NIMBUS

Non-impact bus: Circular economy for sustainable transport

DE1.4 Final report

LIFE19 ENV/ES/000191

www.life-nimbus.eu

LIFE Project Number

LIFE19 ENV/ES/000191

Final Report

Covering the Project activities from 01/09/2020 to 30/06/2025

Reporting Date

30/09/2025

LIFE PROJECT NAME or Acronym

LIFE NIMBUS

Data Project

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Project start date:	01/09/2020
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(%) of eligible costs:	55%

Data Beneficiary

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Package completeness and correctness check - Obligatory elements	
Technical report	**N/A**
The correct latest template for the type of project (e.g. traditional) has been followed and all sections have been filled in, in English. *In electronic version only*	✓
Index of deliverables with short description annexed, in English. *In electronic version only*	✓
Mid-term report: Deliverables due in the reporting period (from project start) annexed Deliverables in language(s) other than English include a summary in English. *In electronic version only*	✓
Financial report	**N/A**
The reporting period in the financial report (consolidated financial statement **and** financial statement of each Individual Beneficiary) is the same as in the technical report with the exception of any terminated beneficiary for which the end period should be the date of the termination.	✓
Consolidated Financial Statement with all 5 forms duly filled in and signed and dated *Electronically Q-signed or if paper submission signed and dated originals* and in electronic version (pdfs of signed sheets + full Excel file)*	✓
Financial Statement(s) of the Coordinating Beneficiary, of each Associated Beneficiary and of each affiliate (if involved), with all forms duly filled in (signed and dated). The Financial Statement(s) of Beneficiaries with affiliate(s) include the total cost of each affiliate in 1 line per cost category. *In electronic version (pdfs of signed sheets + full Excel files) + in the case of the Final report the overall summary forms of each beneficiary electronically Q-signed or if paper submission, signed and dated originals**	✓
Amounts, names and other data (e.g. bank account) are correct and consistent with the Grant Agreement / across the different forms (e.g. figures from the individual statements are the same as those reported in the consolidated statement)	✓
Mid-term report (for all projects except IPs): the threshold for the second pre-financing payment has been reached	**N/A**
Beneficiary's certificate for Durable Goods included (if required, i.e. beneficiaries claiming 100% cost for durable goods) *Electronically Q-signed or if paper submission signed and dated originals* and in electronic version (pdfs of signed sheets)*	**N/A**
Certificate on financial statements (if required, i.e. for beneficiaries with EU contribution ≥750,000 € in the budget) *Electronically Q-signed or if paper submission signed original and in electronic version (pdf)*	**N/A**
Other checks	
Additional information / clarifications and supporting documents requested in previous letters from the Agency (unless already submitted or not yet due). *In electronic version*	✓
This table, page 2 of the Mid-term / Final report, is completed - each tick box is filled in, in English. In electronic version only	✓

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List of Acronyms and Abbreviations

AB	Aigües de Barcelona
AMB	Àrea Metropolitana de Barcelona
AWE	Alkaline Water Electrolysis
BES	BioElectrochemical System
BOO	Build-Operate-Own
BOT	Build-Operate-Transfer
CBA	Cost-Benefit Analysis
CH_4	Methane
CHP	Combined Heat and Power
CNG	Compressed Gas Natural
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
EPC	Engineering, Procurement and Construction
FU	Functional Unit
GA	Grant Agreement
GHG	Greenhouse Gas
GoOs	Guarantee of Origins
GRT	Gas Retention Time
H_2	Hydrogen
HDVs	Heavy-Duty Vehicles
HRT	Hydraulic Retention Time
H_2S	Hydrogen Sulfide

IRR	Internal Rate of Return
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
S-LCA	Social Life Cycle Assessment
LPI	LIFE Performance Indicators
MEC	Microbial Electrolysis Cell
NG	Natural Gas
NH_4	Ammonium
NO_X	Nitrogen Oxides
O&M	Operations and Maintenance
P2G	Power-to-Gas
PA	Project Advisor
PC	Project Coordinator
TBR	Trickle-Bed Reactor
TMB	Transport Metropolitan de Barcelona
TRL	Technology Readiness Level
UAB	Universidad Autónoma de Barcelona
WWTP	Waste Water Treatment Plant

Executive summary

This report covers the overall progress of the LIFE NIMBUS project from its start in September 2020 until June 2025. Technical actions, partner coordination, project management, and communication activities have been implemented, with some deviations from the original schedule. These deviations were mainly related to delays in the design, construction, and start-up of the prototypes, which were addressed through Amendments 2 and 3, resulting in a total 19-month project extension. In addition, the withdrawal of one beneficiary was managed under Amendment 1.

Detailed technical progress is presented in Section 3, while the financial update is provided in Section 5. A summary of the main activities carried out under each action is outlined below.

- Preparatory actions: Required permit procedures for the prototype installation in Baix Llobegrat WWTP were successfully acquired in Action A1.

Implementation actions:

- Action B1: The design, construction, and commissioning of LIFE NIMBUS experienced delays due to the withdrawal of Labaqua, the consortium member primarily responsible for prototype construction. In addition, the global supply chain crisis affected the delivery timelines of several key components, and complications arose during the tender process for the Bio-Electrochemical (BES) pilot. Nevertheless, the LIFE NIMBUS solution was successfully designed, constructed, and commissioned.

- Action B2: The operation of the NIMBUS biomethanation prototype was delayed by 13 months, with construction completed in March 2023, Site Acceptance Tests in June 2023, and plant inoculation in July 2023. A further 7-month extension was granted due to accumulated delays related to ATEX certification and electrolyzer malfunctions. These delays were compensated with two project extensions (Amendment 2 and 3). The LIFE NIMBUS solution, comprising the biomethanation prototype and the BES units, was successfully operated under stable conditions. This action encompassed the implementation of an experimental and analytical plan, the optimisation of each pilot's processes, and their stable operation. The biomethanation prototype achieved a consistent biomethane production of 1,5 Nm^3/h, which was used as fuel for the NIMBUS bus.

- Action B3: An environmental, economic, and cost–benefit assessment of the LIFE NIMBUS solution was carried out against three scenarios: (1) the conventional process for natural gas (NG) production, (2) the scaled-up LIFE NIMBUS application, and (3) biomethane production with membrane integration. Results showed that NIMBUS achieved the best environmental performance, while the conventional NG process had the lowest costs due to technological maturity. Overall, LIFE NIMBUS proved the most cost-effective for urban fuel supply, particularly when combined with P2G technologies. Socially, the project generated positive impacts, with workers reporting improved skills and wellbeing, and strong value-chain acceptance confirming its deployment potential.

- Action B4: A techno-economic assessment was conducted for biomethane commercialization at the Baix Llobregat wastewater treatment plant (WWTP) under the LIFE NIMBUS project, evaluating two business models: direct on-site supply to the municipal bus fleet, and indirect distribution via injection into the NG grid for industrial or compressed natural gas (CNG) station use.

- Action B5: This action assessed the technical and economic feasibility of replicating the LIFE NIMBUS solution across Europe. Five replication cases were selected, supported by detailed technical guidelines, financial analyses, and implementation recommendations for biomethanation combined with Power-to-Gas (P2G), either for vehicle fuel or injection into the natural gas grid. A feasibility study was conducted for the Veolia facility in Ireland, and a final replication plan for the LIFE NIMBUS solution was also developed.

- Action B6: A comprehensive market and competitor analysis, identifying strong opportunities in Europe's biomethane sector was analyzed. The technology stands out as a next-generation biological methanation P2G system, enhancing methane yields, reducing operational costs, and supporting decarbonization through circular carbon management. Key markets include WWTPs, industrial organic effluent facilities, and energy operators seeking P2G solutions. The business plan outlines a phased, scalable commercialization strategy: demonstration projects, regional clusters, strategic partnerships, modular design, and robust quality assurance.

- Impact monitoring: Based on the LIFE Performance Indicators (LPI), the impact of the LIFE NIMBUS project in the environment and the resilience of climate change, as well as the project societal and economic outcomes, have been defined. Throughout the project lifetime, the impact of LIFE NIMBUS will be monitored by updating the LPIs.

- Communication Actions: In Action D1, various dissemination and communication activities were carried out, including networking with other projects, maintaining the project website and notice boards, hosting knowledge transfer webinars, presenting at workshops and conferences, producing the Layman's report and project videos, and organizing events. All activities are recorded in the project communication database.

- Project management: The LIFE NIMBUS project (Sept 2020 – June 2025) was managed through structured coordination between the project coordinator, consortium partners, the Advisory Board, and the LIFE Programme monitoring team. Executive meetings and regular technical sessions ensured alignment on objectives, milestones, and task execution, while four external monitoring meetings with ELMEN and CINEA tracked progress. The project faced challenges including post-COVID supply chain disruptions, particularly chip shortages, caused delays in industrial equipment delivery (e.g., compressors, control systems) and consortium changes. Three amendments to the Grant Agreement were approved to reassign tasks following Labaqua's withdrawal and to extend the project timeline by 19 months, addressing delays caused by ATEX certification, supply chain issues, and technical complexities with the bio-methanation prototype.

1 Introduction

The transport sector accounts for around one-third of Europe's total primary energy consumption. While energy sources such as NG and electricity have been increasingly integrated, further efforts are needed to reduce environmental impacts. In 2023, **renewable energy** comprised just **10,8%** of the transport sector's energy use—only a slight improvement from previous years and well below the EU's **2030 target of 29%** [1].

Biomethane is now emerging as a key player in decarbonising road transport: production reached **4,9 billion m³ in 2023**, with an installed capacity of **6,4 billion m³ per year** as of early 2024. However, its overall share in transport's renewable mix remains modest—and needs to scale significantly to meet emission reduction goals [2].

At the same time, **renewables accounted for nearly 47% of all electricity generated in the EU in 2024**, with solar power surpassing coal for the first time at **11%** of the mix [3]. However, the good prospects for wind and solar sources into the power mix are limited by the storage capacity of the grid and often the renewable power plants are forced to decrease the supply during low demand periods.

P2G concept is a solution to store excess of renewable energy when the power generation is higher than the demand and use it to obtain a renewable biofuel, biomethane, which can be then used for transport and thus contribute to reduce carbon dioxide (CO_2) emissions up to 88% compared to fossil NG, which goes in the direction of European standards to reduce CO_2 emissions in transport (Regulation 2019/631). Therefore, biomethane produced from P2G technologies is an opportunity to link renewable electricity generation with decarbonization of the transport sector. It also improves the circular economy between the city and the WWTP, which have a huge potential to produce biomethane, minimizing the city's overall impacts.

There are cities that have already taken actions to introduce biomethane fueled buses in their fleet, such as Stockholm, Bergen, Lille and Bristol, obtaining biomethane through different biogas upgrading technologies (separation of methane and CO_2), such as water scrubbing or membranes. However, these technologies only provide the amount of biomethane that is already in the biogas, approximately 60-65%. Biogas methanation is a P2G solution based on biological carbon hydrogenation able to convert the remaining 35-40% of CO_2 into additional biomethane, which therefore increases the renewable biofuel production potential.

The aim of the LIFE NIMBUS project is to demonstrate the P2G technology based on biological processes to produce biomethane by biological methanation and bio-H_2 by BES (Fig. 1). From a technical point of view, the main objective is to produce biomethane that accomplishes the quality to be used as a biofuel and, at the same time, store renewable energy that would be lost otherwise as gas.

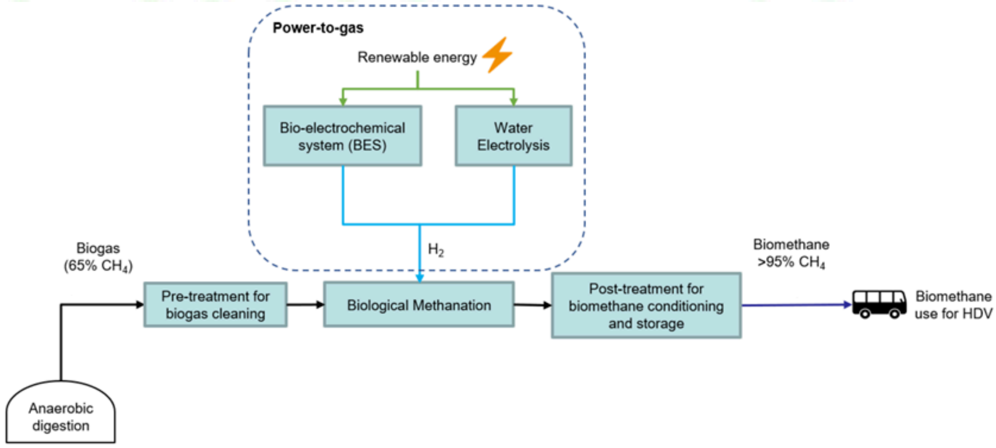


Figure 1. LIFE NIMBUS technologies

To address this objective, a biological methanation demonstration plant was designed, built, and operated at the Baix Llobregat WWTP in Barcelona. The biomethane produced by the plant was used to fuel a public bus. In addition, to improve the efficiency of energy storage, an innovative mixture of H_2 and bio-H_2 sources was evaluated.

The project demonstrates the technical and economic feasibility of a P2G solution based on biological processes, contributing to increasing the renewable energy production and therefore reducing the carbon footprint of the bus, which was one of the proposed solution's environmental benefits.

LIFE NIMBUS heads for a green energy and transport model in Barcelona based on a P2G technology in the 2.000.000 PE WWTP of Baix Llobregat (entirely supplied by renewable energy), allowing to store **10,7 toe/year of renewable energy** through biological biogas methanation. As the current use of biogas in the WWTP is cogeneration of heat and power, the solution proposed by LIFE NIMBUS allows to increase **up to 68% the efficiency of the renewable energy production**. The biomethane will be used to feed one bus that covers a daily route of 100 km of the fleet of Transports Metropolitans de Barcelona (TMB), consequently reducing **29 t CO_2 /year.**

A business model analysis for the industrial-scale implementation of the LIFE NIMBUS project at the Baix Llobregat WWTP shows that it could supply fuel for approximately 77 buses, reducing CO_2 emissions by **6.403 t/year**. The investment plan of Aigües de Barcelona (AB) could fully finance the construction of the full-scale methanation plant, with an initial estimated cost of €9 million.

LIFE NIMBUS also incorporates a replication strategy to extend the proposed P2G solution to other sites, particularly additional WWTPs. Five replication sites of different capacities are planned within the Agbar/Veolia group, along with facilities in other European countries such as Italy and Germany. In addition, WWTP in Madrid have already expressed interest in adopting the technology to power their CNG vehicle fleets.

Beyond its application in urban transportation, the technology can also enable biomethane injection into the NG grid. Furthermore, it is versatile enough to methanate not only biogas but also pure captured CO_2, paving the way for a highly circular synthetic fuel production pathway with a near-zero carbon footprint.

2 Administrative part

A description of the main **project meetings** held between September 2020 and June 2025 are detailed.

