Joint policy recommendations on Biomethane

Cluster of Horizon Europe-funded projects on innovative biomethane production. First report (Version 10/2023)

METHAREN | innovations in the BIOMETHAne uniVERSE | HYFUELUP | SEMPRE-BIO

Funded by the European Union

Grant Agreement	101084200	101084148	101084288	101084297
Acronym	BIOMETHAVERSE	HYFUELUP	METHAREN	SEMPRE-BIO
Project title	Demonstrating and Connecting Production Innovations in the BIOMETHAne uniVERSE	HYBRID BIOMETHANE PRODUCTION FROM INTEGRATED BIOMASS CONVERSION	Innovative bioMETHAne system integration boosting production while managing Renewable energies intermittENcy	SEcuring doMestic PRoduction of cost-Effective BIOmethane
Start date	01/10/2022	01/11/2022	01/11/2022	01/11/2022
Duration	54 months	48 months	60 months	42 months
Website	www.biomethaverse.eu	https://hyfuelup.eu/	https://metharen.eu/	https://SEMPRE-BIO.com/
Deliverable num.	**D4.5**	**D8.12**	**D7.4**	**D5.4 (D21)**
Deliverable date	10/2023			

FUNDING SCHEME	Horizon Europe
CALL IDENTIFIER	HORIZON-CL5-2021-D3-03
TOPIC	HORIZON-CL5-2021-D3-03-16
DELIVERABLE LEADER	DBFZ
CONTRIBUTING PARTNERS	ACEA, BIOGAS-E, BIOPLAT, BioREF,CET, CIC, DTU, ENAGAS, Energigas, Envipark, ERGaR, INV, ISINNOVA, LNEG, RISE, UABio, UVIC
AUTHORS	Jaqueline Daniel-Gromke, Velina Denysenko, Katharina Kramer, Tim Hamers, Oriol Casal Valls, Alejandra Córdova Valencia, Stefano Proietti, Gonçalo Lourinho, Francisco Gírio, José A. Lana, Paloma Pérez, Margarita de Gregorio
CONTRIBUTORS	Antonio Grimalt Alemany, Lidia Paredes Barrios, Pablo Martin Binder, Nick Chapman, Alberto Confalonieri, Ilaria Galvano, Estelle Goonesekera, Júlia Gómez, Linus Klackenberg, Yuri Matveev, Antonio Montón, Laura Foix Pericot, Gustav Rogstrand, Nazih Toubal, Tine Vergote, Céline Wyffels, Paola Zitella

DOCUMENT LOG

VERSION	DATE	AUTHOR	DESCRIPTION OF CHANGE
V1.1	24.05.2023	Jaqueline Daniel-Gromke, Velina Denysenko	Table of contents, initial version
V1.2	09.06.2023	Jaqueline Daniel-Gromke, Velina Denysenko	Second version, survey responses included
V1.3	20.09.2023	Jaqueline Daniel-Gromke, Velina Denysenko	Third version, compilation of feedback from partners, adaptation of subchapter
V1.4	29.09.2023	Jaqueline Daniel-Gromke, Velina Denysenko	Complete version ready for review
V1.5	18.10.2023	Jaqueline Daniel-Gromke, Velina Denysenko	Internal review all involved partners
V2.1	24.10.2023	Jaqueline Daniel-Gromke, Velina Denysenko	Final version approval
V2.2	27.10.2023	Jaqueline Daniel-Gromke, Velina Denysenko	Ready for submission

DISCLAMER

Funded by the European Union

"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them."

