I.FAST

Innovation Fostering in Accelerator Science and Technology

Horizon 2020 Research Infrastructures GA n° 101004730

MILESTONE REPORT

Approval of basic engineering

VALIDATED BY DESIGN OFFICE

MILESTONE: MS59

Document identifier:	IFAST-MS59
Due date of deliverable:	End of Month 24 (April 2023)
Report release date:	30/04/2023
Work package:	WP12: Societal Applications
Lead beneficiary:	INCT
Document status:	Final

ABSTRACT

The main result of the task reported in MS59 is approval of basic engineering validated by design office. Basic engineering has been based on documents elaborated by licensed designers according to the requirements of construction permit following Polish Law, adopting Environmental Impact Assessment (EIA) Directive (2011/92/EU as amended by 2014/52/EU), Assumptions for basic engineering were elaborated and are reported in DELIVERABLE: D12.2 report which cover laboratory research with use of two types of electron accelerators. The technology has reach TRL4 at this stage. Basic engineering covers all technological and technical aspects of both systems two stage biogas plant equipped in electricity generator and sludge hygenization installation equipped in an electron accelerator. The final product of the system is safe organic fertilizer based on WWTP sludge. Electricity supply for the accelerator is provided from generator using biogas as a fuel. Development technology solves ecological problem related to the hazard waste disposal and follows EU Circular Economy principle. In the era of circular economies, municipal wastewater treatment plants (WWTPs) are viewed as resource recovery facilities.

For more information on IFAST, its partners and contributors please see https://ifast-project.eu/

This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730. IFAST began in May 2021 and will run for 4 years.

Delivery Slip

	Name	Partner	Date
Authored by	Andrzej G. Chmielewski Andrzej Pryzowicz, Zbigniew Zimek et al.	INCT Biopolinex Co.	07.04.2023
Reviewed by	M. Vretenar [on behalf of Steering Committee]	CERN	
Approved by	Steering Committee		

TABLE OF CONTENTS

1 INTRODUCTION......4

2 DESIGN OF IRRADIATION MODULE OF ADVANCED ELECTRON ACCELERATOR PLANT FOR BIOHAZARDS TREATMENT......5

2.1 CONTENT OF THE DOCUMENT 5
2.2 ACCELERATOR SELECTION CRITERIA 5
2.3 PERFORMANCE OF THE INSTALLATION 7
2.4 ACCELERATORS FEASIBLE FOR APPLICATION IN THE TECHNOLOGICAL LINE 9

3 BIOGAS MODULE DESIGN......11

3.1 OTHER COMPONENTS OF BASIC ENGINEERING 14
3.2 ENVIRONMENTAL IMPACT ASSESSMENT 15

4 ANNEXES 15

5 CONCLUSIONS 15

6 REFERENCES......16

Executive summary

Basic engineering has been based on documents elaborated by licensed designers according to the requirements of construction permit following Polish Law, adopting Environmental Impact Assessment (EIA) Directive (2011/92/EU as amended by 2014/52/EU), has been elaborated and is attached to this Report.

Basic engineering prepared by Biopolinex Co was prepared using result of the INCT research and prepared assumption and join works on biogas plants and is called 'zero energy' sludge hygienization technology.

According to the invention, biomass originating from waste prior to its fermentation or digestate derived in the process of methane fermentation is irradiated with Ebs that use energies preferably in the range of 1–3 MeV. The selection of electron accelerators is based on their technical parameters , electrical efficiency, reliability and price. Power (beam current) is related to yield of the installation using municipal WWTP sludge as substrate.

The technology reached TRL4 level and basic engineering is needed to move it to the TRL5 which require construction of the pilot plant in real technical environment i.e. on the promises of municipal WWTP.