- **Kick-off meeting** took place via online on September 17, 2020 due to Covid-19 situation. Technical, administrative, financial and communication issues were reviewed.
- **First and Second external monitor meetings** were held on March 12, 2021 online and March 2, 2022 at CETAQUA facilities.
- **Executive meetings** were held on a quarterly basis to monitor the progress of the project. In addition, 2 **Advisory Board Meetings** were held during the project execution.
- **Third and Final external monitor meetings** were held on March 15, 2023 at CETAQUA's facilities and March 31, 2025 in CETAQUA facilities.

Project Management Process and Working Method. In addition, periodic technical meetings with all project beneficiaries have been held to ensure effective coordination and decision-making, with a focus on key actions to achieve project milestones. For the monitoring of the project evolution, 4 Monitoring Meetings have been held with ELMEN. A Project Management Manual provides guidance on internal procedures and reporting deadlines and has been revised periodically ensuring alignment with the evolving needs of the project.

The **organization chart of the project** is based on the interaction between the LIFE Programme, the external monitoring team, the project coordinator, the consortium, Advisory Board and the stakeholders. The External Monitoring Team assigned to the project includes Ms. Estibaliz Gabilondo, with whom there is regular and fluid communication regarding project progress, and Mr. Dimas Ramos, responsible for reviewing the KPIs.

Advisory Board. During the project, two Advisory Board meetings were organized: the first was held online on March 4, 2024, and the second took place on February 7, 2025, at the pilot plant.

Problems Encountered. Throughout the project, various challenges have arisen, including adapting the meeting format due to Covid-19 restrictions, changes in consortium members, the replacement of the Project Coordinator by Cetaqua, and a change in the Project Advisor. Despite these challenges, the consortium demonstrated adaptability and implemented effective problem-solving strategies to ensure the project's progress and success.

Amendments to the Grant Agreement. Since the project began, three amendments to the Grant Agreement have been requested and approved.

3 Technical part

3.1 Technical progress

Action A.1 Permits for the implementation	
Responsible: Aigües de Barcelona	**Status:** completed (100%)
Proposed start: September 2020 **Proposed end:** November 2020	**Current start**: September 2020 **Current end:** November 2020

Main activities during the reporting period:

AB organized a meeting to present the project to the administrative authorization which owns Baix Llobregat WWTP, the Àrea Metropolitana de Barcelona (AMB). Two presentations were pitched in front of the AMB to convince it of the interest of the project for the environment and the AMB as well as develop what would be the necessary resources to carry out the project.

AMB communicated that there was no special permit required for the implementation and operation of the prototypes and gave a green light to the project. AB periodically reports the progress of the LIFE NIMBUS project to the AMB.

Discrepancies / reasons:

None.

Current state of the action and envisaged progress until next report:

This action is 100% completed.

Deliverables (D) and Milestones (M):

MA.1 Authorization for the prototype installation in Baix Llobregat WWTP	Achieved in November 2020

Action B1. Design and construction of the power-to-gas prototype for biomethane production and supply	
Responsible: Cetaqua	**Status:** completed (100%)
Proposed start: December 2020 **Proposed end:** December 2021	**Current start**: December 2020 **Current end:** February 2023

Main activities during the reporting period:

B.1.1 Design of the pre-treatment units
B.1.2 Design of the hydrogen generation units
B.1.3 Design of the biological methanation unit
B.1.4 Design of post-treatment and storage

In the design phase of Action B1, there have been involvement from 3 different partners. For the bio-methanation prototype, there has been involvement from Cetaqua especially in order to define the pre and post-treatments necessary for the biogas and biomethane. Cetaqua has been mainly involved in the definition of the reactor needs as well as the control philosophy, while managing the project timings, budget and supervising each partner subtasks. AB has been technically involved in the location of the plant, as well as the TIE-IN work package: how to interconnect the bio-methanation prototype to the electrical, the control, the biogas, the regenerated water and the wastewater systems of the Baix Llobregat WWTP. The UAB has also been involved in the biological reaction kinetics and design strategy due to their interest in the topic.

It should be underlined, that, as required by the European Commission after awarding the LIFE NIMBUS project, a parallel, privately funded, project was executed to de-risk the reactor design and reaction kinetics. This project was internally referred to as PreNimbus, and was funded entirely by Cetaqua. Experiments on batch bio-methanation were carried out by the UAB at their laboratories under pressures ranging from 1 bara to 4,5 bara, so as to mimic the conditions that will occur in the LIFE NIMBUS bio-methanation prototype.

Furthermore, Duke University was involved in the conceptual design of the LIFE NIMBUS reactor by doing a detailed simulation of the reactor. This task defined technical specifications that could be later used by a workshop and an engineering company for the construction of the reactor.

The biomethanation prototype was designed with an initial capacity of 4 Nm^3/h of biogas and biomethane, which is the value that was used in the LIFE NIMBUS proposal. However, it was difficult finding certain equipment for the 4 Nm^3/h case, such as control valves, compressors and flow meters, so the equipment had to be greatly oversized. Thus, it was decided to aim for a biogas/biomethane capacity of 7,4 Nm^3/h.

B.1.5. Control system and automatization

All plant equipment is connected through a SCADA system, following a strict control philosophy designed to prevent gas leaks or explosion risks. This system allows the biomethanation plant to operate automatically, ensuring safe and efficient operation.

B.1.6. Construction, integration and start-up of the prototype

According to the initial schedule of the project, presented in the proposal, action B1 was to finish in December 2021, resulting in a complete constructed prototype, ready to be started.

By September 2021, there was a 2-month delay resulting from the change of Project Manager, combining the absence of project manager as well as the training period of the new Project Manager. Later, this delay has been increased up to 5-6 months by a combination of events. The departure of one of the consortium members froze the procurement process, as Labaqua, the partner that left the consortium, had a large budget on prototype construction, and the procurement budget of Labaqua had to be distributed among consortium members and approved by the financial instruments of each one of these partners.
Furthermore, the global supply crisis has had an impact on the expected delivery periods of several pieces of equipment, such as the biogas compressor.

All the equipment was installed and interconnected (Fig.2) in February 2023.

Figure 2. Bio-methanation prototype at Baix Llobregat WWTP

All of these delays have affected the methanation unit, whereas they have completely missed any impact on the BES unit, for its construction was entirely managed by UAB by subcontracting through a public tendering process. This process has proven itself to be much more straightforward and resilient, for all procurement is taken care of by the contractor, which has a much broader network of relations with suppliers.

The BES was built during the first months of 2022 in the TRABINOX S.L. facilities under a close collaboration with UAB. It was decided to build 5 out of the 15 potential cells in case some practical modifications needed to be done afterwards. The BES unit container was delivered to the Baix Llobregat WWTP during the second week of March 2022. As of March 31, 2022, only two tasks remained pending: the electrical interconnection and the physical connection to the WWTP's primary settler for water intake. The implementation of the BES prototype was completed in December 2022, and it was successfully commissioned in February 2023.

Figure 3 shows the unloading of the BES unit container and its location in relation to the primary settler. Compared to the initial layout, which planned to place the BES unit near the biomethanation reactor, it was necessary to install it closer to the primary settler to facilitate the supply of wastewater to the cells. As a result, the H_2 produced by the BES was stored in Tedlar bags and supplied to the biomethanation reactor via a virtual pipeline. In Figure 4 the arrangement of the cells can be seen.

Figure 3. Downloading and installation of the BES container

Figure 4. Detail of the cells arrangement of the BES unit

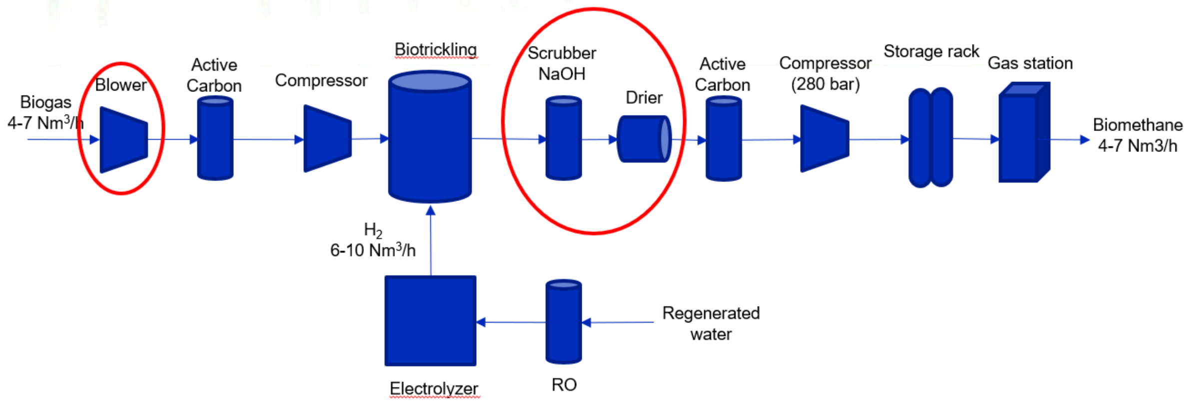
Discrepancies / reasons:

Regarding the prototypes, there are four main discrepancies regarding their construction:

- **Delays in commissioning**: Both the BES and the bio-methanation units have experienced delays, with the latter facing a more significant delay. In the case of the BES unit, the delay was primarily due to a longer-than-anticipated public tendering process managed by UAB, as well as unforeseen delays from the supplier's component providers. These issues resulted in a total delay of approximately three months, which is considered non-critical. The bio-methanation unit, on the other hand, has experienced delays of approximately five to six months, due to a combination of more complex factors. A detailed explanation of these reasons is provided in Deliverable DB1.1.
- **Higher capacity for the bio-methanation unit**: It was decided to increase the treatment capacity of the bio-methanation unit, as it was observed that economies of scale had a significant impact on costs. In fact, the capacity could be increased by 85% with only a marginal rise in expenses. Another key reason for this decision was the difficulty in sourcing equipment at the originally proposed design scale. A further explanation on the details of this higher capacity can be found in Deliverable DB1.1.

- **Spatial separation of the BES and the bio-methanation units**: The BES container unit and the bio-methanation prototype will be separated and located in different parts of the WWTP. This is done that way because it greatly helps implementation, for the primary settler and the biogas header are very far from each other in the Baix Llobregat WWTP, and for this prototype it was not cost-effective to have a gas/water pipeline crossing over 500 meters of WWTP. Although the prototypes are physically separated, the H_2 from the BES unit will be tested at the bio-methanation plant by storage and batch transportation to the prototype. This is deemed as a much simpler solution than trying to locate both prototypes next to each other or having pipeline transport. There will be no impact to the project arising from this arrangement besides a slight operating cost increase due to the need of storing that H_2. For the study of the replication cases, pipeline transportation of either biogas or primary settler water is easily enabled by economies of scale and not an implementation issue at all.

- **Modification in the treatment train of the bio-methanation unit**: If the latest pre-treatment and post-treatment train of the bio-methanation unit is compared to the early one, such as in the Kick-off meeting, it can be seen how several units have been eliminated and some others are have been added. See Figure 5 for a comparison of both process trains. Besides the more detailed depiction, in which auxiliary instrumentation and control loops can be seen, it can be noticed how the biogas blower has been suppressed, as well as the caustic soda scrubber and the drier, greatly reducing capital expenditures. However, reactor auxiliary equipment has been added, such as the nutrient feed and the recirculation pump, and there are now buffer storages and a gas odorizer piece of equipment, necessary in order for gas leaks to be detectable by smell.



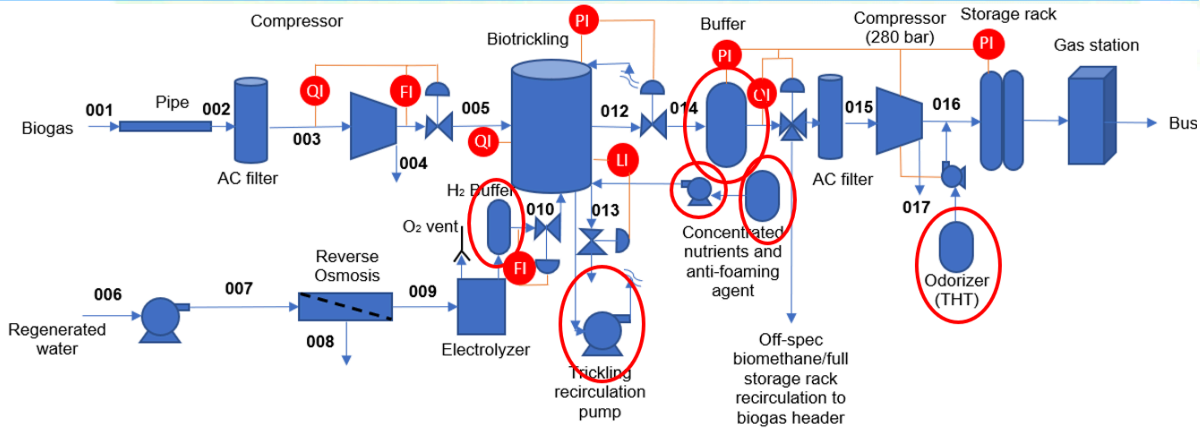


Figure 5. Original process flow diagram (up) and updated process flow diagram (down)

Current state of the action and envisaged progress until next report:

This action is completed (100%) with the LIFE NIMBUS prototype installed and commissioned.

Deliverables (D) and Milestones (M):

DB1.1 Design and technical specifications of the LIFE NIMBUS prototype	100% completed in December 2021
MB1.1 Completion of the design of the prototype	100% completed in December 2021
MB1.2 Implementation of the prototype in Baix Llobregat WWTP	100% completed in February 2023
MB1.3 Validation of functionality and performance of the prototype (mechanical tests)	100% completed in April 2023

Action B2. Start-up and operation of the power-to-gas prototype	
Responsible: Cetaqua	**Status:** Completed (100%)
Proposed start: January 2022 **Proposed end:** November 2023	**Current start**: February 2023 **Current end:** June 2025

Main activities during the reporting period:

B.2.1 Start-up of the power-to-gas prototype

The start-up sequence of the biomethanation prototype was determined based on supplier availability, process-specific requirements, and safety considerations from February 2023 to April 2023. Once all the pieces of equipment had been started up and their functionalities had been tested, a warning was issued from SADIM, the subcontractor in charge of the ATEX classification. The 3-way valves selected by Ginstalnou, the subcontractor in charge of prototype construction, did not comply with the required ATEX specifications and were replaced. This issue postponed the inoculation and start-up of the reactor, which did not take place until June 30, 2023.

After the mechanical start-up was completed and the ATEX certifier approved the entire system, biogas and H_2 were introduced into the Trickle Bed Reactor (TBR) in July 2023, following reactor inoculation. A further explanation on the details of the inoculation process can be found in Deliverable DB2.1.

