waste collection point and possibly directly liquid waste. The tank must be equipped with a waste mixing and dilution system. It is assumed that for dilutions, process water and warm digested sludge discharged from the WKFs will be used. The active capacity of the tank should enable the accumulation of a few days' portion of waste, ensuring the possibility of averaging its composition and even dosing into the chambers. It is assumed that with an expected daily amount of waste of 12 Mg/d, the buffer tank should have an active capacity of about 50 m^3.

c) System for dosing waste into the WKFs

Such a system should include a macerator and a pump enabling pumping of a medium with a density of up to 10% DM. The proposed place of introduction of waste into the digestion system are the heating circulation pipelines of the chambers behind heat exchangers.

d) A biofilter should be provided as an accompanying structure to the above-mentioned systems to purify the air of the gas spaces in the collection point and the buffer tank.

When designing WKFs for a 20-25 day retention period, an additional volume of waste introduced into the process should be taken into account. Assuming that waste with a dry matter content of about 15% is accepted, it should be presumed that it has to be diluted in order to bring it to a relatively easily pumpable consistency (the content of solid fractions in the waste introduced into the chambers should not be higher than 10% DM). Therefore, it can be assumed that with a delivery of about 12 Mg/d of waste, after its dilution, the additional volume of the medium introduced into the chambers should not exceed 20 m^3. This is a relatively small volume when compared to the planned volumes of raw sludge to be pumped, according to the concept of expansion:

- 80 m^3 of thickened primary sludge (5 % DM)
- 85 m^3 of thickened excess sludge (5 % DM).

The gas management facilities should be prepared for the additional biogas production. The estimated additional amount of biogas produced as a result of accepting co-ferments is[4]:

1,460 kg ODM/d x 1.0 Nm^3/kg ODM = 1,460 Nm^3/d.

This additional amount of biogas should be taken into account when designing the biogas tank, desulphurisation and siloxane removal plant as well as co-generation units.

[4] The biogas production factor adopted as for fat waste at the level of 1.0 m^3/kg ODM of the waste introduced to the WKFs. This value is consistent with the literature data and confirmed by the tests carried out under the Agreement.

8. Economic analysis of the co-digestion process introduction

Revenues and main costs related to the reception of waste into the co-digestion process were analysed. For the purpose of the economic analysis, the following assumptions were made:

a) The cost of transport is covered by the waste supplier,
b) Waste is accepted into the system free of charge,
c) Electricity price 0.4 PLN/kWh
d) Dose of flocculant for dewatering 8 g/kg DM
e) Price of flocculant for dewatering 12 PLN/kg
f) Cost of the final disposal of dehydrated sludge 120 PLN/Mg

Projected revenues

a) Revenue from waste reception fees

   No revenue assumed – waste reception free of charge

b) Revenue (savings) from the production of additional electricity from biogas

   - additional biogas production 1,460 Nm^3/d
   - biogas calorific value 6.4 kWh/Nm^3
   - electrical efficiency of co-generation units 38%

   The amount of additional electricity produced

   1,460 Nm^3/d x 6.4 kWh/Nm^3 x 38% = 3,550 kWh/d

   The amount of savings from the electricity production

   3,550 kWh/d x 0.4 PLN/kWh = 1,420 PLN/d = **518,300 PLN/year**

c) Revenue from the production of heat in co-generation – savings on the purchase of fuel (LPG) will only occur if it is necessary to use all the heat generated e.g. in the case of sludge drying.

   - additional biogas production 1,460 Nm^3/d
   - biogas calorific value 6.4 kWh/Nm^3
   - heat efficiency of co-generation units 42%

   The amount of additional thermal energy produced

   1,460 Nm^3/d x 6.4 kWh/Nm^3 x 42% = 3,924 kWh/d

   - LPG price 1.25 PLN/l
   - 1l of LPG mixture (50/50%) is an energy carrier in the amount of 25.19 MJ/l (7.0 kWh/l)

   Savings by not having to purchase LPG

   3,924 kWh/d / 7.0 kWh/l x 1.25 PLN/l = 700 PLN/d = **255,500 PLN/year**

Projected costs

a) Costs of dewatering

- additional load of DM at the input to the WKF 12 Mg/d x 15% = 1.8 Mg DM/d

- organic fraction 80%, 1.44 Mg ODM/d

- projected degree of digestion 55% ODM

- additional amount of DM load after digestion (1.8 – 1.44) + 1.44 x (100-55)% = 1.008 Mg DM/d