1 Introduction

This Milestone Report is related to DELIVERABLE: D12.2 Report "The Basic engineering of e-beam sludge processing line" at which laboratory research and technology concept were presented. Technology was validated in lab and reached TRL 4, multiple component pieces were tested with one another , therefore we may consider that this level has been achieved. Therefore basic engineering approved by licensed engineers is a key to move to next level TRL5 – Technology validated in relevant industrial environment TRL 5 is a continuation of TRL 4, however, a technology that is at 5 is identified as a breadboard technology and must undergo more rigorous testing than technology that is only at TRL 4. Basic engineering has been elaborated by Biopolinex Company and validated by design office certified engineers. Biopolinex Co. is a company which implements new biogas technologies targeted towards applications at municipal wastewater treatment plants, which are a large supplier of biomass in the form of generated sludge, hence Biopolinex Co. uses its knowledge and experience and in cooperation with the Institute of Nuclear Chemistry and Technology deals with the development of new solutions for this sector of the economy. Currently, purification costs are incurred for the processing and utilization of sewage – sewage sludge. The technology offered enables us to generate revenues from waste water treatment. The company is a co-author of this solution. Basic engineering :Development of design basic engineering for the use of an advanced installation using a biogas module and an advanced module with an electron accelerator to remove biological hazards" .contain two main parts "Basic engineering of irradiation module of advanced electron accelerator plant for biohazards treatment" and "Biogas module". In case of the use of ionizing radiation to hygienize sewage sludge, an electron accelerator seems to be a better solution in comparison to isotope gamma sources, however such a choice requires a low-cost electricity supply, which is very important for the profitability. This can be solved by biogas production and electricity generation on site. The concept of so called "zero energy technology" combining electron beam sludge treatment technology with biogas production in an industrial plant that is equipped to generate electricity to power the accelerator has been elaborated in the frame of the INCT project. Work performed concerned processing line concept, based on laboratory studies, and development of assumptions for industrial electron accelerator based sludge processing unit.

2 Design of irradiation module of advanced electron accelerator plant for biohazards treatment

2.1 CONTENT OF THE DOCUMENT

The study concerns a radiation module equipped with an electron accelerator working with a biogas plant with a biomass throughput of 22300 t per year and an average dry matter content of 7.4%. The study includes:

- Determination of the geometry of the radiation treatment process,
- Determining the optimal parameters of the accelerator,
- Selection of accelerators that meet the requirements,
- List of accelerator manufacturers to collect offers,
- Determination of service requirements (frequency of replacements, cost of spare parts, service time),
- Determining the requirements for the room where the accelerator will be installed,
- Determining the requirements for the employment of personnel operating the accelerator,
- Preliminary determination of operating, unit and investment costs of the radiation installation

2.2 ACCELERATOR SELECTION CRITERIA

Although there are many different types of accelerators offering a wide range of performances ratings, only few would be suitable for particular application (Marshall R. Cleland, 1992). The most important tool for each application is not the accelerator but the beam. Radiation facility must satisfy the beam specifications for a given application.

Criteria of selection:

Fundamental accelerator parameters

The basic requirements which define technological abilities and facility productivity

Are electron energy and average beam power.

Terms of accelerator purchase

Economical aspects of accelerator purchase which define investment and exploitation costs; period of time needed for facility completion: price, producer, terms of delivery and installation, warranty conditions, exploitation cost.

Auxiliary accelerator parameters

Auxiliary parameters which may characterize accelerator quality and provide necessary data for facility design: scan performances, auxiliary parameters, measure and control, main components and systems and accelerator external supply service. General requirements are listed below:

- Product to be radiation treated dimensions, densities and throughputs;
- Operation schedule and seasonal requirements;
- Vertical or horizontal beam direction;
- Reliability of the accelerator (availability);
- Remote accelerator operation;
- Factory assembling test;
- Warranty conditions;
- Post warranty service;
- Staff training;
- Facility certification (equipment, safety, personnel).

Advantages of certain accelerator selection (low risk decision):

- Proven accelerator technology;
- Simplicity of construction;
- Long life power components (klystron, tetrode);
- High parameters stability;
- High beam power;
- Narrow energy spread;
- Wide range of power adjustment;
- Computer supported control system;
- Low accelerator cost;
- Low exploitation cost;
- High quality maintenance service.

2.3 Performance of the Installation

The module equipped with an electron accelerator is designed for radiation treatment of biomass used in a biogas plant for methane production. The design of the radiation module is based on the output data presented below:

- Radiation-based sludge hygienization plant capacity of 18 tons per hour (22300 tons per year),

- Target operating time of 8000 hours per year,

- Sludge density of 1 t/m^3,

- Dry matter content of 7.4% on average,

- Expected irradiation dose of 6 kGy,

- Tank capacities at the inlet 7pprox.. 300 m^3,

- The tank at the radiation facility outlet,

- Formation of sludge layer with a thickness of about 0.8 cm,

- Belt conveyor for radiation treatment of biomass.