The LIFE NIMBUS prototype TBR reactor was tested for biomethanation using raw biogas (~67,5% CH_4, ~32,5% CO_2, 3000 ppm H_2S) and H_2 from a 60 kW electrolyzer. During the initial semi-continuous phase (Aug–Sept 2023), methane concentrations reached 95–97%, but productivity decreased and remained low due to insufficient biofilm formation, nutrient deficiencies, and temperature fluctuations. Despite this, in September the first bus refueling was successfully carried out with 30 kg of biomethane.

Under steady-state operation (Oct 2023–Jan 2024), CH_4 productivity remained well below theoretical levels (max 47,6% CH_4 in output gas). Analyses showed strong temperature dependence (improved performance above 36°C), insufficient biofilm coverage (confirmed by boroscopy), uneven trickling distribution, and nutrient depletion (NH_4 <5 ppm). In addition, a series of mechanical problems with the electrolyzer prevented continuous operation.

Following the first advisory board's recommendation, a new inoculation strategy was implemented in March 2024: biomass concentration was tripled (12 g/m³), inoculum volume increased (1.200 L), and nutrient media optimized (NH_4 maintained >300 ppm, trace metals increased, pH stabilized at 7,4). This led to rapid biofilm growth, effective H_2 consumption, and CH_4 concentrations of 95% within days. Productivity improved tenfold compared to the first start-up, though it remained sensitive to temperature fluctuations (a 5°C drop reduced productivity by ~20%). Between March and May 2024, the system produced ~230 Nm^3 of biomethane, equivalent to ~251 km of bus travel.

The BES unit, on the other hand, was started-up much quicker than the methanation plant, as soon as electricity supply was resumed after the fire that broke out in the WWTP in November 2022. The BES prototype implementation finished in December 2022 and was started-up successfully in February 2023. Since April 2023 it has been operating in steady state, with a capacity increase by a factor of 5 completed as of August 2023.

B.2.2 Steady-state operation of the prototype and biomethane use in HDV

Since May 2024, the NIMBUS pilot plant has been running in continuous mode for 14 months, going through several operating phases. At nominal flow (7,4 Nm^3/h), CO_2 conversion was too low due to insufficient Gas Retention Time (GRT), confirming the reactor was not ready for high flow rates. The operational conditions of the methanation unit will be optimized, such as pressure, temperature or recirculation rate, increasing the flowrate gradually from 0,5 Nm^3/h to 1,5 Nm^3/h of biomethane in order to provide proper gas quality to fuel the bus. From March 2025 to June 2025 the pilot plant has been operating in continuous mode at a flow rate of 1,5 Nm^3/h, the NIMBUS system produces around 22 kg of biomethane per day, which is equivalent to approximately one-third of the bus's fuel tank.
A further explanation on the details of steady-state operation can be found in Deliverable DB2.1.

During the design phase of the plant, it was challenging to find equipment suitable for the nominal capacity of the pilot. One of the problematic pieces of equipment was the biomethane compressor, which required a minimum flow rate of 7 Nm^3/h to start up. Because of this limitation, the biomethane produced during continuous mode could not be stored. Instead, it was injected into the biogas line of the CHP motor, resulting in a 68% increase in energy production compared to using the same amount of biogas. The company Bauer Kompressor had been working on a solution to operate at lower flow rates, and starting in May 2025 they provided a new compressor capable of functioning at reduced flow rates. This finally allowed us to store the produced biomethane. In Table 1, the total biomethane produced and the kilometers traveled by the bus were summarized.

As shown in Table 1, a substantial proportion of the biomethane produced is injected into the CHP system, as storage is not technically feasible. Under these conditions, an increase of 68% in the energy efficiency of the CHP engines is achieved. If storage and subsequent use of the total methane produced for refuelling had been possible, the distance travelled by the bus would have risen from 3.028 km to 11.150 km.

Table 1. Biomethane production via biomethanation unit operation

Biogas SP (Nm^3/h)	CH_4 produced (Kg/d)	Operation Time (d)	CH_4 fed in CHP engines (Kg)	CH_4 stored for bus refueling (Km)	Total CH_4 produced (Kg)	Theoretical Km traveled by the bus (Km)
Semi-continous	3,15	100	-	513	315	513
Steady-state 0,5	7.5	80	600	-	600	1.000
Steady-state 1	15	45	675	-	675	1.125
Steady-state 1,5	22.5	227	3.600	2.515	5.100	8.512
Total			4.875	3.028	6.690	11.150

Although we had not yet reached the target kilometers indicated in the grant agreement (GA), during this period of operation we concluded that the NIMBUS technology was validated. We demonstrated that it was possible to obtain biomethane with the characteristics required for use as fuel. Furthermore, we learned many valuable lessons that were essential for scaling up the NIMBUS system and for conducting replicability studies.

Even though the project was officially concluded in June 2025, the pilot plant continued producing biomethane until the end of September 2025 so that the bus could travel additional kilometers and the engine performance using biomethane could be further analyzed.

Respecting H_2 production via BES, the 1 m³ Microbial Electrolysis Cell (MEC) pilot plant was developed and operated within a real wastewater treatment facility to evaluate its potential for H_2 production and wastewater treatment under practical conditions. The system included carbon felt anodes for microbial growth, nickel foam cathodes with an innovative dual-sheet design, and an ion-exchange membrane separating the anodic and cathodic compartments.

Tests with synthetic wastewater demonstrated efficient biofilm development, high current densities, and stable hydrogen generation, requiring a minimum applied potential of 0,4 V. When treating real urban wastewater, the MEC successfully established biofilms without external inoculation, maintained continuous H_2 production despite fluctuations in influent and temperature, and achieved average performances of 0,39 ± 0,04 A/m² current density and 2,69 ± 0,35 L H_2/m²·d. Extrapolated operation suggested a potential of 0,042 m³ H_2/m³·d.

In addition to energy recovery, the MEC contributed to organic matter removal, with COD reduction efficiencies of ~34% at 1-day HRT and ~51% at 2-day HRT. However, energy neutrality was not reached due to hydrogen losses, overpotentials, and ohmic limitations.

Green H_2 produced within the BES facility was collected using tedlar bags by the pilot plant operator and subsequently fed into the biomethanation reactor. A weekly input of 10 L of BES generated green H_2 was introduced into the biomethanation reactor.

Overall, the BES pilot demonstrated the technical feasibility and robustness of scaled-up microbial electrolysis systems in real conditions, highlighting both their potential for sustainable hydrogen production and the need for further optimization to enhance energy efficiency and scalability.

Discrepancies / reasons:

- Due to the delays in Action B1, operation of the NIMBUS biomethanation prototype was delayed 13 months. The construction of the bio-methanation prototype was not completed until March 2023 and its Site Acceptance Tests were not finished until June 2023, whereas the inoculation of the plant did not take place until early July 2023.
- Second extension of 7 months to ensure the successful demonstration of the prototype, considering steady state operation of the prototype was not possible until March 2024 after receiving the explosion protection certification.The reason for requesting the second amendment is the accumulated delay in complying with ATEX regulations for the prototype and malfunctions of electrolyzer. In March 2024 McPhy technicians replaced the faulty parts, as they were aware of these problems since they had also occurred in other units. From that moment on, and with proper maintenance on our part, we have not encountered any issues, even when operating 24 hours a day.
- The nominal production capacity indicated in the proposal was not reached due to technical reasons and the design of the plant. Reactor productivity was strongly affected by temperature and pH variations, which limited overall production. Productivity is closely related to temperature and pH, making it important to implement external measures to maintain both within the desired range.

  Additionally, it was necessary to consider that the electrolyzer can operate at a maximum of 4 barg, which is the same as the reactor pressure. Setting the reactor pressure to 3,6 barg created a slight pressure gradient, preventing the electrolyzer from supplying a flow rate of 5,5 Nm^3/h — the amount needed to achieve a biogas flow rate of 4 Nm³/h. To provide this H_2 flow, the reactor pressure had to be below 2,2 barg. Reducing the pressure while increasing the flow rate leads to a lower GRT, which limits operation at higher flow rates if the reactor does not contain sufficient biomass capable of converting CO_2 within such a short residence time.

- The bus covered fewer kilometers compared to the amount of biomethane produced. The plant reached a production capacity of 1,5 Nm³/h of biomethane, while the compressor used to store the biomethane was designed to operate with a minimum flow rate of 7 Nm³/h. This limitation did not allow biomethane to be stored for several months, until the compressor was modified.

Current state of the action and envisaged progress until next report:

This action has been fully completed (100%) through the optimization and stable continuous operation of the LIFE NIMBUS prototype. The prototype will remain in operation until September 2025, with efforts focused on increasing the kilometers covered by the bus.

Deliverables (D) and Milestones (M):

DB2.1 Report of the start-up of the LIFE NIMBUS prototype	100% completed in March 2024
DB2.2 Report of the operation of the LIFE NIMBUS prototype and biomethane use in HDV	100% completed in August 2025
MB2.1 Successful start-up of the prototype	Achieved in June 2023
MB2.2 Stable operation of the prototype	Achieved in May 2024
MB2.3 Biomethane supply to a public bus	Achieved in September 2023

Action B3. Environmental and economic assessment	
Responsible: Cetaqua	**Status:** Completed (100%)
Proposed start: April 2022 **Proposed end:** July 2023	**Current start**: December 2022 **Current end:** March 2025

Main activities during the reporting period:

In this action a comprehensive technical, environmental, and economic assessment of three distinct approaches for obtaining NG or biomethane for use in public transport were compared. These approaches are:

1. The conventional process for NG production
2. The scaled-up application of the LIFE NIMBUS project
3. The integration of membrane technology for biomethane production

The assessed scenarios take into account the planned upgrade of the Baix Llobregat WWTP, as outlined in Deliverable DB3.1, together with the results and lessons learned from the operation, as reported in Deliverable DB2.1.
This study has revealed several important lessons regarding the integration of renewable and circular technologies into urban transport systems.

B.3.1. Environmental assessment of the LIFE NIMBUS process through Life Cycle Assessment (LCA)

The environmental assessment was conducted using the LCA methodology. Environmental impacts were evaluated across various categories, including climate change, eutrophication, acidification, ozone depletion, mineral resource depletion, and water consumption. The objective of this analysis is to determine the pathway with the lowest environmental impact for the production of 60 kg of biomethane, corresponding to the FU defined as the quantity required to fuel a bus for a distance of 100 kilometers.

From an environmental standpoint, the NIMBUS scenario demonstrates the most favourable performance, achieving net negative greenhouse gas (GHG) emissions of −6,72 kg CO_2eq/FU. In contrast, the baseline scenario records emissions of +73,9 kg CO_2eq/FU. The biogas upgrading scenario also results in improved environmental outcomes compared to conventional NG, although it does not reach the performance level of the NIMBUS solution.

B.3.2. Economic assessment of the LIFE NIMBUS process through Life Cycle Costing (LCC)

The Baseline scenario is currently the most cost-effective for urban transport, reflecting the maturity of conventional NG production. The NIMBUS scenario shows higher CAPEX due to its early-stage status, but costs are expected to decline, particularly with reductions in electrolyser investment—its main cost driver. Progress in R&D and favorable market conditions will be crucial to realizing these cost reductions.

B.3.3. Social assessment (S-LCA)

The S-LCA assessed the social impacts of the LIFE NIMBUS project across its life cycle, considering stakeholders in Barcelona and beyond. Results show overall positive effects: workers reported improved skills and wellbeing, and value-chain actors expressed strong acceptance of the technology. However, community engagement was limited, and involvement from decision-makers and academia was moderate, highlighting areas for stronger institutional and social outreach in future implementation.

B.3.4. Cost Benefit Analysis (CBA)

In CBA environmental and economic parameters are jointly considered to assess the overall feasibility of the three alternatives. The NIMBUS scenario emerged as the most cost-effective solution for urban fuel supply, due to its enhanced potential for biomethane production through integration with P2G technologies. While its economic costs exceed those of the Baseline, its substantial environmental advantages result in the lowest overall costs. The Upgrading scenario, although environmentally superior to the Baseline, continues to face significant economic drawbacks, especially due to high electricity-related operational expenses.

Discrepancies / reasons:

The present evaluation incorporates findings presented during the final project meeting held on March 31, 2025 after discussions with the external monitoring team and the PO. A critical update in this analysis involves the revision of electricity cost assumptions. While initial evaluations applied a uniform tariff across all scenarios, this study differentiates between electricity sourced from guarantees of origin (GoOs) and surplus renewable energy. Following consultations with Spanish electricity distributors and energy consultancies, it was established that the cost of unused renewable surplus energy can be considered negligible. This adjustment delayed the completion of the action by two months, but it was necessary to enhance the robustness and realism of the economic and environmental comparison.

Current state of the action and envisaged progress until next report:

This action is completed and no further activities are planned.

Deliverables (D) and Milestones (M):

DB3.1 Environmental (LCA), economic (LCC), social (S-LCA) and CBA of the LIFE NIMBUS solution	100% completed in May 2025
MB3.1 Data questionnaire (for LCA, LCC and sLCA) available	100% completed in June 2023
MB3.2 LCA-LCC-sLCA data inventory available	Achieved in February 2024
MB3.3 LCA, LCC and sLCA assessment	Achieved in November 2024
MB3.4 Cost-benefit of the LIFE NIMBUS solution	Achieved in February 2025

Action B4. Business model for the biomethane trading in the site	
Responsible: Aigües de Barcelona	**Status:** Completed (100%)
Proposed start: April 2023 **Proposed end:** November 2023	**Current start**: February 2024 **Current end:** June 2025

Main activities during the reporting period:

B.4.1. Evaluation of scale-up costs

This action presents a comprehensive techno-economic analysis developed within the framework of the LIFE NIMBUS project to evaluate the commercial viability of biomethane produced at the Baix Llobregat WWTP. An exhaustive assessment that addresses both technical and economic aspects of two alternative approaches for biomethane commercialization is presented, each with distinctive characteristics in terms of infrastructure, commercial profile, and risk distribution.

The evaluation of scale up cost explores two alternative business models:

1. A direct supply model, in which biomethane is produced, stored, and supplied on-site to the municipal bus fleet via a dedicated refuelling station.
2. An intermediated model, in which biomethane is injected into the natural gas grid and distributed indirectly to end users such as industrial consumers or CNG stations.

The methodological analysis employed combines empirical data from the pilot plant, cost scaling techniques, stakeholder ecosystem mapping, and key economic indicators. The evaluation includes detailed estimates of capital expenditures and initial investment, recurring operational costs, distribution and commercialization expenses, as well as sensitivity analysis under different operational scenarios and market conditions.

In terms of infrastructure and costs, the direct model requires a higher initial investment due primarily to the construction of the on-site refueling station and additional components for local supply. Conversely, the intermediated model presents lower initial capital needs by avoiding refueling infrastructure costs, although it includes investments in grid connection and metering systems. Annual operational costs are comparable between both models, reflecting identical production processes and similar output volumes.

B.4.2. Development of a business model for the biomethane trading

The first model analyzed is the direct supply model, where biomethane is produced, purified, and stored directly at the WWTP facilities to subsequently supply it to the metropolitan bus fleet through a dedicated refueling station located at the plant itself. This approach prioritizes local decarbonization and promotes circular economy principles by converting organic waste generated at the treatment plant into a clean energy source for urban public transport. The model allows complete operational control over the entire biomethane value chain, from production to final distribution, eliminating the need for injection into the natural gas grid.

