ETV
VERIFICATION REPORT

Final

CARBOREM TECHNOLOGY

Report N° 20DG18MP

Revision N° 00

22/12/2020

Contents

1. INTRODUCTION

RINA SERVICES S.P.A. (RINA), commissioned by CARBOREM s.r.l., has verified the performance claim of "CARBOREM TECHNOLOGY" according to the relevant procedures for EU ETV as for GVP Version 1.3 - April 1st, 2018 and the requirements set in the Specific Verification Protocol N° 20DG18MP, Revision N° 00 dated December 4th, 2020.

1.1. NAME OF TECHNOLOGY

CARBOREM TECHNOLOGY

1.2. NAME AND CONTACT OF PROPOSER

Name: CARBOREM srl

Contact: Michela LUCIAN

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Email: michela.lucian@carborem.com

1.3. NAME OF VERIFICATION BODY/VERIFICATION RESPONSIBLE

RINA SERVICES S.P.A, accredited EU ETV Verification Body, conform to the requirements of ISO/IEC 17020 for inspection bodies type A and of the GVP version 1.3.

1.4. ORGANISATION OF VERIFICATION INCLUDING EXPERTS, AND VERIFICATION PROCESS

The RINA's verification team is reported in the following table.

Table 1: Organization of Verification including Experts, and Verification Process

Role/Qualification	Last Name	First Name
ETV Technical Manager	Laura	SEVERINO
ETV Service Coordinator (CM) / ETV Inspector / Deputy Technical Manager	Giovanni	D'ANGELO
ETV Technical Expert	Giovanni	D'ANGELO
Internal Reviewer (ITR)	Laura	MARTI
External Reviewer (E-ITR)	Andrea	MAFFINI

The verification carried out by RINA Services included described in the following.

Eligibility Assessment: CARBOREM TECHNOLOGY is a technology eligible for EU ETV. This technology falls within the scope of the EU ETV pilot programme and in the Technological Area 1 “Water Treatment and Monitoring” according to the GVP; it is already on the market and contributes to the efficient use of natural resources and a high level of environmental protection.

Verification Proposal Assessment: The initial performance claim has been revised. RINA has provided a detailed cost estimate for the verification procedure. Based upon the cost estimate, the verification contract has been drafted and signed by CARBOREM.

Specific Verification Protocol review and approve: Upon successful completion of the contact phase and proposal phase RINA developed the specific verification protocol following the provisions of the GVP. The drafted SVP was reviewed by an internal and by an external technical expert. The SVP includes:

- Summary description of the technology, its intended application and associated environmental impacts;
- Definition of verification parameters (revised performance claim):
- Requirements on test design and data quality;
- Requirements on test and measurement methods, definition of calculation methods for performance parameters;
- Description of the way in which operational, environmental and additional parameters are to be dealt with in the verification process; and
- Assessment of existing data and conclusions on the need or not for additional tests or measures.

Test system audit / test performance audit: a physical audit was conducted by RINA (01/12/2020) during the actual testing of the technology in order to perform a qualitative and quantitative evaluation of the measurement system as used in the specific test. The testing activities were performed by ECOOPERA (TN), accredited by ACCREDIA (accreditation number 0252).

1.5. DEVIATIONS FROM THE VERIFICATION PROTOCOL

The verification’s time schedule is reported in the following table.

Table 2: Time schedule of the activities carried out by RINA

Task	Date
Eligibility Assessment	September 2020
Specific Verification Protocol – Internal Independent Review	December 2020
Specific Verification Protocol – External Independent Review	December 2020
Test System / Test Performance Audit	December 2020
Verification Reporting	December 2020

2. DESCRIPTION OF THE TECHNOLOGY

2.1 SUMMARY DESCRIPTION OF THE TECHNOLOGY

Carborem technology is based on Hydrothermal Conversion (also called Hydrothermal Carbonization or HTC), an innovative process treating sewage sludge in a continuous mode at 180-190 °C and 9-14 bar, in about one hour.

In Figure 1 is reported a simplified scheme showing a conceptual scheme of a common waste water treatment plant including Carborem process.