To meet the requirements of the radiation treatment process, the basic parameters of the electron accelerator were determined. The basic parameters of the radiation installation are presented in Table 1.

Table 1. Basic accelerator parameters for the radiation installation.

Parameter	Value
Electron energy	2.5 MeV
Beam power	50 kW
Width of scanning	160 cm
Beam current	20 mA
Dose	5-7 kG
Distance window-product	20 cm
Ti window thickness	50 µm

Assuming the useful area of radiation treatment, defining the depth at which the depth dose is equal to the surface dose, the thickness of the useful layer of the order of 8 mm was obtained in this case. Beam power losses related to the specified range of the electron beam (greater than the useful range) were assessed as not greater than 20%.

In technical terms, for the average beam power of 50 kW and electron energy of 2.5 MeV, it is possible to limit the scanning width to 80 cm, which would bring significant technological advantages. Considering a compromise solution, it is worth considering the case of a scan width of 120 cm. The possibility of adopting a scan width of 120 cm should be confirmed by the accelerator manufacturer, combined with the possibility of assessing the impact on the lifetime of the accelerator output foil. Maintaining the efficiency of the installation while reducing the scan width of the beam from 160 cm to 120 cm is associated with limiting the width of the biomass transport system and increasing the linear speed of the conveyor from 24.3 m/min to 32.4 m/min. If the 160 cm wide electron beam sweeping system offered by the accelerator manufacturer is maintained, a technically feasible variant of the accelerator operation may be to reduce the current amplitude in the beam scanning electromagnet to obtain a scan width of 120 cm.

The idea related to the processing line is presented in Fig.1. The pipe system forms labyrinth and can be directly used for sludge transport. In such case intermediate tank is not necessary, and sludge piston pumps and nozzles should create the system capable form sludge layer 8 mm thick with necessary linear speed under pressure provided by sludge pumps. To obtain better tolerance of sludge layer thickness even three parallel nozzle system can be applied.

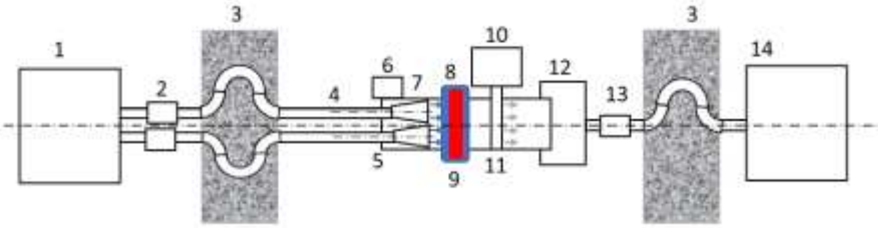


Fig. 1 Layout of technological equipment with single wall side shielding: 1 – inlet tank, 2 – piston pumps for sludge transport, 3 – shielding wall, 4 – pipe, 5 – linear conveyor, 6 – drive system for conveyor, 7 – nozzles, 8 – electron beam exit zone, 9 – Faraday cup, 10 – limestone tank, 11 – limestone sprayer, 12 – sludge collection tank, 13 – piston pump, 14 – outlet tank,

The design of the building intended for the installation of a radiation module for the treatment of sewage sludge in a biogas plant is closely related to the intended use of the plant, and is therefore a direct result of the parameters of the electron accelerator to be installed in the plant. This includes the need for shielding walls and the design of rooms associated with the operation of the accelerator. A typical solution is a building with two storey. The lower level houses the room with the electron beam exit and process equipment, while the upper level is used to install the basic components of the accelerator.