The second model evaluated is the intermediated or grid injection model, where the produced biomethane is injected into the existing natural gas network, enabling its indirect distribution to various end users such as industrial consumers, gas suppliers, and compressed natural gas stations. This approach offers greater commercial flexibility and scalability by decoupling production from local consumption, leveraging existing gas infrastructure to access a broader market.

A significant difference is found in distribution and commercialization costs, where the direct model maintains minimal expenses related primarily to legal contracts and certification, while the intermediated model incurs substantial fees for grid access, injection rights, and regulatory compliance procedures.

The stakeholder mapping identifies and categorizes key actors involved in the deployment of each business model throughout the entire biomethane value chain. In the direct model, the ecosystem centers on a short distribution chain with actors such as the WWTP operator, transport fleet manager, infrastructure contractors, and regional mobility authorities. The intermediated model extends the value chain through regulated gas infrastructure, involving network operators, gas system coordinators, and downstream suppliers.

The economic viability analysis employs standardized financial indicators including Levelized Cost of Biomethane, Minimum Viable Selling Price, Net Present Value, and Internal Rate of Return. Results confirm that both configurations are economically viable, although their strategic profiles differ significantly. The direct model provides local impact and control, while the intermediated model offers greater scalability and market integration.

The sensitivity analysis evaluates economic robustness under variable operational conditions, including full-load operation scenarios and different energy cost structures. Results demonstrate that both models benefit significantly from higher utilization rates, with the intermediated model showing greater sensitivity to scale due to its more favorable cost structure under high-volume scenarios.

Regarding financing strategies, the document recommends blended financing approaches that combine public support instruments with structured private sector engagement. This includes public-private partnerships, access to European-level financing mechanisms, long-term purchase agreements, and energy service company models to improve bankability and reduce risk exposure.

The proposed iterative negotiation process establishes a structured framework for transitioning from concept to implementation, including bilateral technical-commercial dialogues, multilateral roundtables, and strategic facilitation by public authorities. This process is essential for translating strategic options into operational agreements between stakeholders and securing the regulatory, financial, and contractual conditions necessary for deployment.

The study's conclusions confirm that both business models represent viable and strategically relevant pathways for biomethane commercialization, each responding to distinct operational realities and policy objectives. The direct model offers complete control over the production and supply chain with local environmental impact, while the intermediated model leverages existing gas infrastructure to access a broader market and aligns with national energy integration policies. The document provides a solid foundation for informed decision-making and offers a replicable analytical framework for other urban and industrial environments seeking to valorize wastewater-derived biomethane.

Discrepancies / reasons:

The activities under this action commenced one year later than initially proposed, once stable operation and validation of the NIMBUS technology had been achieved.

Current state of the action and envisaged progress until next report:

This action is completed and no further activities are planned.

Deliverables (D) and Milestones (M):

DB4.1 Business model of the biomethane in the site of Barcelona	100% completed in July 2025
MB4.1 Completion of the scale-up of the technology	Achieved in October 2024
MB4.2 Completion of the business model in the site of Barcelona	Achieved in June 2025

Action B5. Replication of the technical solution	
Responsible: Cetaqua	**Status:** Completed (100%)
Proposed start: August 2022 **Proposed end:** July 2023	**Current start**: February 2024 **Current end:** June 2025

Main activities during the reporting period:

B.5.1 Detailed feasibility assessment and replicability of the technology in Sète WWTP

This action presents a comprehensive feasibility assessment and replicability study of the LIFE NIMBUS solution, which integrates biogas upgrading with P2G technology to produce renewable biomethane. The main actions carried out encompass a detailed technical and economic analysis conducted at a Veolia sludge treatment facility (STF) in Ireland, where the study evaluated implementing NIMBUS technology to convert biogas into biomethane using H_2 produced through alkaline water electrolysis (AWE) powered by surplus wind energy. A detailed inventory of the Irish STF will be developed, encompassing existing sewage sludge treatment methods, volumes of biogas currently generated, fuel consumption associated with sludge transportation, and the availability of local renewable energy sources. This information, in combination with the operational data collected from the Baix Llobregat WWTP prototype and its subsequent scale-up under Action B4, have served as the foundation for a comprehensive technical analysis. This analysis includes system configuration design, projections of biomethane production potential, and an evaluation of the associated environmental benefits, particularly the reduction of GHG emissions.

A LCC methodology was applied, revealing a total CAPEX of €7,1 million with H_2 production via AWE representing the largest investment share at 36%. The cost-benefit analysis demonstrated a 39% reduction in total costs compared to baseline scenarios when environmental benefits are monetized, achieving a payback period of 7,5 years and minimum viable selling price of €1,39/m³ for biomethane.

B.5.2 Identification and preliminary contact of 2-4 sites at European level suitable for replication and transfer

For the replicability study, the analysis considered various application contexts of the NIMBUS technology, including the availability of renewable energy, biogas production levels, CO_2 emissions, applicable regulatory frameworks, and objectives for promoting sustainable transportation.

Four detailed case studies were conducted across different European contexts:

- Italy (Lombardy Region): Implementation at the Depuratore Sud-Est Milano WWTP operated by CAP Group, designed to supply biomethane to public transport. The study assumed 6 hours daily of surplus renewable energy availability, enabling production of 80 m³ of biomethane per day with a CAPEX of €2,2 million.

- Germany (Stuttgart WWTP): Leveraging Germany's 457 hours of negative electricity prices in 2024, this case study evaluated continuous 24-hour H_2 production to generate 1.920 m³ of biomethane daily for public transport, with total investment costs of €3,3 million.

- Spain (Sabadell Riu Ripoll WWTP): Integration with solar energy surpluses to produce 960 m³ of biomethane daily for urban transport decarbonization, requiring €4,1 million investment and operating during 6-hour daily windows of surplus renewable electricity.

- Italy (Sardinia Cement Facility): Innovative CO_2 capture and utilization approach at an industrial cement plant, producing 600 m³ of synthetic biomethane daily with a CAPEX of €5,3 million, demonstrating industrial sector applications.

Comprehensive environmental impact assessments were conducted using ISO 14040 and ISO 14044 standards with SimaPro software and ReCiPe Midpoint methodology, with all scenarios demonstrating significant environmental advantages and achieving net negative GHG emissions ranging from -2,2 to -45 tCO2eq across different applications, primarily due to avoided emissions principles and fossil fuel displacement. The study included detailed identification of target groups and beneficiaries for each case study, encompassing WWTP operators, regional authorities, public transport operators, energy companies, and local communities, with identified benefits including new revenue streams, reduced environmental footprints, improved air quality, and enhanced energy security.

Specific technical configurations were designed for each application, incorporating biogas upgrading systems, hydrogen storage solutions, biomethanation reactors, and biomethane refueling stations or grid injection systems, addressing integration challenges with existing infrastructure and operational requirements.

Detailed financial simulations were performed using direct supply models, incorporating CAPEX amortization, operational costs, revenue projections, and sensitivity analyses, while identifying critical success factors including access to low-cost renewable electricity, supportive regulatory frameworks, long-term off-take agreements, and blended financing mechanisms.

The study also conducted comprehensive analysis of national and regional policy frameworks for each country, identifying opportunities and barriers for NIMBUS deployment through examination of renewable energy targets, transport decarbonization policies, biomethane incentive schemes, and EU-level initiatives like the Green Deal and REPowerEU, ultimately concluding that NIMBUS technology demonstrates strong technical viability across diverse European contexts with particular promise in regions experiencing high renewable energy curtailment, recommending prioritization of deployment in areas with established biogas infrastructure, surplus renewable generation, and supportive policy environments while ensuring access to blended financing mechanisms combining public support with private investment.

B.5.3 Replicability and transferability plan of the solution

The LIFE NIMBUS project has achieved significant technical maturity with a Technology Readiness Level (TRL) of 7-8, demonstrating consistent production of high-quality biomethane with methane concentrations reaching up to 98% in operational conditions at the Baix Llobregat WWTP in Barcelona.

The technology's core innovation lies in its biological methanation approach, which offers a sustainable alternative to conventional chemical-physical upgrading technologies. The system features a modular design that enables efficient integration with existing anaerobic digestion infrastructure across diverse WWTP and sludge treatment facilities. This modularity ensures high interoperability and adaptability to different plant scales, configurations, and operational models, while maintaining compatibility with multiple H_2 supply sources including water electrolysis and emerging green H_2 technologies.

The comprehensive replicability and transferability plan identifies three main categories of implementation barriers: technological/technical, economic, and legislative. From a technical perspective, the system requires medium-level sophistication with precise control of biological reactor conditions and safe H_2 handling, but can be effectively operated by trained WWTP staff. The technology demonstrates excellent transferability potential due to its modular design and compatibility with existing infrastructure.

Economically, the system creates multiple value streams by converting both biogenic CO_2 from anaerobic digestion and non-biogenic CO_2 from industrial sources into valuable biomethane. This enables operators to valorize excess renewable electricity, reduce energy purchase costs, and generate additional revenue through grid injection or bio-CNG supply for transport applications. The expected return on investment ranges from 3-5 years, depending on factors such as surplus renewable electricity availability, local incentives, investment costs, and revenue streams from biomethane sales and emission certificates.

The strategic deployment plan prioritizes initial implementation in Spain, leveraging strong political and institutional support for biogas and biomethane production, favorable renewable energy conditions, and recent regulatory developments including Royal Decree 1085/2024. This provides a stable framework for renewable gas production while establishing clear guidelines for biomethane quality certification and grid injection mechanisms. Future expansion targets high-potential markets in Italy, Germany, and Ireland, where extensive anaerobic digester infrastructure and surplus renewable energy generation create optimal conditions for technology adoption.

The implementation strategy follows a structured five-phase approach spanning 44 months: Phase I involves comprehensive target plant analysis (0-6 months), Phase II focuses on feasibility studies and customization (6-12 months), Phase III develops detailed implementation plans (12-24 months), Phase IV encompasses operation and monitoring (24-42 months), and Phase V evaluates impact and scalability (36-44 months). This systematic approach ensures progressive and controlled scaling while maintaining technical robustness and stakeholder engagement.

Discrepancies / reasons:

- During the preparation of the project proposal, CETAQUA was part of the SUEZ Group. However, following Veolia's acquisition of both CETAQUA and AB in November 2021, it became necessary to revise the original feasibility study plan. Due to organisational restructuring, the previously designated site—the Sète WWTP in France—was no longer available for the study. Consequently, another facility within the Veolia Group was selected to conduct the assessment.
- The activities under this action commenced 18 months later than initially planned, once stable operation and validation of the NIMBUS technology had been achieved, and after identifying an alternative facility to replace the Sète WWTP in France, for the reason explained in the previous point.

Current state of the action and envisaged progress until next report:

This action has been completed. However, during the workshop with stakeholders held on May 22, 2025, Canal de Isabel II and AQUAMBIENTE—the company in charge of operating the Butarque WWTP in Madrid—there was strong interest in using the NIMBUS prototype at their WWTP for biomethane production. A technical and economical proposal was prepared in order to combine the rejected CO_2 from the existing biogas upgrading system with H_2 supplied either by an AWE or directly from a H_2 refueling station located near the plant. The biomethane produced would be intended for vehicular use.

The plant is expected to produce 1,5 Nm^3/h of biomethane, which, assuming 330 days of continuous operation, corresponds to about 45.144 kWh/year of renewable energy. This level of biomethane production would be sufficient to cover approximately 13.000 km/year. The resulting CO_2 emission reduction over 330 days of operation is estimated at 870 kg CO_2/year.

The CAPEX for transferring and implementing the NIMBUS prototype from Baix Llobregat WWTP to Butarque WWTP is estimated at 200.000 €, including personnel training as well as support during start-up and operation in the first year.

Deliverables (D) and Milestones (M):

DB5.1 Feasibility assessment and replicability of LIFE NIMBUS solution in Sète WWTP	100% completed in August 2025
DB5.2 Replicability and transferability plan of LIFE NIMBUS solution	100% completed in August 2025
MB5.1 Identification of 2-4 sites at European level suitable for replication and transfer	Achieved in October 2024
MB5.2 Completion of the feasibility assessment for Sète WWTP	Achieved in May 2025
MB5.3 Completion of the replicability and transferability plan	Achieved in June 2025

Action B6. Business plan of the technology	
Responsible: Cetaqua	**Status:** Completed (100%)
Proposed start: February 2023 **Proposed end:** November 2023	**Current start**: February 2024 **Current end:** June 2025

Main activities during the reporting period:

B.6.1. Market and competitor analysis

A thorough market analysis was undertaken to evaluate the potential of the LIFE NIMBUS technology within the evolving renewable gas landscape. The study provides an in-depth overview of current dynamics in the European biomethane sector, highlighting both the structural barriers that could hinder expansion and the opportunities that can drive future growth. It also presents a detailed competitive landscape, benchmarking LIFE NIMBUS against leading players developing comparable technologies—including Electrochaea, MicrobEnergy, GICON, Micro-Pyros, and BiogasClean—as well as major biogas upgrading companies such as Greenlane, Air Liquide, and Smack Carbotech.

From this comparative assessment, LIFE NIMBUS emerges as a next-generation solution: an innovative biological methanation P2G system specifically engineered to maximize the efficiency, scalability, and sustainability of biogas valorization. Unlike conventional approaches, the technology demonstrates added value from a customer perspective by improving resource utilization, reducing operational costs, and delivering significant environmental benefits through circular carbon management.

One of the defining features of LIFE NIMBUS is its integration of green H_2 into the biomethanation process. This not only enhances methane yields but also contributes to decarbonization by coupling renewable electricity with biogenic CO_2 streams. Part of the H_2 required can be generated on-site using a BES, which operates at less than half the energy demand of traditional electrolysis methods. While this BES technology is still under development and not yet ready for large-scale deployment, it represents a promising pathway for future optimization and cost reduction in hydrogen supply.

Market analysis identifies substantial opportunities across multiple segments, including WWTPs, industrial facilities with organic effluents, and energy operators seeking P2G solutions.

B.6.2. Detection and description of most adequate business models for the technology

The market assessment highlights the rapid expansion of biomethane adoption across Europe, largely propelled by ambitious sustainability policies and the pressing need to secure energy independence. Within this evolving landscape, several viable business models have been identified, ranging from grid injection and commercialization, the use of biomethane as a transport fuel, and its deployment as an industrial feedstock, to more advanced hybrid energy solutions and locally embedded circular economy initiatives.

LIFE NIMBUS positions itself as a key solution for decarbonization and the transition towards a low-carbon circular economy. Its technical replicability in over 11.000 biogas plants in Europe reinforces its scalability potential. However, to maximize its impact, it is crucial to address challenges such as regulatory disparities among EU member states and social resistance to biofuel plants. It is recommended to promote public education and community engagement to enhance social acceptance.