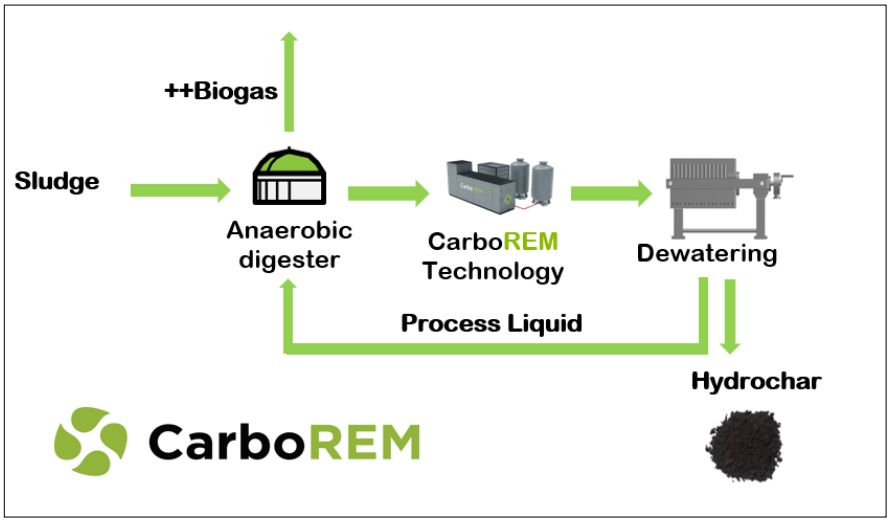

Figure 1: Conceptual scheme of a common wastewater treatment plant including Carborem process

The process, which is perfectly aligned with the trends in EU legislation on sewage sludge management[1], aims at **sanitizing sewage sludge**, **reducing the amount of pathogens** and the **concentration of the total suspended solid**. After the HTC process, the treated sludge (namely HTC slurry) is mechanically dewatered in a centrifuge, obtaining mainly a liquid, that is used as a substrate into anaerobic digestion for biogas production or into the wastewater treatment plant. A minor part of the products is constituted by a solid product (called hydrochar), that is rich in carbon and phosphorus and may be potentially valorized as a soil improver in agriculture. Hydrochar is highly hydrophobic and can be dewatered more easily than sludge. As a result, higher % of dry matter content can be reached by using Carborem technology before a common dewatering system like centrifuge. The drop of the total suspended solid during the process and the higher dewaterability of hydrochar allows to reduce sludge by 50-70 wt.% compared to using the sole traditional dewatering system (centrifuge, filter press). Carborem technology, which is the objective

[1] European Union legislation on sewage sludge management (PDF Download Available). Available from: https://www.researchgate.net/publication/261365754_European_Union_legislation_on_sewage_sludge_management

of this EU ETV Verification, was implemented in Carborem plant, called “C700”, treating approximately 5,000 ton of sludge per year.

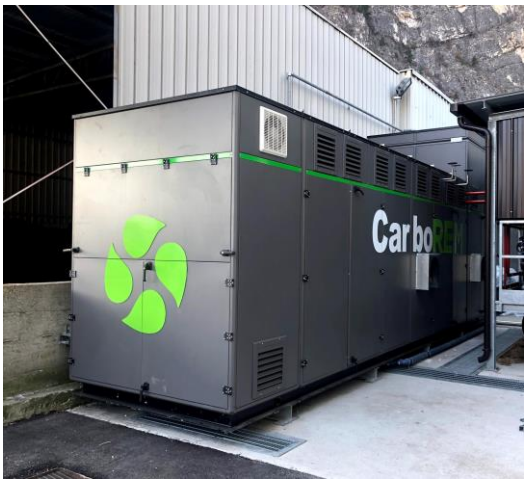

Figure 2: Carborem C700 plant

2.2. INTENDED APPLICATION (MATRIX, PURPOSE, TECHNOLOGIES, TECHNICAL CONDITIONS)

Table 3: Matrix, purpose, technologies and technical conditions

Matrix	Purpose	Technologies and technical conditions
Sewage sludge / digestate from winery making and dairy industry and from civil sludge. The technology could be applied to all the wet organic wastes (with moisture content > 50 wt.%).	The purpose is to sanitize and reduce the volume of sludge to dispose of with a low energy demanding process. In about one hour the sludge is sanitized and converted into a liquid recycled into anaerobic digester and into a solid with no pathogens, rich in carbon and phosphorus and with reduced amount of polyaromatic hydrocarbons (PAHs).	Carborem technology is a continuous process. The sewage sludge/digestate is heated at 180°C-190°C at 9-14 bar for about one hour.