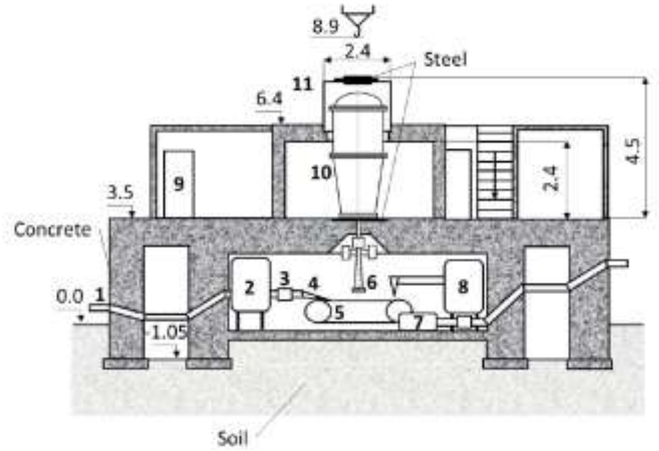


Fig. 2 Cross-section of shielding for an accelerator with an electron energy of 2.5 MeV and a beam power of 50 kW along an axis perpendicular to the beam sweep direction with the location of process line elements marked: 1 – Sewage sludge transport system from the external tank; 2 – intermediate sludge tank; 3 – sludge pump providing the required pressure to form the sludge layer of the desired thickness with a nozzle forming the sludge layer; 4 – nozzle; 5 – conveyor; 6 – output of accelerated electron beam; 7 – installation for collecting sludge after radiation treatment; 8 – lime tank and lime distribution nozzle for stabilization of sludge properties; 9 – accelerator power cabinet; 10 – electron accelerator; 11 – steel enclosure..

2.4 ACCELERATORS FEASIBLE FOR APPLICATION IN THE TECHNOLOGICAL LINE

Based on the technological requirements and expected performance of the plant, a transformer accelerator was selected for further consideration due to its favourable parameters, moderate price and proven operational performance with an electron energy of 2.5 MeV, which limits the radiation treatment of sludge to a thickness of 8 mm. The basic parameters of the such accelerator are as follows:

- Electron energy: 1.0 – 2.5 MeV,

- Energy instability: ≤ ±3%,

- Electron beam current: 20 mA (for electron energy of 2.5 MeV),

- Electron beam current instability: ≤ ±3%,

- Electron beam power: 50 kW,

- Output window length: 1.6 m,

- Heterogeneity of linear current density along the window: ≤ ±10%,

- Pressure of SF6 inside the vessel: ≤ 10 atm

Table 2. Parameters of selected types of accelerators meeting the project requirements.

Producer Parameter	EB-Tech Korea	BINP Russia	Wasik USA	Vivirad France	Waxi El Pont, China	IBA Belgium
	1	2	3	4	5	6
Type of accelerator	ELV-8	ELV-8	-		AB3.0	
Type of HV power supply	Transfor. without core	Transfor. without core	HV transform.	Transfor. isolated core	Voltage multipli-cation	Voltage multipli-cation
HV isolation	SF6	SF6	-	SF6	SF6	SF6
Energy	2,5 MeV	2,5 MeV	do 1 MeV	3 MeV	3 MeV	3 MeV
Current	40 mA	40 mA	-	35 mA	34 mA	34 mA
Beam power	100 kW	100 kW		100 kW	100 kW	100 kW
Scan width	1,6 m	1,6 m	-			
Hight	6300 mm		-			
Efficiency	70 %	70 %	70 %	70 %	30-60 %	30-60 %
Basi spare parts	Cathode Ti foil Vacuum pump	Cathode Ti foil Vacuum pump	Cathode Ti foil Vacuum pump	Cathode Ti foil Vacuum pump	Cathode Ti foil Vacuum pump Tetrode	Cathode Ti foil Vacuum pump Tetrode
Cost	0,85 M$	0,793 M$	-	≈2 MEuro		

Table 2 lists the main manufacturers of industrial accelerators offering devices with parameters that meet the Investor's requirements. The companies with the greatest own potential include IBA, Belgium, BINP Russia and the fast-growing Chinese company Waxi El Pont Radiation Technology. The remaining companies (Wasik, USA; EB-Tech, Korea and Vivirad, France) represent a small potential of their own and have a relatively small contribution to the industrial accelerator market, but they have the necessary experience and (with the exception of Wasik).

The best solutions would be transformer accelerators, designed as industrial equipment are generally capable of 24-hour operation. The main advantages are relatively simple design, low cost in relation to the electron energy and beam power offered, unified systems easily adaptable to user requirements, ease of operation and reliability in operation, electrical efficiency of 70%. An important element in the operation of the accelerator is now computer-based control. This allows the accelerator's operation to be easily adjusted to the user's needs, up to automatic operation as part of a process line. Fig. 3 shows a schematic of the electron accelerator design accelerating electrons to an energy of 2.5 MeV.