The business model combines three revenue streams: EPC (Engineering, Procurement and Construction) contracts, technology licensing, and long-term operation and maintenance services. Financial projections demonstrate robust economic viability with an Internal Rate of Return (IRR) of 23%, a payback period of approximately 3.5 years, and a target deployment of 70-80 plants over 20 years, with a projected cumulative value exceeding €600 million.

B.6.3. Development of a business plan for the technology

The LIFE NIMBUS business plan outlines a comprehensive marketing, sales, and operational strategy for successful market deployment. The marketing and sales approach is built on a positioning strategy that emphasizes three fundamental pillars: superior environmental efficiency through direct CO_2 to methane conversion, circular economy integration with existing WWTP infrastructure, and full alignment with EU regulatory frameworks and green initiatives.

The commercialization strategy targets multiple market segments, including WWTP operators, municipal consortia, industrial facilities with organic effluents, energy companies requiring P2G solutions, and public entities. To reach these segments, LIFE NIMBUS employs various commercialization channels, including strategic alliances with engineering firms and EPC contractors, development of demonstration plants as reference cases, active participation in public tenders, and collaboration with utilities and gas operators. The plan also emphasizes presence in trade fairs and industry platforms to build market visibility and credibility.

The operational plan is structured around a robust production strategy that leverages modular design with selective subcontracting to certified EU workshops. Quality assurance is maintained through strict protocols and Factory Acceptance Tests, while integration of auxiliary systems is handled by specialized biogas integrators. Each installation includes site-specific engineering adaptations to ensure optimal performance in different contexts.

The installation and commissioning process offers flexible contractual execution models, including EPC and BOT/BOO options, supported by a structured commissioning process that includes biological start-up and comprehensive performance validation protocols. After-sales support is a key component, featuring preventive maintenance programs, on-site technical training, remote monitoring via SCADA systems, and long-term O&M service contracts.

The scale-up strategy adopts a phased approach, beginning with demonstration projects and developing regional clusters to maximize economies of scale. This is supported by progressive expansion through strategic partnerships and standardized quality and environmental compliance protocols. A typical project implementation timeline spans 17-29 months, encompassing feasibility studies, engineering, manufacturing, installation, and commissioning phases.

The operational model strongly emphasizes sustainability and environmental compliance, aligning with EU Green Deal objectives and facilitating access to green financing. This comprehensive approach ensures controlled market penetration while maintaining high quality standards and building long-term customer relationships, supporting the overall business objective of deploying 70-80 plants over 20 years.

This integrated marketing, sales, and operational strategy is designed to ensure successful commercialization of the LIFE NIMBUS technology while maintaining quality, performance, and replicability across different markets and applications.

Discrepancies / reasons:

The activities under this action commenced one year later than initially proposed, once stable operation and validation of the NIMBUS technology had been achieved.

To establish the commercial viability of the solution, a comparative study is conducted with the BiogasClean case, which, at the time of this report, is the only full-scale project employing the same technology as LIFE NIMBUS. In this context, direct engagement with the company Biogasclean was established, to gain a deeper understanding of the technology employed. Initially through an online meeting, and subsequently during a visit to the NIMBUS pilot plant by a BiogasClean representative on 23rd May 2025, a valuable exchange of knowledge was established between the two biomethanation projects.

Current state of the action and envisaged progress until next report:

This action is completed and no further activities are planned.

Deliverables (D) and Milestones (M):

DB6.1 Market and competitor analysis	100% completed in January 2025
DB6.2 Business plan of the LIFE NIMBUS technology	100% completed in July 2025
DB6.3 Draft of the business plan of the LIFE NIMBUS technology	100% completed in January 2025
MB6.1 Completion of the market and competitor analysis	100% completed in December 2024
MB6.2 Completion of the business model of the technology	Achieved in June 2025
MB6.3 Completion of the business plan of the technology	Achieved in June 2025

Action C1. Monitoring of the impact of the project actions	
Responsible: Cetaqua	**Status:** Completed (100%)
Proposed start: September 2020 **Proposed end:** November 2023	**Current start**: September 2020 **Current end:** June 2025

Main activities during the reporting period:

C.1.1 Quantification of LIFE Performance Indicators

The project progress has been assessed towards the defined quantified expected results and impacts. Main technical KPIs are presented in the following table 2:

Table 2. Main technical KPIs

Indicators	GA	End of project
Biomethane flow rate	4 Nm^3/h	1,2 Nm^3/h
Energy (gas) from Renewable Energy Sources	29 toe/year	10,7 toe/year
Biomethane Production for Public Transport	48.000 km	3.028 km
Reduction of GHG emissions	72 tCO_2/year	10,4 tCO_2/year
Reduced resource consumption (excluding energy)	9%	3,2%
Cost-Effective Hydrogen Production Technologies	OpEx < 2 or 3 times conventional AWE	OpEx BES: 16,22 €/FU OpEx AWE: 40,52 €/FU

Other LPIs were defined at the beginning of the project (see Deliverable DC1.4) and reviewed throughout the whole project execution. A revision in the Mid Term was presented in Deliverable DC1.1 and the final evaluation at the end of the project was presented in Deliverable DC1.3 and uploaded in the snapshot of webtool. In Table 3 are presented the main technical LPIs.

Table 3. LIFE Performance Indicators

Specific Context	Indicator	Start Value	End Value	Beyond End Value	Unit
NIMBUS	Project area/length	0	0,08	34,5	ha
Replication of the solution	Project area/length	0	0	24,1	ha
NIMBUS	Renewables production	22.334.400	22.370.515	37.382.400	kWh/year
Replication of the solution	Renewables production	15.701.023	15.701.023	26.279.827	kWh/year
NIMBUS	Greenhouse gas emission	1.251.289	1.248.286	0	kg CO_2/year
Replication of the solution	Greenhouse gas emission	687.850	687.850	0	kg CO_2/year
NIMBUS	Greenhouse gas emission	0,806	0,804	0	kg CO_2/km
Replication of the solution	Greenhouse gas emission	0,372	0,372	0	kg CO_2/km

Discrepancies / reasons:

Energy (gas) from Renewable Energy Sources - Reduction of GHG emissions - Reduced resource consumption: The values reported in Table 2 are based on average biomethane production flow rate of 1,2 Nm³/h, achieved under stable continuous operation between May 2024 and June 2025 plus an additional 3 months of operation beyond the project's official end, from July to September 2025. The nominal production capacity outlined in the project proposal was not fully reached (4 Nm³/h), primarily due to technical constraints and design limitations of the plant.

Although the target values specified in the GA have not yet been met, the operational performance during this period supports the validation of the NIMBUS technology. The system has successfully demonstrated its ability to produce biomethane with the required specifications for fuel use. In addition, the operation has yielded valuable insights that will be critical for the future scale-up of the NIMBUS system and for upcoming replicability studies (see Deliverable DB2.2).

Biomethane Production for Public Transport: As detailed in Deliverable DB2.2, during most of the 14-month continuous operation period—when the system operated at flow rates ranging from 0,5 to 1,5 Nm³/h—the biomethane produced was injected into the CHP unit of the Baix Llobregat WWTP. This was due to technical constraints associated with the minimum suction flow rate of the MFE120 high-pressure compressor, which prevented the storage of biomethane for use in mobility applications.

In May 2025, following the replacement of the high-pressure compressor, this limitation was resolved. From that point onward, the biomethane produced could be stored and used to fuel heavy-duty vehicles (HDVs). As a result, a total of 3.023 km was achieved by the demonstration bus, using:

- biomethane generated during the semi-continuous operation phase, and
- biomethane stored between May and July 2025, when the plant operated in continuous mode at 1,5 Nm^3/h.

To further increase the amount of biomethane available for refueling, the operation of the pilot plant was extended until September 30, 2025. During this two-month extension, approximately 1.350 kg of biomethane was produced. This brought the total distance travelled by the demonstration bus during the project to approximately **5.273 km**.

In total, during the 14-month operational period, the pilot plant produced 6.690 kg of biomethane that met the required specifications for use as vehicle fuel. Without the storage limitations imposed by the original compressor, this volume of biomethane would have enabled the bus to travel an estimated 11.150 km.

Current state of the action and envisaged progress until next report:

This action is completed.

Deliverables (D) and Milestones (M):

DC1.1 LIFE Performance indicators including socio-economic impact – Mid-term Report revision	100% completed in March 2022
DC1.2 LIFE Performance Indicators including socio-economic impact – Final Report	100% completed in September 2025
DC1.3 Performance comparison with other methanation technologies	100% completed in August 2025
MC1.1 Impact effectiveness indicators achieved (at the end of the project)	Achieved in June 2025

Action D1. Dissemination and communication	
Responsible: Cetaqua	**Status:** Completed (100%)
Proposed start: September 2020 **Proposed end:** November 2023	**Current start**: September 2020 **Current end:** June 2025

Main activities during the reporting period:

D.1.1 Networking with other projects

LIFE NIMBUS has participated in 7 networking meetings or events with other topic-related projects funded by the EU in order to create synergies and share learnings and results. The projects with which LIFE NIMBUS has carried networking activities are: LIFE Eggshellence, LIFE AGROPAPER, LIFE AUGIA, LIFE BIOREFFORMED, LIFE CB2U, LIFE FutureForest, LIFEFORFIT, LIFEproETV, LIFE BIOGASNET, EU Rise Project RECYCLES, SEMPRE-BIO, H2020 BIOMETHAVERSE, BIOMETAGAS LA GALERA, and Proyecto Ecofactoría Biometano. In addition, LIFE NIMBUS has also taken part in networking meetings with the BiogasClean company.

LIFE NIMBUS has been presented, either orally or with a poster, in 5 national events, 8 local/regional events, and 13 European/international events.

More detailed information can be found in the deliverable DD1.9 Networking activities report, as well as in the Communication Database, submitted to the EC portal as an independent deliverable.

D.1.2 Dissemination planning and development of the Dissemination Pack

Within the first months of the project, the logotype and entire visual identity of LIFE NIMBUS were created. Based on the visual identity, a set of different templates was delivered, as well as a Graphic Identity Manual to guarantee the coherence of the brand. Also during the first 6 months, a Communication and Dissemination Plan was defined by Cetaqua and validated by all the project partners, a Communication Database was settled and shared with all the partners as a key tool to keep track of all the upcoming communication actions, and a website was created with the aim of presenting the project and its objectives, and of keeping all the audiences informed through news (19), event posts (30) and blog articles (13). During the lifetime of the project, the website has got 6.107 views (115 unique visits/month) (Fig.6).

Figure 6. Screenshot of unique visits in the website tracked by Matomo from May 2022 to June 2025

In an initial phase of the project, an informative brochure, an infographic and a short animated video were created and promoted through social media and the project website. In addition, this video was also displayed at Barcelona's subway stations to promote the project among Barcelona citizens.

During the second phase, the pilot was branded with vinyls and stickers, the NIMBUS bus was also labeled, and one notice board was designed and installed at the Baix Llobregat WWTP. Also, visits to the plant began, with more than 100 attendees in total. With the aim of ensuring the maximum number of people interested could discover the pilot plant, a virtual tour that shows the plant and the processes undertaken in an easy way was also launched both in Spanish and English, gaining more than 200 virtual visits.

In order to reach a broader audience, the project has launched 5 press releases with the participation of all partners, and thanks to this effort it has appeared several times in local (40 times), national (25), and international (5) general media outlets, and in national (30 times) and international (5) technical media outlets (mainly focused on water, energy and transport).

Additionally, LIFE NIMBUS was featured in three technical articles: "CoSin, hacia la neutralidad climática con la producción de gas renovable a partir de biogás", published by *TecnoAqua*, "LIFE NIMBUS apuesta por transformar lodos de depuradora en biometano para acercar a Barcelona a la neutralidad climática" by *IndustriAmbiente*, and "LIFE NIMBUS: From Wastewater to Green Fuel" by *EU Researcher*, and two scientific papers have been published within the project: "Exploring key operational factors for improving hydrogen production in a pilot-scale microbial electrolysis cell treating urban wastewater", published by the *Chemical Engineering Journal*, and "Enhancing bioelectrochemical hydrogen production from industrial wastewater using Ni-foam cathodes in a microbial electrolysis cell pilot plant", published by *Water Research*. Full details can be found in the Communication Database.

Other actions undertaken throughout the project have been the launch of social media campaigns by different consortium members, resulting in 143 posts among X (formerly Twitter), LinkedIn, Facebook, TikTok and Instagram to give visibility to the project and share the latest news, and the organisation of 2 webinars, one in 21/3/2023 and another one in 15/11/2023 (hybrid stakeholders workshop). These webinars aimed to disseminate the knowledge generated during the project among potential end-users, the scientific community, similar projects and key decision makers.

During the final phase, LIFE NIMBUS organised a stakeholders workshop in the Baix Llobregat WWTP to present the project's objectives, results, and benefits among interested audiences, and that included a visit to the plant. In total, over 200 people attended the workshops and/or webinars.

LIFE NIMBUS also celebrated a final event on 18/6/2025 that gathered 63 people from the water, public transportation and energy sectors, as well as from scientific community, and public administration, to present the results and discuss the continuation of the project.

To present the final results among a wider audience, a final video and a Layman's report were also produced and shared on the project's website and social media channels.

Discrepancies / reasons:

The implementation of the notice board in the project's pilot plant was planned for April 2022, but instead, it was installed in January 2023 along with the prototype implementation/start-up.

MD1.4 related to website performance has not been fully achieved due to visits tracking issues, which affected the number of reported visits. It is important to note that data is only available from May 2022, as there was a period of transition between the tracking tool used at the beginning of the project and the tracking tool used currently in which information was lost. That implies that the first year of the website accounts for 0 visits. If only data from 2022 onwards was considered, the average would rise to 170 unique visits/month.

LIFE NIMBUS has carried out extra tasks not foreseen in the proposal, such as press releases or the virtual tour.

DD1.7 Layman's report was submitted in August 2025 in order to include LIFE NIMBUS final results and conclusions.

Finally, **following the indications provided during the monitoring meeting,** the virtual tour was translated to English, and, in Aigua de Barcelona's TikTok related to LIFE NIMBUS, the logo indicating the LIFE Programme's support was included.

Current state of the action and envisaged progress until next report:

This action is completed. Further communication and dissemination activities are planned as described in Action E2.

Deliverables (D) and Milestones (M):

DD1.1 Logo and templates	100% completed in November 2020
DD1.2 Communication Plan	100% completed in November 2020
DD1.3 Short promotional video	100% completed in February 2021
DD1.4 Promotional Leaflet	100% completed in February 2021
DD1.5 Notice Board	100% completed in January 2023
DD1.6 Final video	100% completed in June 2025

DD1.7 Layman's report	100% completed in August 2025
DD1.8 Website of the project	Achieved in February 2021
DD1.9 Networking activities report	Achieved in March 2025
MD1.1 Website availability	Achieved in February 2021
MD1.2 Final dissemination event	Achieved in June 2025
MD1.3 Reaching 50% of stakeholders under awareness raising	Achieved in March 2025
MD1.4 Reaching 1.800 website visits every 12 months as 150 visits are planned monthly	75% achieved. Partially achieved due to issues in website visitors tracking tool

Action E1. Project management	
Responsible: Cetaqua	**Status:** Completed (100%)
Proposed start: September 2020 **Proposed end:** November 2023	**Current start**: September 2020 **Current end:** June 2025

Main activities during the reporting period:

CETAQUA coordinated the technical and administrative aspects of the project through continuous communication with project partners to coordinate technical activities and supervise the financial aspects, the organisation of consortium meetings every six months, communication with ELMEN and the EC when required, and the coordination and revision of deliverables and reports.