2.3 VERIFICATION PARAMETERS DEFINITION

Table 4: Parameters considered in the specific verification protocol

Parameter	Value	Existing legal requirements and/or	Test or measurement	Test /available data (+

		BAT values	method(s)	performer of tests)
PERFORMANCE PARAMETERS				
Process time	55-59 min [54-60 min]	>120 min	PLC time counter	Test /available data
Total Organic Carbon (TOC)	Before HTC: 30±4%DM [26-34%] After Carborem process+dewatering: 27±1 %DM [25-29%]	Not applicable	UNI EN 15936 2012	Test /available data
Total phosphorus	Before HTC: 14,100±500 mg/kg$_{DM}$ [13,600-14,600] After Carborem process+dewatering: 35,080±3,920 mg/kg$_{DM}$ [30,200-41,000]	Not applicable	UNI EN 15936 2012	Test /available data
Total Suspended Solid (TSS)	Before HTC: 44.5±0.5 g/l [43.9-45 g/l] After Carborem process: 25.1±2.8 g/l [21.2-27.7 g/l]	Not applicable	CNR IRSA 1B Q64 Vol2 1984	Test/available data
PAHs	Before Carborem process: 4.30±1.5 mg/kg$_{DM}$ After Carborem process+dewate	Not applicable	EPA 3550C 2007 + EPA 8270E 2018	Test/available data

	ring: < 0.1 mg/kg_{DM}			
Escherichia Coli	Before HTC: 66,667±38,793 MPN/g [12000-98 000] After Carborem process: < 10 MPN/g [<10-100]	Not applicable	IS 08.03/106 Rev.1 2015	Test/available data
Methane consumption (per 760 liters of sludge treated)	6.5±0.3 m^3 [6.2-6.7 m^3]	Not applicable	Gas meter	Test/available data
Electricity consumption (per 760 liters of sludge treated)	3.5±0.1 kWh [3.4-3.5 kWh]	Not applicable	Electrical meter	Test/available data

OPERATIONAL PARAMETERS				
Process Temperature	180±10°C	>200 °C	Temperature probes	Test/available data
Process Pressure	9-14 bar	Not applicable	Pressure probes	Test/available data
Flow	12±2 l/min	Not applicable	Electromagnetic flowmeter	Test/available data
ENVIRONMENTAL PARAMETERS				
Ambient temperature	24±3°C	Not applicable	Temperature probes	Test/available data

3. EXISTING DATA

3.1. ACCEPTED EXISTING DATA

During the period March-October 2020, Carborem collected all the data to verify the performance claims.

Carborem has been supported by the laboratory of “Ecoopera Soc. Coop.” for the measurement of the following analyses:

- Carbon content;
- Phosphorus content;
- TSS;
- PAHs; and
- Escherichia Coli.

The following measurements were determined by Carborem through the electricity and gas meters:

- Methane consumption; and
- Electrical energy.

The time counter of PLC (programmable logic controller) is used to define the duration of HTC reaction.

3.2 CARBON AND PHOSPHORUS DENSIFICATION

“Ecoopera Soc. Coop.” was designated by Carborem for the measurement of Total Organic Carbon (TOC) and phosphorous of hydrochar (solid product). Samples were named as the following:

- Digestate (“*DIG_N°sample*”); and
- Solid product (Hydrochar) (“*HC_N°sample*”).

During the period 14/05/2020 - 11/09/2020 two samples of digestate and four samples of hydrochar were collected by Carborem operators and analyzed in terms of carbon and phosphorous content. The analyses were reported in the test report, properly identified by the identification number, which reported the analysis data, the collection data and the method used for the analyses (please see tables below).

In the following tables the carbon and the phosphorus densification, defined in section 6.1, were calculated by referring to both the raw samples (DIG_1 and DIG_2).