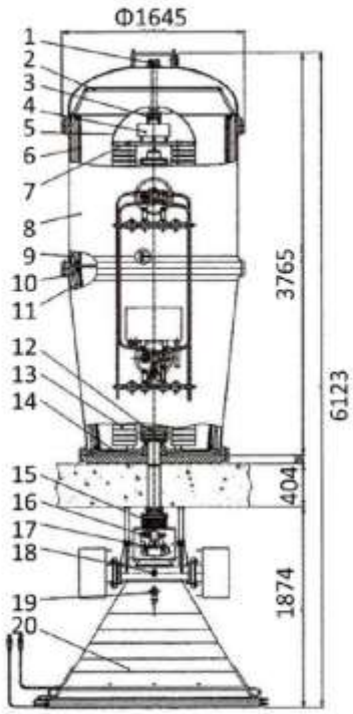


Fig. 3 Schematic of the electron accelerator design accelerating electrons to an energy of 2.5 MeV: 1 – transmitter, 2 – cone magneto wire, 3 – receiver, 4 – gun parameter control system, 5 – high voltage electrode, 6 – top primary winding, 7 – WN electrode base, 8 – pressure case, 9,10 – magnetic circuit element, 11 – WN power supply pressure case, 12 – accelerating section, 13 – rectifier, 14 – magneto wire disk, 15 – valve, 16 – HF scanning section, 17 – LF scanning section, 18 – thermocouple, 19 – high vacuum valve, 20 – scanner

3 Biogas module design

The guidelines were developed on the basis of a technical and technological solution reserved in the patent no. 197595 of the Republic of Poland and the patent application in the European Patent Office no. PCT/PL 02/00044 entitled: “Method and system of methane and electricity and heat generation” and patent application no. 395860 entitled: “Method and system of transport and mixing of biomass suspension in hydrolyser and fermenter” and are the author’s elaboration of the applicants for these patents. The company ‘’BIOPOLINEX’ with its registered office in Lublin and the Institute of Nuclear Chemistry and Technology in Warsaw have the right to use these solutions on the basis of agreements concluded with the Patent Inventors. Application of this technology will reduce the amount of substrate needed to achieve the same heat/electrical power and will allow to achieve at least 10% higher methane content in the obtained biogas, and the digestate obtained using this technology will have 10 times lower COD (Chemical Oxygen Demand) than coming from other types of biogas plants. . These effects can be achieved by separating the processes of hydrolysis of the mixture of sewage sludge and process covering biomass methane fermentation in one of used in practice conditions :mesophilic, thermophilic and psychrophilic, by returning leachate obtained in in of these technological processes containing appropriate bacterial cultures for mixing and watering of biomass feed. The process diagram is presented in Fig.4.

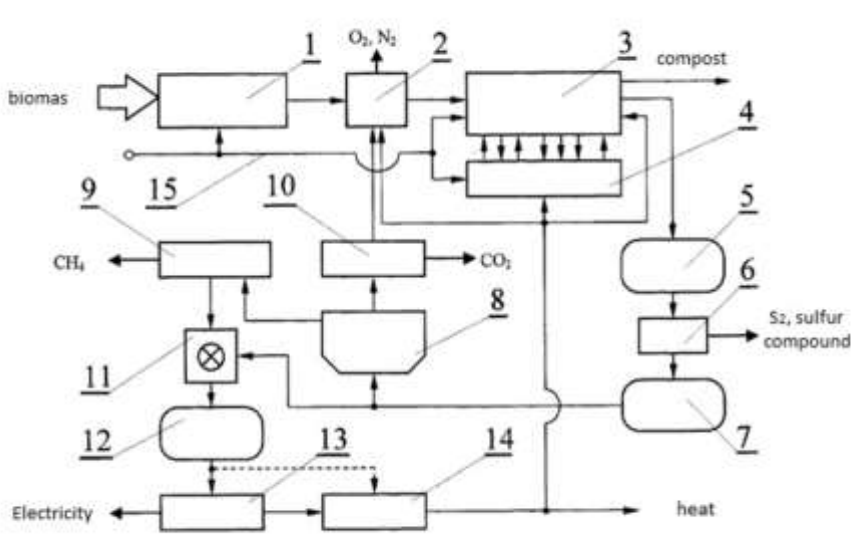


Fig. 4 Process diagram. Biomass preparation system 1, hydrolyser 2, series system of fermenters and composter 3, leachate return and enrichment system 4, crude biogas tank 5, biogas purification system 6, purified biogas tank 7, biogas separation system 8, methane processing system 9, carbon dioxide conversion system 10, gas mixer 11, standard fuel gas tank 12, electricity and heat generation system 13, heat conversion system 14 and external water intake 15.