- **Kick-off** meeting took place online due to the coronavirus pandemic, on September 17th, 2020. Technical, administrative, financial and communication issues were reviewed with all the consortium partners.
- **First external monitoring meeting** was held online again due to the coronavirus pandemic on March 12th, 2020. The LIFE Programme External Monitor of LIFE NIMBUS, Ms. Estibaliz Gabilondo explained the main rules of the LIFE program and an update of the project status was done.
- **Second monitoring meeting** was held in the Cetaqua offices in Barcelona the 2nd of March, 2022.
- **Third external monitor meeting** was held on March 15, 2023 in CETAQUA facilities.
- **Final external monitor meeting** was held on March 31, 2025 in CETAQUA facilities. The LIFE Programme External Monitor for LIFE NIMBUS (ELMEN), Ms. Estibaliz Gabilondo, together with the Project Advisor (PA) from the CINEA agency, Ms. Nadia Lamhandaz, visited the pilot plant. During the meeting, the project status, results, and ongoing tasks were presented and discussed.
- **Executive board meetings** have been held with recurring frequency in order to tackle technical and managerial issues, such as subtask allocation and budget control. Two meetings have been held with the entire executive board, although many more partial consortium meetings have been held for the technical issues. The meetings were initially held on a monthly basis during the prototype design phase, and subsequently every three months during the operation phase. In the first meeting, held on November 19, 2021, it was agreed that an amendment would be submitted to ensure the achievement of all project objectives, following LABAQUA's withdrawal from the consortium. Cetaqua, AB, and UAB assumed responsibility for carrying out LABAQUA's tasks, guaranteeing that prototypes were constructed, testing was

properly executed and technically assessed, and that the biomethane was used in the urban bus. In the subsequent meetings, discussions focused on design, construction, delays, operations, and dissemination activities.

- **Gantt chart** of the project was periodically updated
- **Reporting to EC:** Mid-term report
- **Project management manual:** updated after major changes (departure of Labaqua)
- **Advisory Board.** During the project, two Advisory Board meetings were held. The first meeting took place on March 4, 2024 (online), where project progress, biomethane productivity data, and strategies for restarting production were reviewed. On February 7, 2025, Advisory Board members visited the biomethanation pilot plant to assess the current project status, including recent achievements, challenges encountered, and milestones reached.

Three amendments to the Grant Agreement were submitted and approved, resulting in a total project extension of 19 months.

- **First amendment (February 2022):** Triggered by the voluntary withdrawal of Labaqua from the consortium, following a change in the partner's strategic interests. As a result, the consortium redistributed the remaining tasks, actions, and budget among Cetaqua, AB, and UAB.

- **Second amendment (August 2023):** Requested due to significant delays in *Action B1* (design, tendering, construction, and commissioning of the prototype). These delays stemmed from unforeseen challenges, including the change in Labaqua's business orientation after the acquisition of Suez by Veolia, global supply chain disruptions in the post-COVID period, and the need to obtain two additional certifications that had not been anticipated during the proposal or design stages. Since the construction of the prototype was only completed in March 2023, a 12-month extension was granted to allow sufficient time for demonstration activities and to ensure the expected results of the LIFE NIMBUS project.

- **Third amendment (July 2024):** Required due to additional delays in compliance with ATEX regulations. The prototype could not reach steady-state operation until March 2024, when the explosion protection certification was finally obtained. Furthermore, technical malfunctions of the electrolyzer contributed to the delay in start-up and operation of the bio-methanation prototype. To ensure an adequate demonstration period and the achievement of project objectives, a further 7-month extension was granted.

Discrepancies / reasons:

Due to delays in the technical actions, the completion date of Action B1 was postponed. With respect to Action B2, although the biogas upgrading prototype began its commissioning phase in February 2023, the BES was not affected by delays in its startup. In the final amendment, the start date of Action B2 will be indicated as May 2022.

Action B3 has a duration of 28 months instead of the initially planned 15 months. This extension is a result of the action having started but currently being on hold pending the availability of final operating data. Similarly, Actions B4, B5, and B6 have been extended well beyond their original timeframe. These actions were run in parallel with Action B2 (operation of the plant), thus benefiting from both the additional time and the accumulated operational experience. This will allow a higher degree of maturity to be achieved in the replication case studies and business models associated with the site and the technology. Nevertheless, the extension of these activities is not considered critical, as they could also have been executed within their originally foreseen duration.

The budget allocation and subdivision of tasks within each action have been substantially modified compared to the original proposal. This adjustment stems from the withdrawal of Labaqua from the consortium. Labaqua was excluded from the acquisition of Suez's Spanish assets by Veolia in order to comply with legal requirements and prevent a monopoly in the air quality sector. Following its departure from the AGBAR group—which includes Aigües de Barcelona and Cetaqua—Labaqua shifted its strategic focus and interests, which no longer aligned with the objectives of LIFE NIMBUS. Consequently, its withdrawal from the consortium was agreed upon by the remaining partners. As of 1 December 2021, Labaqua is no longer part of the consortium. Its main contributions had been concentrated in Action B1, where its technical expertise was essential for the design of the biomethanation unit, particularly the pre- and post-treatment trains.

The withdrawal of Labaqua does not compromise the objectives of the project, the targeted environmental challenge, its replicability and transferability, nor the expected EU added value. The demonstration character and the scope of the actions remain unaffected. The minor consequences of Labaqua's withdrawal are summarized as follows:

- Redistribution of involvement in Actions B1, B2, B5, and B6 among Cetaqua, Aigües de Barcelona, and UAB.

- Redistribution of the budget among the remaining partners, with the exception of TMB, whose budget remains unchanged.

Current state of the action and envisaged progress until next report:

This action is completed.

Deliverables (D) and Milestones (M):

DE1.1 Project Management Manual	100% completed in February 2022
DE1.2 Guidelines for green procurement and EU Ecolabel products prioritization	100% completed in January 2021
ME1.1 Kick-off meeting	Achieved in September 2020
ME1.2 Mid-term Report validation	Achieved in March 2022
ME1.3 Final Report	Achieved in September 2025

Action E2. After LIFE Plan	
Responsible: Cetaqua	**Status:** Completed (100%)
Proposed start: September 2023 **Proposed end:** November 2023	**Current start**: September 2020 **Current end:** June 2025

Main activities during the reporting period:

E.2.1 Execution of LIFE NIMBUS Exploitation Plan

AB, particularly its Innovation Department, has shown strong interest in the results obtained from the project. The LIFE NIMBUS technology could represent a key solution to achieving energy self-sufficiency and advancing the decarbonization of the WWTP. In the five years following the end of the project, the feasibility of full-scale implementation at the Baix Llobregat WWTP will be assessed in alignment with the plant's planned upgrade. In parallel, the business plan and business model agreement will be defined jointly by AB and TMB. The projected full-scale facility is expected to generate 326 Nm^3/h of biomethane, sufficient to fuel approximately 80 buses of the TMB fleet.

With respect to the replication studies identified at European sites (see Deliverable DB5.1), the consortium is prepared to build upon the preliminary techno-economic assessments carried out during the project, either by supporting full-scale implementation or by deploying the prototype for demonstration trials in other WWTPs and STF. Although the prototype was originally conceived as a portable solution, ATEX regulations prevented its full portability. Nevertheless, selected components of the prototype can be transported and connected to demonstration sites across Europe.

The **Butarque WWTP in Madrid** has expressed strong interest in testing the NIMBUS prototype. Both Canal de Isabel II and AQUAMBIENTE, the operator of the Butarque WWTP, have confirmed their interest in integrating the prototype for biomethane production. A technical and economic proposal was prepared, aiming to combine the rejected CO_2 stream from the existing biogas upgrading system with hydrogen supplied either by an AWE or directly from a nearby H_2 refueling station. The resulting biomethane would be dedicated to vehicular use. The estimated cost of transferring and implementing the NIMBUS prototype from Baix Llobregat WWTP to Butarque WWTP is approximately €200.000, covering personnel training as well as technical support during the first year of start-up and operation.

This activity is considered a first step towards full-scale deployment, as on-site piloting of the process is regarded as the most effective approach to encourage investment in this type of solution.

Thanks to the media campaign carried out through various European and national newspapers and journals, several requests for information regarding the biomethanation prototype have been received from other facilities across Europe.

Regarding the BES, several contacts have been established with industrial stakeholders to assess the installation of the plant at their facilities, leveraging its modular design to test the treatment of industrial wastewater with high organic load and salinity. In parallel, an agreement has been formalized with the UAB to install the plant as a demonstration unit, allowing visits to observe the system's performance under real operating conditions.

In addition, the relocation of the plant to a Living Lab at UAB is under consideration, with the objective of applying the technology for ammonium recovery. The TRL reached is estimated at 6–7, demonstrating a high degree of maturity while still requiring further development for full-scale deployment. Furthermore, the forthcoming Marie Skłodowska-Curie programme will host 10 PhD researchers focused on overcoming the challenges related to the scale-up of bioelectrochemical systems.

The exploitation plan of LIFE NIMBUS is strategically designed to combine EPC contracts, technology licensing, O&M services, and establish multiple revenue streams that strengthen long-term financial sustainability. Based on market and competitor analysis, as well as current trends in wastewater treatment and biomethane management across the EU, technology licensing has been identified as a highly suitable business model for the exploitation and scaling of LIFE NIMBUS. Under this approach, licenses are granted to third parties—such as engineering companies, EPC contractors, or technology integrators—allowing them to use the LIFE NIMBUS technology under predefined contractual conditions, including territory, duration, and royalties. This model enables rapid market penetration by leveraging the established networks and capabilities of licensees while minimizing the need for direct investment and reducing the operational risk for the technology owner.

D.1.1 Execution of LIFE NIMBUS Communication Plan

The After-LIFE Communication Plan for LIFE NIMBUS was developed by Cetaqua during the last months of the project to offer an overview of all the communication and dissemination activities that took place during the lifetime of the project, and to outline those that will take place after its lifetime.

It includes dissemination activities which connect research outputs and results and the key target audiences by means of appropriate communication tools. Detailed information can be found in Deliverable DE2.1.

Discrepancies / reasons:

Demonstration Trials: The prototype was initially designed as a portable system; however, during the design phase, it was determined that ATEX regulations prevented full portability. Nevertheless, for demonstration trials, selected components—such as the reactor unit, compressor, and peripheral equipment—can be transported and connected at demonstration sites across Europe.

Current state of the action and envisaged progress until next report:

The after-LIFE plan was elaborated in Action E2 and will be executed after the end of the project.

Deliverables (D) and Milestones (M):

DE2.1 After LIFE Plan: Communication Plan of LIFE NIMBUS	100% completed in August 2025
ME2.1 Definition of target audience of the After-LIFE Communication Plan	Achieved in August 2025
ME2.2 After LIFE Plan of LIFE NIMBUS	Achieved in September 2025

3.2 Main deviations, problems and corrective actions implemented

The main deviations addressed which justify the delays and other difficulties experienced during the project implementation are summarized in Table 4.

Table 4. Summary of deviations and corrective actions in the report period.

Deviation (Action)	Cause(s)	Actions taken/foreseen
Delay in tender process adjudication, prototype design, construction and commissioning (Action B1)	Both the BES and bio-methanation units experienced delays, the latter being more significant. The BES unit was delayed by about three months due to an extended public tendering process and supplier-related issues, while the bio-methanation unit faced delays of six months caused by the global supply crisis.	Bottleneck identification, both in prototype equipment procurement (continuous contact with suppliers to update delivery timings) and development actions, such as identification of project future needs (Hazop and ATEX study and pressure homologation).
Physical separation of both the BES unit prototype and the biomethanation prototype (Action B1)	Distance from the primary settler and the biogas header: unreasonable piping for a prototype.	Testing of the BES unit H_2 in the bio-methanation unit by storage in tedlar bags.
Higher nominal capacity in the bio-methanation unit (Action B1)	Identifying equipment compatible with the initial nominal capacity of the pilot (4 Nm^3/h) proved challenging, particularly in the case of the biomethane compressor and the H_2 valve. By leveraging economies of scale, the plant was designed with a substantially higher nominal capacity at a fraction of the cost, thereby increasing its impact and resulting in a more robust biomethanation prototype.	No action was foreseen
13 months delay in the pilot operation (Action B2)	The operation of the NIMBUS biomethanation prototype was delayed by 13 months due to setbacks in Action B1, ATEX compliance, and electrolyzer malfunctions. Construction was completed in March 2023, Site Acceptance Tests in June 2023, and plant inoculation in July 2023.	An Amendment to the GA was requested and approved by the EC to extend the project duration 12 months.

Interruption of continuous operation of the biomethanation unit (Action B2)	Operations were interrupted due to several mechanical and technical issues.	A comprehensive maintenance and monitoring plan will be implemented to minimize the risk of mechanical and technical failures. This includes preventive maintenance of critical components, closer supervision during operation, and the establishment of rapid response protocols with suppliers to ensure timely replacement or repair of faulty equipment
Technical unfeasible storage of biomethane (Action B2)	Faced technical limitations from the MFE120 high-pressure compressor, whose minimum suction flow rate prevented biomethane storage	The biomethane produced was redirected into the CHP unit of the Baix Llobregat WWTP to ensure continuous energy utilization; in May 2025, coordinated the replacement of the compressor with a new unit capable of operating at lower inlet pressure.
Delay of completion of Action B3	The activities under this action finished once stable operation of the NIMBUS prototype was achieved.	No action foreseen; time contingencies are enough to absorb this delay.
Extension of Actions B4, B5, and B6	These actions ran in parallel with Action B2 (plant operation), allowing them to benefit from both the extended timeframe and the accumulated operational experience. This approach enables a higher level of maturity to be achieved in the replication case studies and the development of business models associated with the site and the technology.	No action foreseen; time contingencies are enough to absorb this delay.
Relocation of facility for feasibility assessment study (Action B5)	Following Veolia's acquisition of CETAQUA and AB in November 2021, the originally planned Sète WWTP site was no longer available for the feasibility study, and an alternative Veolia facility was selected for the assessment. Consequently, another facility within	An alternative Veolia facility was selected to carry out the feasibility assessment, and the study plan was revised accordingly to ensure continuity of the project objectives and proper evaluation of the

	the Veolia Group was selected to conduct the assessment.	technology under comparable operational conditions.
Departure of one of the technological partners, Labaqua (Action E1)	Change of partner's interest due to acquisition of most of Suez assets by Veolia.	An amendment request to the GA was submitted to redistribute Actions B1, B2, B5, and B6 among Cetaqua, Aigües de Barcelona, and UAB, along with a corresponding budget reallocation

3.3 Evaluation of Project Implementation

The results achieved in the reporting period met partially the objectives that were initially set. Comparison of results and objectives for the actions completed or in progress is provided in Table 5.