Table 5: Existing data - Carbon

Sample	DIG_1	DIG_2	HC_1		HC_2	HC_3	HC_4
Test report n°	2004040-12	2001758-002	2003230-001		2004040-006	2004040-007	2002040-008
Analysis data	15 sep-9 oct 2020	15 jun 2020	28 jul-6 aug 2020		15 sep-8 oct 2020	15 sep-8 oct 2020	15 sep-8 oct 2020
Collection data	11 sep 2020	14 may 2020	28 jul 2020		11 sep 2020	11 sep 2020	11 sep 2020
Method	UNI EN 15936 2012	UNI EN 15936 2012	UNI EN 15936 2012		UNI EN 15936 2012	UNI EN 15936 2012	UNI EN 15936 2012
TOC (%s.s.)	26.0±1.4	34.3±1.7	28.8	1.5	26.3±4.2	25.8±4.2	25.4±4.1
TOC HC/TOC DIG_1			**1.11**		**1.01**	**0.99**	**0.98**
AVERAGE: 1.02 ± 0.05 (claimed performance > 0.45)							
TOC HC/TOC DIG_2			**0.84**		**0.77**	**0.75**	**0.74**
AVERAGE: 0.77 ± 0.04 (claimed performance > 0.45)							

Table 6: Existing data - Phosphorus

Sample	DIG_1	DIG_2	HC_1	HC_2	HC_3	HC_4
Test report n°	2004040-12	2001758-002	2003230-001	2004040-006	2004040-007	2002040-008
Analysis data	15 sep-9 oct 2020	15 jun 2020	28 jul-6 aug 2020	15 sep-8 oct 2020	15 sep-8 oct 2020	15 sep-8 oct 2020
Collection data	11 sep 2020	14 may 2020	28 jul 2020	11 sep 2020	11 sep 2020	11 sep 2020
Method	EPA 3051A 2007+EPA6010D 2018	EPA 3051A 2007+EPA6010D 2018	EPA 3051A 2007+EPA6010D 2018	EPA 3051A 2007+EPA6010D 2018	EPA 3051A 2007+EPA6010D 2018	EPA 3051A 2007+EPA6010D 2018
Total Phosphorus (mg/kgD	14600 ±4400	13600±4100	30200±4100	41000±12000	34000±10000	38000±11000

M)						
P HC/P DIG_1			**2.07**	**2.81**	**2.33**	**2.60**
AVERAGE: 2.40 ± 0.27 (claimed performance > 0.7)						
P HC/P DIG_2			**2.22**	**3.01**	**2.5**	**2.79**
AVERAGE: 2.58 ±0.29 (claimed performance > 0.7)						

3.3 TSS

Total suspended solid (TSS) was determined on three raw sludge samples (DIG_1, DIG_2 and DIG_3) and on three slurry samples (S_1, S_2, S_3). The reduction of TSS after Carborem process compared to the initial digestate fall within the claimed range for all the samples (Reduction > 30%).

Table 7: Existing data - TSS

Sample	**DIG_1**	**DIG_2**	**DIG_3**	**S_1**	**S_2**	**S_3**
Test report n°	2004040-012	2004688-001	2004688-002	S_2004040-010	S_2004688-003	S_2004688-004
Analysis data	15 sep-9 oct 2020	14 oct-23 oct 2020	14 oct-23 oct 2020	15 sep-9 oct 2020	14 oct-23 oct 2020	14 oct-23 oct 2020
Collection data	11 sep 2020	14 oct 2020	14 oct 2020	11 sep 2020	14 oct 2020	14 oct 2020
Method	CNR IRSA 1B Q64 Vol.2 1984	CNR IRSA 1B Q64 Vol.2 1984	CNR IRSA 1B Q64 Vol.2 1984	CNR IRSA 1B Q64 Vol.2 1984	CNR IRSA 1B Q64 Vol.2 1984	CNR IRSA 1B Q64 Vol.2 1984
TSS (g/l)	44.5±2.0	45±2.0	43.9±2.0	21.23±0.98	27.7±1.3	26.5±1.2
TSS Reduction _Slurry (DIG_1, DIG_2, DIG_3)				**52%**	**38%**	**40%**

AVERAGE: 43.5% ± 6.3% (claimed performance > 30%)

3.4 PAHS

During the period 13/03/2020-11/09/2020 two samples of digestate and four samples of hydrochar were collected by Carborem operators and analyzed in terms of PAHs content. The PAHs reduction (in %), calculated with the formula reported in section 6.1, by referring to the corresponding sample (DIG_1 and DIG_2), were reported below.