Content

Figure index

Table index

Acronym Glossary

a: year	**HHV**: High heating
AD: anaerobic digestion	**H_2:** Hydrogen
AIB: Association of Issuing Bodies	**H_2O:** Water
bcm: billion cubic metres	**IBM**: In-Situ Biological methanation
BIP: Biomethane Industrial Partnership	**ISCC**: International Sustainability and Carbon Certification
CAP: Common Agricultural Policy	**LNG**: Liquefied natural gas
CAPEX: Capital Expenditures	**M**: million
CaO: Calcium oxide	**NECP**: National Energy and Climate Plan
CH_4: methane	**NGOs:** Non-Government organizations
CHP: combined heat and power	**OPEX**: Operational Expenditures
CINEA: European Climate, Infrastructure and Environment Executive Agency	**PJ**: petajoule
CNG: Compressed natural gas	**PoS**: Proof of Sustainability
CO: carbon oxide	**PV**: photovoltaics
CO_2: carbon dioxide	**R&D&I**: Research, development and innovation
CoO: Certificate of Origin	**RE**: renewable energies
EBM: Ex Situ Biological Methanation	**RED**: Renewable Energy Directive
EMG: Electromethanogenesis	**RFNBOs**: Renewable Fuels of Non-Biological Origin
ERGaR: European Renewable Gas Registry	**SEG**: sorption enhanced gasification
ESB: Ex-Situ Syngas Biological methanation	**SOEC:** solid oxide electrolyzer cell
ETM: Ex-Situ - Thermochemical/ catalytic Methanation	**T:** ton
EU: European Union	**TBR**: Trickle Bed Reactor
FiT: Feed-in-tariffs	**TRL**: technology readiness level
GHG: greenhouse gas emissions	**TWh**: terawatt hour
GoO: Guarantee of Origin	**WWTP:** waste water treatment plant
HE: Horizon Europe	

1. Executive Summary

The political aim for doubling of biomethane production by 2030, aiming to achieve a target of at least 35 bcm (350 TWh) of an annual biomethane production by 2030. Against this background, more biogas must be produced and existing biogas plants converted to biomethane with the need for more incentives to build up new plants and provide biomethane by repowering existing plants in the EU.

At the European level, multiple regulations shape the development of renewable energies, thereby the national deployment of biogas resp. biomethane sector is especially influenced by the legal norms transposed into the national law or by the exclusive jurisdiction at the member state level. Main policies and regulations supporting biomethane are primarily driven at the member country level. The level and type of coordination varies by each member state.

The country-specific barriers and perspectives determined based on the survey results of the involved project partners. The main barriers for the development of biomethane are a lack of planning security, missing or complex regulations which are less harmonized with faster amendments in shorter time, lack of the overall political strategy, and ambiguity relating the priority of the pathways for biomethane use.

In order to increase biomethane production in the short resp. medium term, in particular legal and administrative barriers must be reduced. Currently, there is a huge heterogeneity and complexity of national biomethane markets in Europe. The long duration of approval procedures for biomethane projects is often mentioned as an obstacle for the development of the biomethane sector. Here, the comparatively short approval time of projects of max. 1 year as in Denmark and Portugal is pointed out, while in other countries usually 3-5 years have to be planned (as e.g. in Germany, France). It is also important to continue to adjust the political and economic framework to facilitate trade between different countries and to create more purchase opportunities for biomethane.

Furthermore, national biomethane strategies with long-term incentives for the production of biogas / biomethane have to be implemented for the planning security of plant operators and investors. Therefore, robust and long-term framework conditions as well as the planning security for the stakeholders are needed. The uncertainties resp. challenges embrace possible conversion of existing on-site electricity generation plants – especially larger plant facilities – to biomethane, which could provide significant contribution to the ambitious EU targets, focus on waste-based biomethane. At the European level, cross-border biomethane trade must be promoted, implemented and enforced through uniform certification systems at the national level.

The consortium includes the most experienced biomethane experts from different stakeholder groups: universities, NGOs, associations, industrial partners and consulting experts in the field of biomethane. In total, the consortium of all 4 Horizon Europe funded biomethane projects contains 65 partners, 14 countries and 10 demonstration plants (demo-sites) in 8 countries. The EU projects use different innovative technologies, mainly advanced gasification and biomethanation processes, based on waste and residues. To do the fact, that it is too early to make concrete policy recommendations focussed on the investigated innovative biomethane technologies, it is recommended that funding be provided on an open technology basis.

2. Introduction

Biomethane can play an important role to achieve the REPowerEU plan's objectives of diversified gas supplies and reduce the EU's dependence on Russian fossil fuels, while simultaneously reducing exposure to volatile natural gas prices. As a renewable and dispatchable energy source, scaling up the production and use of biomethane also helps to address the climate crisis.

Therefore, biomethane projects are in the spotlight. 4 EU projects – funded under the Call: HORIZON-CL5-2021-D3-03 (Sustainable, secure and competitive energy supply), Topic: HORIZON-CL5-2021-D3-03-16 - were awarded on biomethane instead of the initial 2. To align policy recommendations developed by projects funded under the same topic the collaboration of all 4 biomethane clusters in drafting policy recommendations on biomethane is expected.