Table 5. Evaluation of results achieved in the tasks completed or in progress

Action	Objectives	Results achieved	Evaluation
A1	To obtain the necessary authorizations from the Àrea Metropolitana de Barcelona for the installation and operation of the prototype to produce biomethane in the selected Baix Llobregat WWTP and supply it to an urban bus.	Permit was obtained from the AMB.	Results have been achieved as expected. The associated milestone is achieved (MA.1).
B1	To design the biomethanation unit, hydrogen production units, the pre-treatment and the post-treatment unit for biomethane conditioning and supply. To construct and assemble the different units of power-to-gas prototype integrated in the WWTP and test the correct functioning.	The LIFE NIMBUS prototype's design, construction and commissioning were completed. Integration of the BES unit with the biomethanation unit was achieved via a virtual pipeline.	This action was successfully completed, although delays in the tender process and supply chain affected the commissioning of the different units. Associated deliverable is completed (DB1.1) and associated milestones are achieved (MB1.1, MB1.2 and MB1.3).
B2	To start up and operate the prototype, achieving stable operation and a continuous supply of biomethane while obtaining enough quality operation data that can later be used for the development of Actions B3-B6 as well as in Action C1 and Action E2.	The operation of the LIFE NIMBUS prototype successfully demonstrated its ability to produce biomethane meeting the required fuel-use specifications. Biomethane production achieved stable operation and continuous supply at a flow rate of 1,5 Nm^3/h. In parallel, the BES unit continuously produced green H_2 while reducing the COD of wastewater,	The evaluation of the prototype operation highlights the success in achieving the set objectives. Despite several technical, mechanical, and design limitations, the technology was validated, and the operation provided valuable insights critical for the future scale-up of the NIMBUS system and for replicability studies.

		thereby increasing the TRL to 6–7.	The biomethanation pilot consistently met all regulatory requirements and demonstrated robust performance in biomethane production, setting a benchmark for sustainable biogas upgrading via power-to-gas and ensuring biomethane quality while benefiting urban ecosystems. Similarly, the BES unit within the MEC pilot demonstrated the technical feasibility and robustness of scaled-up microbial electrolysis systems under real conditions, highlighting their potential for sustainable hydrogen production and the need for further optimization to enhance energy efficiency and scalability. Associated deliverables are completed (DB2.1, DB2.2) and associated milestones are achieved (MB2.1, MB2.2 and MB2.3).
B3	To perform a Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and social cycle assessment (sLCA) to compare the social, economic and environmental impact of the LIFE NIMBUS process to produce biomethane with the corresponding existing baseline.	The analysis compares three scenarios: conventional natural gas production and use (baseline), the NIMBUS solution, and a conventional biogas upgrading process based on membrane separation technology. LCA: NIMBUS achieves net negative GHG emissions versus the baseline, outperforming	The NIMBUS system demonstrates the lowest environmental footprint and total cost when environmental externalities are accounted for, highlighting the potential of circular bioenergy systems. Its economic viability depends on electricity costs and renewable energy availability, requiring supportive policies and incentives.

		both conventional biogas upgrading and natural gas scenarios. LCC: Baseline shows lowest CAPEX/OPEX but high environmental costs. NIMBUS has higher CAPEX and OPEX but delivers long-term environmental benefits. sLCA: Positive impact on workers' skills and wellbeing; strong acceptance among value chain actors. The BES unit has lower OPEX compared to AWE, but its current feasibility for scaled-up biomethane production is constrained by substantial space requirements and significantly higher CAPEX.	Improvements in H_2 production efficiency, including advancements in AWE and BES technologies, are critical for enhancing performance. This action was successfully completed following a critical revision of electricity cost assumptions after the 3rd Monitoring Meeting. Associated deliverable is completed (DB3.1) and associated milestones are achieved (MB3.1, MB3.2, MB3.3 and MB3.4).
B4	To define the business model for biomethane trading in a circular economy context, considering Baix Llobregat WWTP and Barcelona city, identifying risks and benefits between biomethane producers and end-users.	Two business models for biomethane were analyzed: direct on-site supply to a municipal bus fleet, and injection into the natural gas grid for indirect distribution. Both are economically viable, with the direct model offering local impact and control, and the intermediated model providing greater scalability and market integration..	Results have been achieved as expected.The analysis provides a replicable framework for valorising wastewater-derived biomethane, supporting decarbonised urban mobility and circular energy systems. Associated deliverable is completed (DB4.1) and associated milestones are achieved (MB4.1 and MB4.2).
B5	To evaluate the replicability and transferability of the proposed biomethane production technology in other European contexts with different	The LIFE NIMBUS technology demonstrates strong technical viability across diverse European contexts.. The technology	The study highlights strong replication opportunities for NIMBUS across Europe, particularly in Italy,

	regulatory and market characteristics. To develop a replication plan.	shows particular promise in regions with high renewable energy curtailment, such as Germany and Ireland. A replicability plan was also developed, identifying potential barriers and challenges for implementing this innovative power-to-gas solution focused on biomethane production via biological methanation.	Germany, and Spain, each offering unique advantages in biogas infrastructure and renewable energy availability. Success depends on access to low-cost or surplus renewable electricity, supportive regulations, long-term biomethane off-take, and blended public-private financing. Associated deliverables are completed (DB5.1 and DB5.2) and associated milestones are achieved (MB5.1, MB5.2 and MB5.3).
B6	To develop a business plan and a commercial offer of the demonstrated solution for biomethane production, which will be oriented towards water treatment and transport companies. To understand market needs, evaluate the competitors and the market potential of the biomethane production solution developed.	The LIFE NIMBUS business plan demonstrates strong technological and commercial potential. The evaluation confirms that this innovative biomethane production solution is technically viable and offers clear competitive advantages over existing technologies. Its modular, scalable design allows efficient adaptation to various WWTP sizes and industrial contexts, greatly enhancing its deployment potential. The LIFE NIMBUS technology could be technically replicated in approximately 11.000 biogas plants across Europe—over 60% of the total—given a minimum biogas flow around 100 m³/h to justify the investment. The	This action was successfully completed after a critical revision of the target objectives following the 3rd Monitoring Meeting. Associated deliverables are completed (DB6.1, DB6.2 and DB6.3) and associated milestones are achieved (MB6.1, MB6.2 and MB6.3).

		technology is applicable to both solid waste and wastewater treatment plants and CO_2 capture.	
C1	To measure, to monitor and to report the impact and outputs of the project actions at the end of the project and 5 years after the project ends as compared to the initial situation, objectives and expected results.	Selection of LIFE performance indicators (LPIs) and evaluation during the different stages of the project. Final KPIs values have been updated.	Associated deliverables are completed (D1.1, DC1.2 and DC1.3) and associated milestone is achieved (MC1.1).
D1	To raise awareness among the general public, energy players, transportation companies, the WWTP sector and key decision-makers of the energy and transportation sectors. To allow both the general and specialized public to access information about the project and the LIFE program. To share knowledge and experiences with other similar projects. To ensure stakeholders involvement into the project's solution beyond the lifetime of the project.	The logo, templates, project website, informative brochure, infographic, short animation video, communication database, communication plan, notice boards, final video and Layman's report were created and promoted through different channels (social media, website, events, etc.). The project has been present in general and technical media, as well as in social media and in several conferences. Networking activities have been done (meetings, planification for future joined activities with other European projects, and several events have been organised to promote the project among stakeholders, potential end-users and decision makers.	Almost all targets were met or exceeded. Targets not met were the number of visits to the website due to tracking issues mentioned above. Associated deliverables are completed (DD1.1, DD1.2, DD1.3, DD1.4, DD1.5, DD1.6, DD1.7, DD1.8 and DD1.9). Milestones MD1.1, MD1.2 and MD1.3 are achieved and MD1.4 partially achieved.
E1	To guarantee that LIFE Program obligations are met.	Correct development of the	Associated deliverables are completed (DE1.1 and DE1.2) and associated milestones achieved

	To ensure, monitor, document and report the progress of project actions. To efficiently allocate, track and record human and financial resources. To establish a fruitful legal framework and to regulate intellectual property. To obtain an independent final audit report and receive full financial contribution.	project management.	(ME1.1, ME1.2 and ME1.3).
E2	To ensure the extension of the results obtained from the dissemination and communication actions after the project ends. To identify target audience in the scientific and research community, as well as potential users of the project outcomes. To draft an exploitation strategy and plan of the technology knowledge generated in the project and to manage intellectual property.	The After-LIFE communication plan was designed to ensure the extension of the results obtained from the dissemination and communication actions after the projects' end. Several replication options for the After LIFE NIMBUS exploitation are currently ongoing.	Associated deliverable is completed (DE2.1) and associated milestones are achieved (ME2.1 and ME2.2).

3.4 Analysis of benefits

3.4.1 Environmental benefits

The goal of the LIFE NIMBUS project is to reduce the carbon footprint of urban transportation by bio-methanating biogas from a WWTP with green hydrogen. The application of this technology will allow replacing fossil natural gas with biomethane, greatly reducing the impact on CO_2 emissions. For biomethane, when burnt, only emits biogenic CO_2, which means that it does not increase CO_2 levels in the atmosphere when the whole cycle is taken into scope. This means that the greenhouse effect is not impacted by the use of these technologies.

The LIFE NIMBUS solution produces 7.805 kg/year of biomethane, compliant with the standards required for use as fuel. This volume corresponds to approximately 13,000 km of bus travel, reducing CO_2 emissions by 10,7 tons per year compared to a bus running on CNG.

The LIFE NIMBUS solution offers environmental improvements with respect to membrane technology, the state of the art technology for biogas upgrading and gas natural extraction. Specifically, NIMBUS achieved a value of -0,065 €/kg CH_4, representing a 106% improvement compared to the gas natural scenario, which incurs an environmental cost of 1,08 €/kg CH_4.

3.4.2 Economic benefits

The NIMBUS scenario emerged as the most cost-effective solution for urban fuel supply, due to its enhanced potential for biomethane production through integration with P2G technologies.

In terms of renewable energy, the LIFE NIMBUS project has achieved an annual production of 67.003 kWh, representing a 68% improvement in energy efficiency compared to the current use of biogas in CHP.

Comparing the operational costs of producing green H_2 via BES and AWE, the BES solution proves to be 2,5 times more cost-effective than AWE.

3.4.3 Social benefits

The LIFE NIMBUS project has demonstrated a positive impact on various social aspects in Barcelona city. By replacing conventional fuels, the biomethane bus helps to improve urban air quality through the reduction of particulate matter (PM) and nitrogen oxides (NOx), directly contributing to a healthier environment for citizens. This improvement in air quality has a positive impact on public health, lowering the incidence of respiratory and cardiovascular diseases linked to pollution.

Moreover, producing biomethane from organic waste and sludge strengthens the local circular economy, turning residues into valuable resources. This process not only supports sustainable resource management but also creates green jobs along the value chain, from plant operation and maintenance to logistics and related services. With large-scale implementation, an increase in the creation of green jobs is expected, strengthening the local economy and consolidating job stability in a strategic sector for the city.

The visible use of a biomethane-powered bus in the city also acts as a demonstrator, raising public awareness and fostering greater acceptance of renewable energy solutions. At the same time, local production of renewable fuel reduces dependency on external energy sources, enhancing the city's energy resilience. Finally, this initiative contributes to climate action goals by reducing greenhouse gas emissions and aligning with European, national, and local sustainability strategies such as the Green Deal, the National Energy and Climate Plan, and the 2030 Agenda.

3.4.4 Replicability, transferability, cooperation

The replication potential of this project is extremely high. For example, a WWTP in Madrid has already expressed interest in investing in the replacement of its conventional biomethane membrane upgrading system, currently used to supply biomethane to a small fleet of CNG vehicles, with the LIFE NIMBUS bio-methanation technology. The plant is awaiting the first results from the Baix Llobregat WWTP pilot to begin cooperation with Cetaqua.

In addition, interest in scaling up the technology has also been shown by stakeholders in Ireland STF, Germany, Italy, and the Sabadell WWTP. These replication initiatives are planned at a scale slightly larger than that of the LIFE NIMBUS pilot, representing full-scale implementation opportunities.

This bio-methanation technology, combined with the BES, has an immense potential to be applied on a variety of industries and fields, from biogas and biomethane, to CO_2-to-fuels pathways, to WWTP, landfills and energy crops, to power-to-gas schemes to stabilize electric grids. The combinations are immense and the knowledge for the diverse players on this technology is at the moment very limited, so it is foreseeable that it will be replicated at small scale in many different facilities and eventually it will be done at full commercial scale.

3.4.5 Best practice lessons

All partners of this project know and apply quality protocols on the work they realize. Good Laboratory Practices, Good Manufacturing Practices, ISO norms and standardized protocols are applied in every action when relevant. Moreover, an effort is being done to reduce this project's carbon footprint, such as not travelling for events and rather joining online when possible. The objective of the project itself includes energy and fossil fuel consumption reduction which lower carbon emissions. In addition, equipment is designed to be energy-efficient, travelling and paper use is limited, and the different partners apply carbon management strategies to approach a carbon neutral activity.

3.4.6 Innovation and demonstration value

The business model developed in this project comprises a value chain that rises from waste to end, marketable, green fuels. The definition of this model and how it connects actors and stakeholders of those different industries (WWTPs, landfills, transportation companies...) and administrations is innovative, since there are very few success examples, specially at this scale, and in Spain. The bio-methanation prototype will be the first one using this reactor configuration for bio-methanation, and one of very few selected examples applying a methanation route directly on biogas and not on CO_2 and with an end use different from natural gas injection, meaning that the impact on the end-user can be directly measured and supervised. The BES unit will be the largest ever built using bio-electrolysis, and the first ever in which the H_2 generated will be used for any process, chemical or energetical.

3.4.7 Policy implications

Demonstrating that biogas can be upgraded to biomethane through a completely different pathway than conventional upgrading, as well as demonstrating a direct use on urban transportation might enable relaxing the biomethane injection standards and CNG standards for CO_2, H_2, inerts and Siloxane concentrations, allowing for more cost-effective plant configurations.

Adding another technology to the upgrading portfolio of biomethane will definitely contribute to the uptake of biomethane and drift apart from conventional fossil fuels, in which Europe is highly dependent as a net importer.

Another side impact on legislation is possible, in the field of electric grid stabilization, for it will be one of the few power-to-gas plants in Europe. Regulation in this sense is still lacking and it is expected to greatly mature in the upcoming years.

4 Key Project-level Indicators

These indicators were previously defined in the official proposal to track the positive effects produced by the project regarding a series of environmental and socio-economic aspects. They reflect the parameters used for the policy making by the EU wherever is possible, complemented by context parameters and economic indicators.