Table 8: Existing data - PAHs

Sample	DIG_1	DIG_2	HC_1	HC_2	HC_3	HC_4
Test report n°	2001041-001	2004040-012	2001041-002	2004040-006	2004040-007	2004040-008
Analysis data	13-27 mar 2020	15 sep-9 oct 2020	13-27 mar 2020	15 sep-8 oct 2020	15 sep-8 oct 2020	15 sep-8 oct 2020
Collection data	13 mar 2020	11 sep 2020	13 mar 2020	11 sep 2020	11 sep 2020	11 sep 2020
Method	EPA 3550C 2007 + EPA 8270E 2018	EPA 3550C 2007 + EPA 8270E 2018	EPA 3550C 2007 + EPA 8270E 2018	EPA 3550C 2007 + EPA 8270E 2018	EPA 3550C 2007 + EPA 8270E 2018	EPA 3550C 2007 + EPA 8270E 2018
PAH (mg/kgDM)	4.30 ±1.5	<1	<1	<0.3	0.33	<0.3
PAH Reduction [DIG_1] (%)			**77%**	**-**	**-**	**-**
AVERAGE: 77% (claimed performance > 50%)						
PHA Reduction [DIG_2] (%)			**-**	**70%**	**67%**	**70%**

AVERAGE: 69% ± 1%

(claimed performance > 50%)

3.5 ESCHERICHIA COLI

Escherichia Coli was determined on three raw samples (DIG_1, DIG_2 and DIG_3) and on four slurry samples (S_1, S_2, S_3, S_4) obtained at different conditions or at different time. Slurry samples are considered to be the liquid and solid mixture obtained after Carborem process, before dewatering. The reduction of Escherichia Coli in the slurry compared to the initial digestate fall within the claimed range for all the samples (Reduction > 50%).

Table 9: Existing data - Escherichia Coli

Sample	DIG_1	DIG_2	DIG_3	S_1	S_2	S_3	S_4
Test report n°	2004040-12	2004688-001	2004688-002	S_2004040-011	S_2004040-010	S_2004688-003	S_2004688-004
Analysis data	15 sep-9 ott 2020	14 oct-23 oct 2020	14 oct-23 oct 2020	15 sep-9 oct 2020	11 sep-29 sep 2020	14 oct-23 oct 2020	14 oct-23 oct 2020
Collection data	11 sep 2020	14 oct 2020	14 oct 2020	11 sep 2020	22 sep 2020	14 oct 2020	14 oct 2020
Method	IS 08.03/106 Rev.1 2015	IS 08.03/106 Rev.1 2015	IS 08.03/106 Rev.1 2015	IS 08.03/106 Rev.1 2015	IS 08.03/106 Rev.1 2015	IS 08.03/106 Rev.1 2015	IS 08.03/106 Rev.1 2015
Escherichia Coli (MPN/g)	12000 ±8300-16600	90000±50000-170000	98000±74000-127000	100±<100-600	<10	<10	<10
Reduction of Escherichia Coli_Slurry (DIG_1, DIG_2, DIG_3)				99.2%	100%	100%	100%

AVERAGE: 100% ± 0.3%

(claimed performance > 50%)

3.6 GAS CONSUMPTION, ELECTRICITY CONSUMPTION, DURATION

The data regarding gas consumption of Carborem technology, collected by means of a gas meter and shown in the analytical software managing all the data of the plant, are reported in the table below.

The data were collected in two periods:

- PERIOD 1: from 20:18 of 25/06/2020 to 01:15 of 26/06/2020; and
- PERIOD 2: from 15:12 to 17:02 of 14/07/2020.

PERIOD 1

During the PERIOD 1, Carborem plant has completed 5 lots (720-760 liters of sludge treated each) at T=180 °C ± 2 °C. The selected flow of entering sludge was fixed at 11-13 l/min. The average duration of each lot is 00:59:30, which fall within the claimed value (55-60 min).

The mean value of gas consumption is 6.7±0.1 m^3, value also in the range of the claimed value (6-7 m3 per 760 liters of sludge). The mean value of electricity consumption is 3.4±0.1 kWh per lot. (claim performance: 2-4 kWh per 760 liters of sludge).