Expectations of CINEA:

- *Contribute, upon invitation by CINEA, to common information and dissemination activities to increase the visibility and synergies between Horizon Europe supported actions*
- *Address joint activities in collaboration with projects funded under topic HORIZON-CL5-2021-D3-03-16 (101084297 SEMPRE-BIO, 101084148 HYFUELUP, 101084200 BIOMETHAVERSE, 101084288 METHAREN)*
- *Align the policy recommendations developed by projects funded under the same topic*

SEMPRE-BIO will be in charge of coordinating the first delivery (M12), HYFUELUP the second (milestone 24) and BIOMETHAVERSE the final (milestone 42). As lead of the first delivery of the joint policy recommendations, DBFZ scheduled the first meetings to discuss the content, first steps and time schedule to prepare the draft report regarding joint policy recommendations.

2.1. Objective of report

The objective of the report is to draft a joint policy report with cooperation of all 4 EU Projects on biomethane funded by the EU. In total, the consortium of all 4 Horizon Europe funded biomethane projects contains 65 partners from 14 countries with 10 demonstration plants (demo-sites). Thus, the consortium includes the most experienced biomethane experts in Europe with different stakeholders and is well-positioned to identify barriers, challenges and needs. The results can be used as basis for policy actions. Against a background of current debate on biomethane and RePowerEU Plan and Biomethane Action Plan as a part of it, the HE projects are in demand and should provide input to the Task forces of Biomethane Industrial Partnership (BIP) and preferably the National Energy and Climate Plans (NECPs) to be updated in 2023. Especially Task force 5 (Development & Research of innovative technologies) can be addressed, but also Task force 3 (sustainable potential) and 4 (cost-effective production).

The report contains following aspects:

- State of the art – Biomethane production in Europe
- Overview of innovative technologies investigated in the HE EU Projects on Biomethane
- Main barriers regarding increase of biomethane production in Europe
- Challenges and perspectives of innovative biomethane technologies

The chapter "recommendations for action (focused on investigated innovative technologies) & Outlook" will be included in the following reports. As discussed within the Biomethane cluster this report addresses the more general recommendations to reduce main barriers. However, the recommendations for action (focused on the investigated technologies) from the consortium's point of view will not be presented in subsequent reports until the initial results of the demonstration plants studied are available in the overall assessment.

2.2. Methodology

For the coordination of the joint report, a group with members of the 4 EU biomethane projects was established, consisting of the responsible partners for policy recommendations, communication of the results as well as the respective project leaders. The meeting was scheduled every 2 months. The structure of report was discussed with CINEA project officer in March 2023. A survey in order to gather the country-specific data on main barriers, perspectives and potentials was sent to all project partners in April 2023 to cover involved countries with special focus on the countries with demo-sites.

The semi-standardized questionnaire with the survey on innovative plants, legal frameworks, barriers, and perspectives of biomethane production and utilization in the EU countries was sent by e-mail to the project partners of SEMPRE-BIO. The aim of the questionnaire is to gather the information on status quo, future potential with regard to input materials, market uptake of biomethane in Europe (at least for the involved countries). After a small adaptation, the semi-standardized questionnaire was sent to the project partners of further three Horizon Europe projects BIOMETHAVERSE, HYFUELUP, and METHAREN in April 2023. Besides, status quo and current legal framework on biomethane the survey contains questions regarding the country-specific main barriers and perspectives on biomethane (see Appendix 8.1). The survey responses were received by email. An overview of the projects, partner countries involved, and the number and type of institutions participated in the survey can be found in the Appendix 8.2. In total, 20 experts from 14 organizations took part in the survey so far (as of 9/2023).

The first results of the questionnaire regarding main barriers and perspectives on biomethane from the consortium's point of view were included in this report (see Appendix 8.3).

2.3. State of the art – current biomethane production in EU /political aim

According to IEA 2022, Europe is the largest producer of biogases producing in total around 170 TWh of biogas, and around 35 TWh of biomethane per year. Germany dominates the biogas production with around 9,000 biogas plant and a biogas production of 100 TWh per year, mainly dominated by energy crops. Other countries such as Denmark, France, Italy and the Netherlands have actively promoted biogas production. About 75% of the biogas produced in the EU today is used as a source of local electricity generation and heat and almost 20% of biogas is converted to biomethane. (IEA 2022)

The production of biogas and biomethane is increasing in the Europe; whereas the most of the production results from agricultural sources (mainly energy crops) (see Figure 1).