The electron beam treatment may be applied for the biomass which is in this case substrate being a mixture of WWTP sewage or excess or maybe applied to the final product marked as compost at the process diagram. In first case (Fig.5) beside the hygenization, the sludge disintegration leads to higher biogas yield. The mechanism based on the research performed by INCT is presented in the report DELIVERABLE: D12.2 – Basic engineering of e-beam sludge processing line.

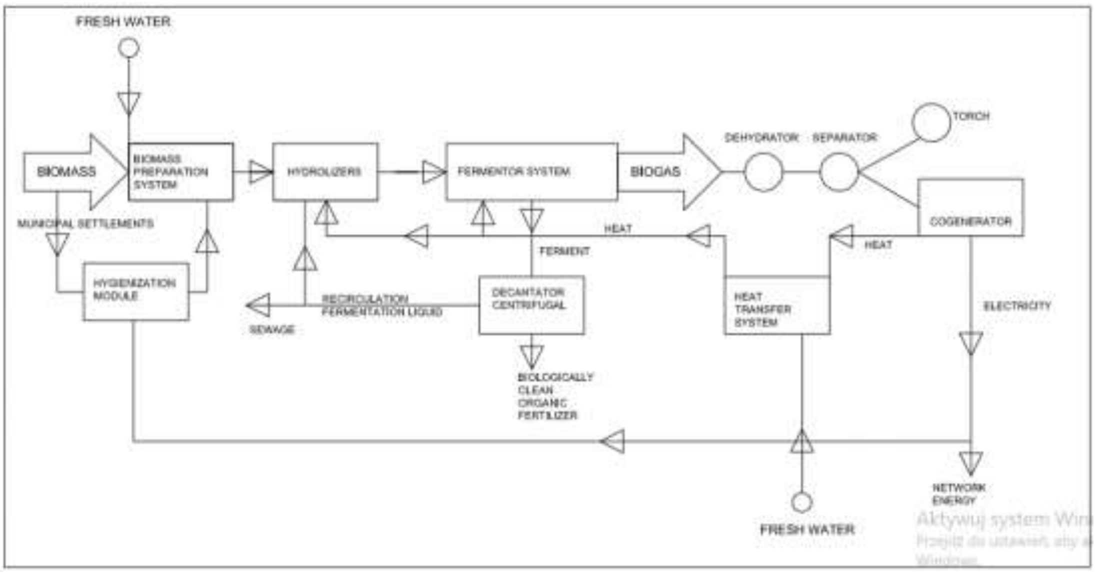
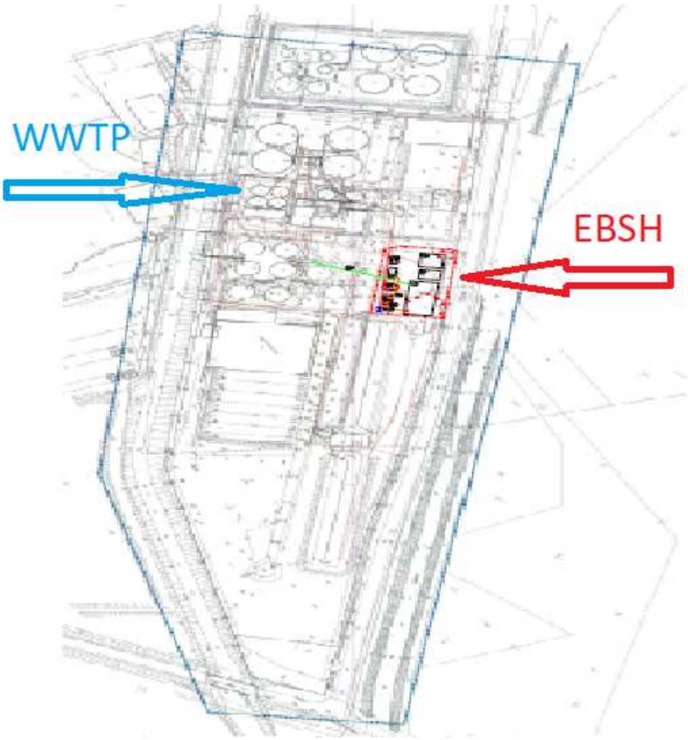


Fig. 5 Process diagram of the system with sludge being substrate irradiation in the inlet of the installation.