Table 10: Existing data – Gas and electricity consumption – Period 1

Lot number	Start	End	Duration (hh:mm:ss)	Gas consumption (m^3)	Electricity consumption (kWh)
175	25/06/2020, 20:18	25/06/2020, 21:17	00:59:26	6.7	3.4
176	25/06/2020, 21:17	25/06/2020, 22:18	01:00:31	6.7	3.3
177	25/06/2020, 22:18	25/06/2020, 23:18	00:59:58	6.7	3.4
178	25/06/2020, 23:18	26/06/2020, 00:17	00:59:24	6.7	3.3
179	26/06/2020, 00:17	26/06/2020, 01:15	00:58:10	6.5	3.6
AVERAGE			00:59:30	**6.7±0.1**	**3.4±0.1**

PERIOD 2

During the PERIOD 2, Carborem plant has completed 2 lots (720-760 liters of sludge treated each) at T=180 °C ± 2 °C. The selected flow of entering sludge was fixed at 11-13 l/min. The average duration of each lot is 00:55:04, which fall within the claimed value (55-60 min). The mean value of gas consumption is 6.2±0.2 m3, value also in the range of the claimed value (6-7 m3 per 760 liters of sludge). The average value of electricity consumption in this time range is 3.5 kWh, which falls within the claim value of 2-4 kWh per 760 liters of sludge.

Table 11: Existing data – Gas and electricity consumption – Period 2

Lot number	Start	End	Duration (hh:mm:ss)	Gas meter CG1 (m^3)	Gas consumption (m^3)	Electricity consumption (kWh)
228	14/07/2020 15:12	14/07/2020 16:06	00:53:43	1907.781	6.0	3.9
229	14/07/2020 16:06	14/07/2020 17:02	00:56:24	1914.179	6.4	3.1
AVERAGE			00:55:04 ± 00:01:20		**6.2±0.2**	**3.5±0.4**

4. EVALUATION

4.1. CALCULATION OF PERFORMANCE PARAMETERS

ELEMENT DENSIFICATION INTO THE SOLID PRODUCT

$$\textbf{Carbon densification} = \frac{\textbf{Total Organic Carbon OUT}}{\textbf{Total Organic Carbon IN}}$$

Where:

- "Total Organic Carbon IN" [%] = total organic carbon into the dry sludge
- "Total organic carbon OUT" [%] = total organic carbon into the dry solid product (hydrochar)

$$\textbf{Phosphorus densification} = \frac{\textbf{Total Phosphorus OUT}}{\textbf{Total Phosphorus IN}}$$

Where:

- "Total Phosphorus IN" [mg/kg] = total phosphorus into the dry sludge
- "Total Phosphorus OUT" [mg/kg] = total phosphorus into the dry solid product (hydrochar)

PAHs REDUCTION INTO THE SOLID PRODUCT

$$\text{PAHs reduction (\%)} = \frac{\text{PAH IN} - \text{PAH OUT}}{\text{PAH IN}} * 100$$

Where:

- "PAHs IN" [mg/kg] = polyaromatic hydrocarbons into the dry sludge (dry basis)
- "PAHs OUT" [mg/kg] = polyaromatic hydrocarbons into the dry solid product (hydrochar) (dry basis)

REDUCTION OF ESCHERICHIA COLI INTO THE SLURRY PRODUCT

$$\text{Escherichia Coli reduction (\%)} = \frac{\text{Escherichia Coli IN} - \text{Escherichia Coli OUT}}{\text{Escherichia Coli IN}} * 100$$

Where:

- "Escherichia Coli IN" [MPN/g] = Escherichia Coli into the sludge
- "Escherichia Coli OUT" [MPN/g] = Escherichia Coli into the slurry product

REDUCTION OF TOTAL SUSPENDED SOLID (TSS)

$$\text{TSS reduction (\%)} = \frac{\text{TSS IN} - \text{TSS OUT}}{\text{TSS IN}} * 100$$

Where:

- "TSS IN" [g/l] = Total Suspended Solid into the sludge
- "TSS OUT" [g/l] = Total Suspended Solid into the slurry product

4.2. EVALUATION OF TEST QUALITY

4.2.1 CONTROL DATA

In order to monitor the electrical and methane consumed by Carborem technology, Carborem operators develop a software analytics tools which collected data of electricity and gas meters. The data regarding consumption are available online after logging in.

The analytical methods used by the test body ISO 17025 "Ecoopera Soc. Coop." to determine the other claim performance parameters were reported in section 2.3, table 4. The analytical results were listed in the test reports issued by the test body "Ecoopera Soc. Coop".