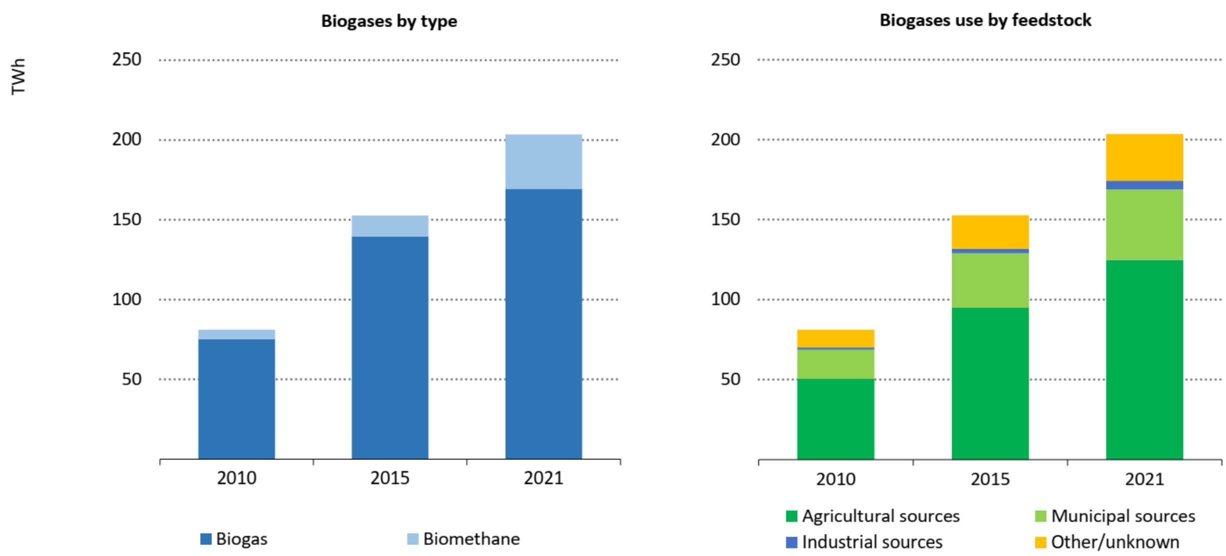

Figure 1: Biogas production in Europe by type and kind of feedstock. Source: IEA 2022 Background paper

The biogas and biomethane production relative to total gas consumption for the top 16 countries is shown in Figure 2. Denmark and Sweden dominate the biomethane production compared to their natural gas demand.

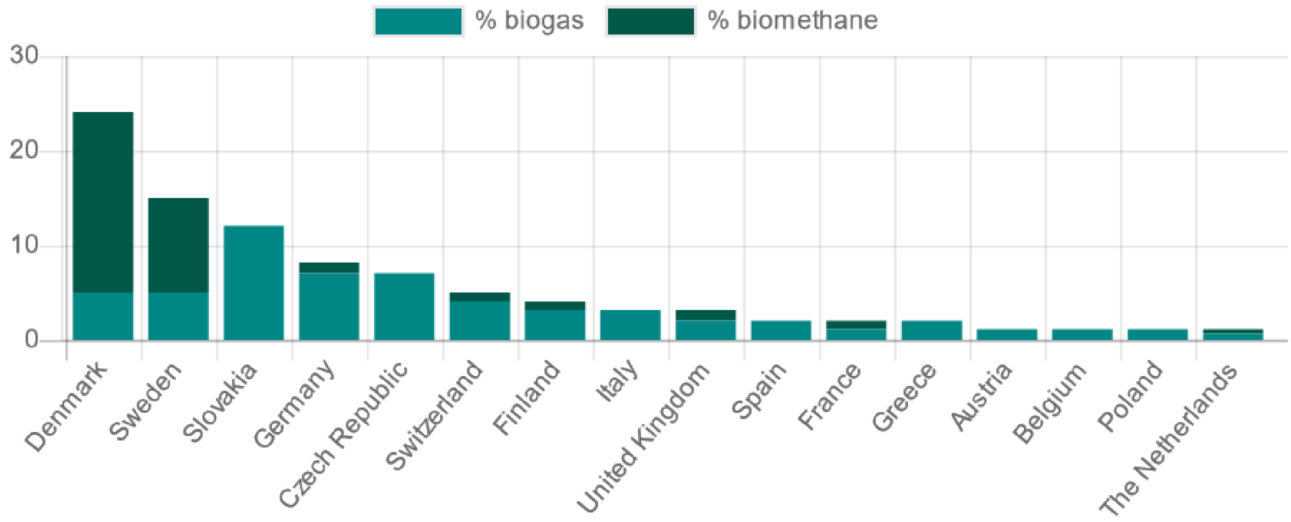

Figure 2: Biomethane and biogas production relative to total gas consumption in 2021, top 16 countries. EBA statistical report 2022.