. The most important facilities to complete under the construction works:

- The bioreactor building with a system for processing sewage sludge with dimensions 25.75 x 18.19m, height 8.95m above the ground level designed.
- Silo for ensilages with dimensions 16.0 x 14.5m, height 4.00m above the ground level designed.
- Liquid sludge inlet tank with dimensions 6.0 x 6.00m, wall height 5m and the height above the ground level designed amounting to 13pprox.. 5.00m.
- Safety burner for burning biogas. Located on a reinforced concrete foundation with dimensions 2.0 x 2.0m, fastened by means of anchors, also stays if necessary.
- Underground networks: biogas pipelines, substrate pipelines, condensate pipelines, digestate (fertilizer) collection pipelines, and wells.

Set of these facilities fits in the arrangement of the most WWPT, small or medium size. Example is given for real plant for which analysis has been done (Fig.6). The irradiation module is located at the same site.



.

Fig. 6. Illustrative drawing illustrating the size of the electron beam sewage sludge hygienization installation in relation to the size of a typical wastewater treatment plant . Investigated sludge samples were collected in this facility.

The total area of both of the plant's aforementioned plots – the sewage treatment plant up to 3.7663ha. The area of the future Biopolinex Co. designed plant, where the planned project may be located, has an area of 0.1549 ha.

3.1 OTHER COMPONENTS OF BASIC ENGINEERING

Construction documents serve two basic purposes: to obtain a building permit, and to get the design built. These may be delivered in two types of construction documents – a permit set and a construction set. While both construction document sets need to be very detailed, it is common practice for the permit set to be delivered prior to the construction set. In so doing, any issues that arise during permitting can be addressed and corrected in the construction set. In order for a completed building to receive its final certificate of construction and operation from the local authority having jurisdiction, the buildings must closely match the construction documents submitted in the permit set. There are two things included in Construction Documents: Drawings and Specifications. All Construction Documents follow this standard, which helps the reader to know where to look among the hundreds of pages of drawings and specifications. The basic engineering cover inly preliminary aspects of the design however after approval has to be followed in technical designs and blueprints. The components of basic engineering are listed below:

Energy and mass balances

The balance of electric energy, biomethane, and heat generation.

Expected biomass balance (primary fuel). Biomass flow.

Biogas production and consumption

Unit operations equipment

Hydrolysers

Digester

Water Supply

Biogas circulation systems

Power generation unit and electric systems

Digestate tanks

Process heat system

Compressed air system

Electric supply system

Process control and automation

Fire and explosion hazards

Additional documentation needed for construction permit

Extract from the construction documentation

Extract from the architectonic – structural documentation

Extract from the process plant design

3.2 ENVIRONMENTAL IMPACT ASSESSMENT

Under the EU's Environmental Impact Assessment (EIA) Directive (2011/92/EU as amended by 2014/52/EU), major building or development projects in the EU must first be assessed for their impact on the environment. This is done before the project can start. An EIA is required for the various projects such as disposal and treatment of waste.

According to the Regulation of the Council of Ministers of 10 September 2019 on Projects that may significantly affect the environment (Journal of Laws 2019 item 1839), the investment project concerned is recognized as a Project That Can Significantly Affect the Environment classified in § 2, sect. 1, item:47) processing systems as defined by Art. 3 section 1 item 21 of the Act of 14 December 2012 on Waste for waste other than listed in item 41 and 46, including storage yards for waste other than listed in item 41, that may process waste in a quantity not smaller than 10 t per day or a total with a capacity of at least 25 000 t, excluding the system for agricultural biogas production as defined by Article 2 item 2 of the Act of 20 February 2015 on Renewable energy sources (Journal of Laws of 2018 item 2389, as amended),)

The EIA assesses the direct and indirect significant impact of a project based on a wide range of environmental factors, including: population and human health; biodiversity; land; soil; water; air; climate; landscape; material assets; cultural heritage. The project developer must provide the approval authority with a report containing the following information; description of the project (location, design, size); potential significant effects; reasonable alternatives; features of the project and/or measures to avoid, prevent, reduce or offset likely significant impacts on the environment, Such assessment has been prepared by certified design office.