The criteria for the KPIs selection were, firstly, response to the mandatory indicators, and secondly to the indicators related to the environmental topic of the LIFE NIMBUS project, which is Environment and Resource Efficiency. The following table 6 presents the selected KPI indicators to monitor the impact of the actions of the LIFE NIMBUS project. DC1.2 "LIFE Performance Indicators – Final Report" the updated KPI values are presented.

Table 6. Key Project-level indicators

Indicator number	Category	Indicator
1.5	Project setting	Project area/length
1.6	Project setting	Humans (to be) influenced by the project
4.1.3	Environmental and Climate action outputs and outcomes	Renewables production
8.1.1	Environmental and Climate action outputs and outcomes	Greenhouse gas emissions - CO_2
10.2	Societal outputs and outcomes	Involvement of non-governmental organisations (NGOs) and other stakeholders in project activities
11.1	Societal outputs and outcomes	Website
11.2	Societal outputs and outcomes	Other tools for reaching/raising awareness of the general public
12.1	Societal outputs and outcomes	Networking
13	Economic outputs and outcomes	Jobs
14.1	Economic outputs and outcomes	Running cost/operating costs during the project and expected in case of continuation/replication/transfer after the project period
14.3	Economic outputs and outcomes	Future funding

5 References

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[2] European Commission, Directorate-General for Energy. (n.d.). REPowerEU – 3 years on. European Commission. Retrieved August 22, 2025

[3] Eurostat. (2025, March 19). Electricity from renewable sources reaches 47% in 2024. Eurostat News. Retrieved from https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20250319-1

6 Annex

DD1.1 Logo and templates

This deliverable presents the LIFE NIMBUS logotype, graphic identity manual and templates developed at the beginning of the project with the objective of ensuring a coherent and unified communication of the project in graphic terms.

DD1.2 Communication Plan

The Communication Plan of the LIFE NIMBUS project is the main document outlining the communication and dissemination activities that will take place throughout the project. Furthermore, a communication database was added to that include the dissemination activity by the partners.

DE1.1Project Management Manual

This document is intended to be a manual for guiding the Consortium in the general management tasks of the Project: LIFE19 ENV/ES/000191- LIFE NIMBUS. It describes the consortium, the schedule of the project, and the protocols for the monitoring of the project progress, the technical and financial reporting, dissemination, procurement and construction.

DE1.2 Guidelines for green procurement and EU Ecolabel products prioritization

This deliverable aims to ensure a tangible application of the green procurement principles and promote Eco-label products by all partners during the project purchasing processes. This deliverable details the procurement procedures for the project and guidance on how environmental considerations can be included at different stages.

DE1.3 Mid-term Report

This report provides a detailed account of the technical progress achieved between September 2020 and March 2022, as well as an update on financial performance covering the period from September 2020 to December 2021.

DD1.3 Short promotional video

This deliverable presents the NIMBUS short promotional video, a concise animated film that summarizes the project's approach, objectives, and expected outcomes in a clear and accessible manner. It is designed for a broad audience, including both technical and non-technical potential end-users, as well as the general public.

DD1.4 Promotional leaflet

This deliverable presents the promotional leaflet of the LIFE NIMBUS project. It provides a concise overview of the project's context, main objectives, and expected results.

DD1.8 Website of the project

This deliverable describes the LIFE NIMBUS, which is designed to provide key information and updates about the project. The website serves as the central hub for the project's online communication. It was regularly updated with the latest news, project progress, generated materials and deliverables, and the results achieved throughout the project.

DB1.1 Design and technical specifications of the LIFE NIMBUS prototype

This deliverable aims at summarizing the basis of design for a prototype whose main objective is to methanate the carbon dioxide in biogas biologically. This bio-methanation takes place in a pressurized biotrickling filter reactor, where green hydrogen is added from an electrolyzer running on renewable electricity. Furthermore, there is a second prototype which aims at producing hydrogen via biological electrolysis for its later use in the bio-methanation unit. The produced biomethane is then compressed and stored to fuel one bus for urban transportation in the city of Barcelona.

DC1.1 LIFE Performance Indicators including socio-economic impact - Mid-term Report revision

The purpose of this deliverable is to provide a description of the Key Project Indicators (KPIs). It includes the value of every KPI at the beginning, at the end and 5 year after the project ends. The specific context and the description of every KPI of the project is also included in this deliverable.

DD1.5 Notice Board

This deliverable presents the Notice Board.

DB2.1 Report of the start-up of the LIFE NIMBUS prototype

This deliverable aims at summarizing the main activities and findings throughout the start-up of the LIFE NIMBUS methanation prototype as well as the BES unit. Although a basic description of both the BES unit and the methanation plant are given, a description in more detail can be found in Deliverable DB1.1 Design and technical specifications of the LIFE NIMBUS prototype. This deliverable integrates both the findings when starting up the plant, piece of equipment by piece of equipment, as well as the first results of the operation of the biomethanation reactor and BES unit. It then combines knowledge gained on an engineering and practical basis of the plant, such as troubleshooting applied to individual pieces of equipment, and expertise on the microbiology and inner findings on the operation of the methanation and BES reactors. The latter results should be taken as a first report and not as final performance indicators of the technology nor KPIs, since both processes are biological and it is known that during microorganism growth and adaptation biological reactors do not perform nowhere near their nominal capacities and that can be clearly seen from the biomethanation plant first results.

DB6.3 Draft business plan of the LIFE NIMBUS technology

This deliverable is a draft for the business plan of the LIFE NIMBUS project. It outlines the main components of the business plan, including an initial market overview and identified business models. The draft establishes a baseline framework for the plan, which will be reviewed and updated throughout the project as additional data becomes available.

DB5.1 Feasibility assessment and replicability of LIFE NIMBUS solution in Sète WWTP

The deliverable analyzes the feasibility and replicability of the LIFE NIMBUS solution across multiple European contexts, including Ireland, Italy, Germany, and Spain. Key findings show NIMBUS achieves net negative greenhouse gas emissions and demonstrates 39% cost reduction compared to baseline scenarios when environmental benefits are considered. While NIMBUS demands higher upfront costs, it proves economically viable long-term with payback periods of 7.5 years and creates new revenue streams from biomethane sales. The technology shows strong replication potential, particularly in regions with renewable energy curtailment like Germany (457 hours of negative electricity prices) and Ireland (14% wind curtailment). Overall, NIMBUS emerges as a promising solution for renewable energy storage and transport decarbonization, pending supportive regulatory frameworks, blended financing mechanisms, and continued integration with existing infrastructure. Due to organisational restructuring, the previously designated site—the Sète WWTP in France—was no longer available for the study. Consequently, another facility within the Veolia Group was selected to conduct the assessment.

DD1.9 Networking activities report

The purpose of this deliverable is to provide a description of the networking activities undertaken during the lifetime of LIFE NIMBUS, including the participation and organisation of networking meetings and events with other EU-funded programmes, as well as the attendance to scientific conferences.

DB6.1 Market and competitor analysis

This deliverable aims at summarizing a detailed market analysis to evaluate the potential of this innovative technology. To conduct a comprehensive analysis, the project will consider several key parameters, including the current market overview, analysis of existing players, competitiveness of the solution from a customer point of view, types of business models, and value engineering study for the proposed technology. The market analysis will provide insights into the potential of the technology and help in identifying suitable markets for its deployment.

DB3.1 Environmental (LCA), economic (LCC), social (S-LCA) and CBA of the LIFE NIMBUS solution

The deliverable analyzes three scenarios for natural gas/biomethane production for public transport. Key findings show NIMBUS has the best environmental performance and lowest total cost when considering environmental benefits , despite higher initial investment. While NIMBUS requires larger upfront costs , it proves most sustainable long-term. Social assessment reveals positive worker outcomes and technology acceptance, though community engagement needs improvement. Overall, NIMBUS emerges as the most promising solution for sustainable urban transport, pending supportive policies and continued technological optimization.

DC1.3 Performance comparison with other methanation technologies

This deliverable provides a comparative performance assessment between the LIFE NIMBUS methodology and other methanation technologies currently under development in the industry. The objective is to underscore the unique advantages and added value of the LIFE NIMBUS approach by analyzing key performance indicators and operational parameters.

DB5.2 Replicability and transferability plan of LIFE NIMBUS solution

This deliverable presents the conclusions of the LIFE NIMBUS project, which has demonstrated an innovative Power-to-Gas system based on biological methanation. The solution converts CO2 and renewable hydrogen into grid-quality biomethane, enabling renewable energy storage, reducing greenhouse gas emissions, and supporting the circular economy. It summarises the technical, economic, and legislative findings, identifies replication opportunities across Europe, and highlights the technology's scalability and integration potential with existing wastewater treatment infrastructure.

DB2.2 Report of the operation of the LIFE NIMBUS prototype and biomethane use in HDV

This deliverable aims to present the operational methodology and results of the LIFE NIMBUS project through a critical assessment of the actions undertaken and the incidents encountered during the operation of the biomethanation plant and the BES system. An analysis is provided of the results obtained, as well as of all resources consumed and the factors influencing performance.

DB4.1 Business model of the biomethane in the site of Barcelona

This deliverable presents a detailed techno-economic analysis for commercializing biomethane from Baix Llobregat WWTP, comparing two business models with distinct infrastructure, commercial, and risk profiles. The direct supply model prioritizes local decarbonization but demands higher investment and single off-taker dependency, while the grid injection model enables scalability but introduces external dependencies. Both approaches are viable but serve different strategic objectives, focusing on local control or system integration, with successful implementation dependent on coordinated stakeholder engagement, stable agreements, and support from public funding.

DB6.2 Business plan of the LIFE NIMBUS technology

This deliverable presents a comprehensive business plan for the commercialization of the LIFE NIMBUS technology, an innovative solution that converts wastewater sludge into high-purity biomethane through a Power-to-Gas approach with Trickle-Bed Reactor technology. The plan analyzes multiple business models including EPC contracts, technology licensing, and O&M services, supported by detailed market analysis and financial projections. The plan confirms LIFE NIMBUS as a technically and commercially viable solution for advancing circular economy objectives.

DC1.2 LIFE Performance Indicators including socio-economic impact - Final Report

The purpose of this deliverable is to provide the updated Key Project Indicators (KPIs) at the end of the project. It includes the value of every KPI at the beginning, at the end and 5 years after the end of the project and an explanation on the changes from the KPIs reported at the beginning of the project and presented in DC1.4 “Extract of the project data from the KPI webtool”. The specific context and the description of every KPI of the project is also included in this deliverable.

DD1.6 Final video

This deliverable is related to the final video of the LIFE NIMBUS project, an audiovisual material that aims to present the project in an-easy-to understand way and includes a brief explanation of the developed solution and the main results of the project. In this deliverable, the script of the video can be found, as well as some illustrative screenshots. A link to the video can be also found.

DD1.7 Layman’s report

This deliverable is related to Layman’s report of the LIFE NIMBUS project. The document is written to explain technical, scientific, or complex topics in a way that is easily understandable by non-experts. Its main goal is to make information accessible to a general audience without specialized knowledge.

DE1.4 Final report

This report covers the overall progress of the LIFE NIMBUS project from its start in September 2020 until June 2025. Technical actions, partner coordination, project management, and communication activities have been reported, with some deviations from the original schedule.

DE2.1 After LIFE Plan: Communication Plan of the LIFE NIMBUS

The After-LIFE Communication Plan for the LIFE NIMBUS project offers an overview of all the communication and dissemination activities that took place during the lifetime of the project, and outlines those that will take place after its lifetime. The After-LIFE Communication Plan includes dissemination activities which connect research outputs and results and the key target audiences by means of appropriate communication tools.

7 Annex

TMB

Justification of driver costs in refueling operations for the NIMBUS project

As part of the normal operation of the Nimbus project, it was necessary to move the bus from its base to the refueling point each time the biomethane tanks were filled, and this required driver hours. TMB is a public transport company with approximately 3,500 drivers. Driving services are assigned daily based on priorities in the supply and availability of drivers.

As expected, passenger transport services are the highest priority, followed by refueling tasks, testing, public events, rehearsals, etc. For this reason, the drivers assigned to refueling for the project were assigned daily within the driver pool and were immediately designated based on availability at that time.

That is, a single driver was not assigned to this task, but rather a different one was used on each occasion. This operation makes tracking with Timesheets difficult, as it is costly to maintain traceability over a period as long as the Nimbus project, for a person who may have only spent two hours refueling. However, these tasks were performed.

For this reason, we attach the total hours spent on these tasks with the dates on which they were performed. Each refueling task has been assigned two hours, which is less than the actual time spent, as the TMB bus depot is relatively far from the El Prat wastewater treatment plant.

The driver cost is the average price for the driver category for TMB.

Josep Maria Armengol i Villà

Director of the Technical Area at TMB

Josep Maria Armengol i Villà

Director del Área Técnica de TMB

Josep Maria Armengol Villà

Firmado digitalmente por Josep Maria Armengol Villà
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	Fecha	Operación	Kg	Duración Horas
1	5.9.23	Repostaje / fallo	-	2
2	22.9.23	Repostaje	10	2
3	6.10.23	Repostaje	27,7	2
4	15.11.23	Evento biometano		2
5	20.11.23	Repostaje	9,2	2
6	30.04.24	Repostaje	60	2
7	08.05.24	Repostaje + Tour virtual	63	4
8	10.05.24	Mesa redonda movilidad		2
9	23.05.24	Repostaje / fallo	-	2
10	06.06.24	Repostaje	50,35	2
11	26.09.24	Repostaje + Tour virtual	36	2
12	16.10.24	Consortium meeting		2
13	12.11.24	Repostaje	38	2
14	31.03.25	Visita Final + Repostaje	33	3
15	15.04.25	Repostaje	45	2
16	22.04.25	Repostaje	54	2
17	29.04.25	Repostaje	57	2
18	05.05.25	Repostaje	58	2
19	06.05.25	Repostaje	60	2
20	08.05.25	Repostaje	60	2
21	13.05.25	Repostaje	55	2
22	15.05.25	Repostaje	60	2
23	16.05.25	Repostaje	60	2
24	20.05.25	Repostaje	50	2
25	22.05.25	Repostaje	60	2
26	24.05.25	Repostaje	60	2
27	23.05.25	Repostaje	58	2
28	29.05.25	Repostaje	60	2
29	03.06.25	Repostaje	60	2
30	04.06.25	Repostaje	60	2
31	05.06.25	Repostaje	58	2
32	10.06.25	Repostaje	60	2
33	12.06.25	Repostaje	60	2
34	13.06.25	Repostaje	60	2
35	16.06.25	Repostaje	55	2
36	18.06.25	Evento Final + Repostaje	46	3
37	20.06.25	Repostaje	60	2
38	23.06.25	Repostaje	60	2
39	26.06.25	Repostaje	58	2
40	30.06.25	Periodista + Repostaje	55	4
				86

NIMBUS

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More info at

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