Additional flocculant consumption

1,008 kg DM/d x 8 g/kg DM = 8.064 kg/d

Cost of additional flocculant

8.064 kg/d x 12 PLN/kg = 97 PLN/d = **35,405 PLN/year**

b) Costs of the final disposal of sludge

- assumed content of DM in the dehydrated sludge 22%

The additional amount of sludge to be disposed

1,008 kg/d x 100 / 22 = 4,582 kg/d = 4.58 Mg/d

Costs of the final disposal of additional sludge

4.58 Mg/d x 120 PLN/d = 549.6 PLN/d = **200,604 PLN/year**

Summary of revenues and costs

Specification	**Value per year** **PLN per year**
Revenues	
Waste reception fees	0
Value of electricity produced	518,300
Value of heat energy produced	255,500
Costs	
Costs of dewatering	35,405
Costs of the final disposal of sludge	200,604
Annual operating profit	**282,289** (without heat production) **537,791** (with heat production)

9. Formal and legal conditions related to the co-digestion process introduction

The implementation of the co-digestion process involves accepting waste and processing it in the system and requires an appropriate administrative decision – a waste treatment permit. Such a requirement results from the Waste Act (Journal of Laws 2019.0.701).

This study assumes that only waste which is not subject to the requirements of European Commission Regulation No. 142/2011 of February 25, 2011 implementing Regulation No. 1069/2009 of the European Parliament and of the Council laying down health rules concerning animal by-products not intended for human consumption will be accepted to the co-digestion system.

In view of this assumption, it is acceptable to receive category 3 zoonotic materials (animal by-products originating from animals which do not show any disease symptoms).

For the reception of category 1 and 2 waste, additional waste pre-treatment processes (pasteurisation) would have to be applied at the entrance to the system, which would significantly complicate the layout of the system and increase investment and operating costs.

10. Operational guidelines

When implementing the co-digestion process, it is recommended to follow the operational guidelines presented below:

a) The start of external waste dosing should be preceded by obtaining a stable course of the sewage sludge digestion process. This is determined by the VFA/Alkalinity ratio < 0.3, degree of digestion close to 50%, stable biogas production, no foaming of the WKF content

b) The dosing of waste should be done with a gradually increasing dosage so that the fermentation bacteria can adapt to the new substrates. It is recommended to start dosing at the level of 1-2% ODM, increasing the dosage by 1-2% ODM every week. Having reached the target dose, it is recommended to maintain a stable dosage of waste. In this context, it is important to sign a properly formulated contract with the waste supplier that would guarantee a correct delivery schedule. It is also important to have the capacity of the buffer tank to accumulate a few days' supply of waste.

c) The dosing of waste should be done daily in small portions: the daily dose should be divided into 2-3 smaller portions. Too high a single dose may result in a rapid increase in the biogas production and foaming in the WKF.

11. Summary and final conclusions

1. The research of the supply of biodegradable waste in the OFAL area and its surroundings initially showed the possibility of supplying the planned digestion system in Henrykowo with waste in sufficient quantities to safely implement the process of the co-digestion of sewage sludge and industrial waste.
2. The recommended substrate to be used in the co-digestion process is waste containing fats.
3. It is not recommended to use aerobically stabilized sewage sludge as a substrate in the co-digestion process.
4. The implementation of the co-digestion process in the wastewater treatment plant in Henrykowo may generate several hundreds of zlotys of operating profit per year.
5. The profitability of the process is influenced by:

   - purchase costs of electricity – higher energy costs mean greater savings because of self-produced energy (observed trend of rising energy prices)

   - actual costs of the final disposal of sewage sludge – higher disposal costs reduce operating profit from co-digestion (an upward trend in the prices of sludge disposal services is observed),

   - final arrangements between the producer and the recipient concerning the commercial conditions for the transfer of waste (which party bears the transport costs, whether the acceptance of waste involves charging the producer or vice versa – the recipient pays for the waste as for “raw material” for the energy production).

12. Appendices

1. Appendix No. 1. Summary of economic operators producing wastewater that could interfere with the operation of the wastewater treatment plant in Henrykowo