4 Annexes

1. DELIVERABLE REPORT, DELIVERABLE: D12.2; Basic engineering of e-beam sludge processing line (assumptions). INCT, Warsaw, 2023
2. BASIC ENGINEERING - VALIDATED BY DESIGN OFFICE, Biopolinex, Lublin, 2023

5 Conclusions

- INCT has elaborated the proof-of-concept technology , which was validated in lab. The technology advances to TRL 4. During TRL 4, multiple component pieces were tested with one another , therefore we may consider that this level has been achieved. Technology validated in relevant industrial environment TRL 5 is a continuation of TRL 4, however, a technology that is at 5 is identified as a breadboard technology and must undergo more rigorous testing than technology that is only at TRL 4. In the next stage should be run in environments that are as close to realistic as possible in our case it should be a pilot plant built at WWTP on the basis of BE elaborated. At TRL 6 technology has a fully functional prototype or representational model. After its operation technology will move to TRL7 System prototype demonstration in operational environment. Next TRL7 comes – System is complete and qualified and it is a proof that it passed all assumed requirements and possess declared advantages over other completive solutions. Technology moves to TRL9 – actual system proven in operational environment. Next step is commercialization. Important to mention that even construction of pilot plant at WWTP is possible after fulfilling all stringent requirements of environmental impact assessment.

- The critical path on the way to the industrial applications of the elaborated technology is the availability, quality and price of the accelerator. High power & high electrical efficiency, low cost, accelerators are required to full fill market competitiveness requirements. Some hope came from the development of the devices using superconducting systems, however their pro – and contras - were not demonstrated in full industrial scale. The fact that they need magnets cooling systems may reduce their predicted energy efficiency.
- The use of renewable energy sources to supply electricity to run accelerators may improve the situation. In this case electricity supply is assured by generator driven by biogas.

6 References

JOURNAL ARTICLES:

[1] Bojanowska – Czajka A. "Application of Radiation Technology in Removing Endocrine Micropollutants from Waters and Wastewaters—A Review. Applied Sciences". 2021; 11(24):12032. https://doi.org/10.3390/app112412032

[1] Gryczka, U., Zimek, Z., Walo, M., Chmielewska – Smietanko, D., Bułka, S. (2021) Advanced Electron Beam (EB) Wastewater Treatment System with Low Background X-ray Intensity Generation". Appl. Sci. 11, 1119. https://www.mdpi.com/2076-3417/11/23/11194

CONFERENCE PAPERS

]1] Chmielewski, A.G., (2022) Applications of electron beam at wastewater treatment plants to implement circular economy principles, International Conference on Ionizing Processes (ICIP), 7-14. 07. 2022, ; virtual ; https://cr2.inl.gov/SitePages/ICIP%202022.aspx

[2] Chmielewski A.G.,(2022) Radiation Technologies : Future is Today. IAEA-CN290-412, Second International Conference on Applications of Radiation Science and Technology (ICARST-2022), 22-26 August 2022, Vienna, Austria. http://streaming.iaea.org/21952

[3] Chmielewski, A. G., (2022) Flue gas and sludge eb treatment, 7th Annual Ad Hoc Working Group Meeting Alternative to high – activity radioactive sources, 5-6.10.2022; https://alttechwg.org/

REPORTS

[1] Gryczka,U., Zimek,Z., Walo, M., Chmielewska-Śmietanko,D., Bułka,S., Chmielewski,A.G.. (2021) X –RAY BACKGROUND INTENSITY MONITORING IN ELECTRON BEAM WASTEWATER TREATMENT SYSTEM, ANNUAL REPORT 2021, INSTITUTE OF

NUCLEAR CHEMISTRY AND TECHNOLOGY, Warsaw, p.104-106 http://www.ichtj.waw.pl/ichtj/publ/annual/annual21.htmAnnex: Glossary

Acronym	**Definition**
COD	Chemical Oxygen Demand
EB	Electron Beam
EBSH	Electron Beam Sludge Hygenization
WWTP	Waste Water Treatment Plant