4.2.2 AUDITS

The test system audit was conducted on site on 01/12/2020 by Giovanni D'ANGELO (Technical manager and Technical expert).

The inspection aimed to verify the claims specified in the SVP.

The auditing activities included the inspection visit at Ecoopera's laboratories, which performed all the analyses regarding the characterization of Carborem technology products.

Ecoopera has been accredited by ACCREDIA (n. 0252) for the majority of the technology's performance claims except the claims about PAHs and EC parameters. Therefore, the inspection focused mainly to check the validity of these two parameters. In particular the auditing activities included the check of the test equipment, the assessment of the preparation, sampling and handling of samples, the check of the test methods applied, of the measurement traceability, the control of data, the quality assurance activities and the result reporting.

It was concluded that there was consistency with the test plan and set up and that handling of measurements were carried out as described.

During the inspection Carborem system and control (PLC) were checked. In particular, the inspection was focused to view the existing data, performance, operational and environmental parameters and claimed values through a software analytical tools and test reports.

It was concluded that all the claimed performances are proved.

4.2.3 DEVIATION

No deviations from the specific verification protocol are reported from the implementation of the test activities.

4.3. VERIFICATION RESULTS (VERIFIED PERFORMANCE CLAIM)

4.3.1. DESCRIPTION OF STATISTICAL METHODS USED

N/A

4.3.2 VERIFICATION PARAMETERS

PERFORMANCE parameters

Carborem technology provides a method to reduce by more than 40% the total suspended solid of sludge/digestate during the HTC process, without the addition of chemicals and/or oxygen.

In about one hour, sludge is converted into a sterilized slurry (Escherichia Coli<10 MPN/g;), which is then dewatered in a centrifuge to obtain a solid with high phosphorus and carbon densification and low PAHs content (PAHs reduction by 67-77% compared to the initial sludge).

The process needs 6-7 m^3 of methane and 2-4 kWh_e per 760 liters of sludge. Methane consumption is lower than competitors' HTC technologies, which report a thermal and electricity consumption of 100 kWh_T (Terranova Energy, 2020). If the thermal consumption related to Carborem technology are reported in kWh_T per ton of input sludge (calorific value of methane: 9.94 kWh/m^3), the values are lower (about 80 kWh_T per ton of sludge). The literature also reports much higher values (310 kWh_T/ton (Lucian et al., 2017).

The electricity consumption per ton of input sludge is about 5.3 kWh_e/ton, which is a much lower value than that of competitors'technology (15 kWh_e per ton of input sludge – please see Terranova Energy, 2020) and literature (40 kWh_e per ton of feedstock, please see Lucian et al., 2017).

The claimed and verified performance are listed below.

Table 12: Claimed and verified parameters

Parameter	Claimed performance	Verified performance
Process time	50-60 min	57 min [54-60 min]
Addition of chemicals/oxygen	No use of chemicals/oxygen	No use of chemicals/oxygen
Carbon densification into hydrochar	70%	90%± 13% [77-102%]
Phosphorus densification into hydrochar	>70%	249%± 9% [248-251%]
Total suspended solid reduction (waste minimization)	30%	43.5% ± 6.3% [38-52%]
PAHs reduction into hydrochar	50%	73%± 4% [69-77%]
Escherichia Coli reduction	50%	100%± 0.3% [99.2-100%]
Methane consumption (per 760 liters of sludge treated)	6-7 m^3	6.5±0.3 m^3 [6.2-6.7 m^3]
Electricity consumption (per 760 liters of sludge treated)	2-4 kWh	3.5±0.1 kWh [3.4-3.5 kWh]

OPERATIONAL PARAMETERS

The performance parameters were obtained by heating sewage sludge at temperature of 180±10°C in the C700 plant of Carborem operating in a continuous mode. The flow rate used was in the range of 12 l/min±2 l/min. The sewage sludge was collected after anaerobic digestion and after thickener, that increases the total suspended solid of sludge from 2-3 wt.% to 4-5 wt.%. A filtration system before Carborem C700 allows to separate any extraneous material from the entering sludge.

Table 13: operational parameters

Operational parameter	Value
Process Temperature	180±10°C
Process pressure	9-14 bar
Flow	12±2 l/min

The slurry obtained by the process was sampled to determine Escherichia Coli and Total suspended solid content. This slurry was properly dewatered in a centrifuge in order to separate solid and liquid. The dewatered solid obtained was also sampled by Carborem operators to determine the total phosphorus, the total organic carbon and the PAHs. For each sampling of hydrochar and slurry, the inlet digestate was also collected as a reference.

Electrical and methane consumption, duration was also determined by using Carborem analytical software, which collects real time and historical data generated by the plant.

ENVIRONMENTAL PARAMETERS

The only environmental parameter measured during each test is the ambient temperature of the entering sludge, which is 24 ± 3°C. This parameter does not influence the performances parameters.

4.3.3 ADDITIONAL PARAMETERS, WITH COMMENT OR CAVEATS WHERE APPROPRIATE

No additional parameters are available.

4.4. RECOMMENDATIONS FOR STATEMENT OF VERIFICATION

N.A.

5. QUALITY ASSURANCE

The personnel and experts responsible for quality assurance as well as the different quality assurance activities are described in the table below.

Review of the SVP: an internal technical review and an external technical review from an external technical expert. The internal review was performed by Laura MARTI (qualified as ETV Inspector). External review was performed by Andrea MAFFINI (qualified as Technical Expert).

Test system audit / test performance audit: a physical audit was conducted by the ETV Inspector Giovani D'ANGELO.

The verification report and the statement of verification will require an external review according to EU ETV programme GVP. Internal review was performed by Laura MARTI and external review was performed by Andrea MAFFINI. The verification report was finally approved by the RINA's ETV Technical Manager Laura SEVERINO.

Table 14: Quality Assurance

Role	Inspector	Technical expert	ITR (by VB)	E-ITR	Proposer
Responsible	Giovanni D'ANGELO	Giovanni D'ANGELO	Laura MARTI	Andrea MAFFINI	Michela LUCIAN
EU-ETV Verification Task					
Specific Verification Protocol	Draft	Draft	Review	Review	Acceptance
Test System at test site	Audit	Audit	-	-	Acceptance
Verification	Draft	Draft	Review	Review	Acceptance

Report					
Statement of Verification	Draft	Draft	Review	Review	Acceptance

6. REFERENCES

European Union legislation on sewage sludge management (PDF Download Available from: https://www.researchgate.net/publication/261365754_European_Union_legislation_on_sewage_sludge_management)

Terranova Energy, 2020. Document available online from: http://s232856347.online.de/pdf/Wirtschaftlichkeitsberechnung%20TerraNova%20Ultra%20100.000%20EW%20en.pdf

Lucian M., Fiori L., 2017. *Hydrothermal Carbonization of Waste Biomass: Process Design, Modeling, Energy Efficiency and Cost Analysis***.** Energies 10(2), 211.

7 TERMS AND DEFINITIONS

"Accreditation" has the meaning assigned to it by Regulation (EC) No 765/2008.

"Deviation" is a change to a specific verification protocol or a test plan done during the verification or test step performance.

"EU ETV – European Environmental Technology Verification" is the EU programme providing for third-party verification, on a voluntary basis, of the performance claims made by technology manufacturers in business-to-business relations.

"GVP – General verification protocol" means the description of the principles and general procedure to be followed by the ETV pilot programme when verifying an environmental technology.

"Performance claim" means a set of quantified and measurable technical specifications representative of the technical performance and environmental added value of a technology in a specified application and under specified conditions of testing or use.

"SVP – Specific verification protocol" means the protocol describing the specific verification of a technology and applying the principles and procedures of the General verification protocol.

"Verification" means the provision of objective evidence that the technical design of a given environmental technology ensures the fulfilment of a given performance claim in a specified application, taking any measurement uncertainty and relevant assumptions into consideration.

'Test system assessment' means determining whether the test system and quality management system applied by a test body to generate data for verification purposes comply with the

requirements of the General Verification Protocol and of the specific verification protocol. It includes the review of the relevant accreditations, and may include a test system audit.

'Test system audit' means the examination of a test system and of a quality management system. It is achieved through the review of relevant procedures, observation of actual practices and evaluation of test performance. Where applicable, it includes the examination of control data for relevant period, participation in proficiency testing and/or control of calibration of measurement devices. It is aimed to provide the necessary evidence for the test system assessment.