EU's biomethane production needs to reach 35 billion cubic metres (bcm) per year by 2030. Against a background of current debate on biomethane and RePowerEU Plan and Biomethane Action Plan as a part of it, the HE projects are in demand and should provide input to the Task forces of Biomethane Industrial Partnership (BIP) and preferably the National Energy and Climate Plans (NECPs) to be updated by the end of June 2023.

REPowerEU plan (A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition) represents formally a non-binding strategy document released in May 2022 aiming for ending the EU's dependence on Russian fossil fuels and tackling the climate crisis. The main aspects include:

- increased energy savings (raising target from 9 to 13 % of the EU Energy Efficiency Directive in light of the "Fit for 55" package);
- diversification of energy imports into the EU (liquefied natural gas);
- substitution of fossil energy through the accelerated expansion of power generation capacities from wind and PV, hydrogen (generation and import), and biomethane.

It proposes changes, e.g., to the RED (increase the 2030 target for RE from 40 % to 45 % under the "Fit for 55" package) and to tenfold biomethane production by 2030, aiming to achieve a target of at least 35 bcm (350 TWh) of an annual biomethane production by 2030 as a part of the Biomethane Action Plan, among others through the incentives under the Common Agricultural Policy (CAP) and the launch of the new Biomethane Industrial Partnership (BIP). In order to do so, more biogas must be produced and existing biogas converted to biomethane with the need for more incentives to build up new plants and provide biomethane by repowering existing plants in the EU (European Commission, 2022a).

Biomethane Action Plan as the document supporting the implementation of the REPowerEU Action Plan entails, among others, key areas in order to unlock biogas to be upgraded to biomethane and biomethane potential from wastes and residues in the EU and by doing so to achieve 35 bcm of biomethane production by 2030. The action areas include:

- Promotion of the sustainable production and use of biogas and biomethane at EU and national/ regional level and the injection of biomethane into the gas grid;
- Provision of the support mechanisms for biogas upgrading to biomethane;

- Promotion of the adaptation and adjustment of existing and the development of new infrastructure for the transport of higher shares of biomethane through the EU gas grid;
- Addressing R&D&I gaps;
- Provision of access to finance (European Commission, 2022b).

Biomethane Industrial Partnership (BIP) was established in September 2022 with the objective of supporting the attainment of the production of 35 bcm per year by 2030 and use of sustainable biomethane thus reducing cost-effectively EU's dependency on Russian natural gas. It should further support an integrated net-zero energy system while realizing circular approach and diversifying farmers' incomes. The working principle of the BIP is based on the multi-stakeholder involvement of representatives from the Commission, member states, companies, industry, academia, and NGOs covering the whole biomethane value chain (European Commission, 2022c). BIP consists of the following five Task Forces:

- National biomethane targets, strategies and policies;
- Accelerated biomethane project development;
- Sustainable potentials for innovative biomass source;
- Cost efficiency of biomethane production and grid connection;
- Research, Development and Innovation needs (Biomethane Industrial Partnership, 2023).

Gas Package on internal markets for renewable and natural gases and for hydrogen (not yet approved). In December 2021 the European Commission published the draft of the so called *Gas Package*. This is a set of documents that will regulate the gas market (renewable and natural gas and hydrogen) once approved. These documents are currently under discussion amongst the European Commission, the European Parliament and the European Council (*trialogue process*) in order to find a common position. The documents mention in several articles the importance of facilitating the injection of biomethane into gas grid by defining a common European quality specification.

3. Overview of innovative biomethane technologies

The EU projects use different innovative technologies, mainly advanced gasification and biomethanation processes, based on waste and residues.

Figure 3 shows the joint map of the 4 Horizon Europe-funded projects on innovative biomethane production (SEMPRE-BIO, BIOMETHAVERSE, HYFUELUP, METHAREN) by demonstrating the involved countries and countries with demo-sites investigated in the 4 biomethane projects (involved countries vs. countries with demo-sites).

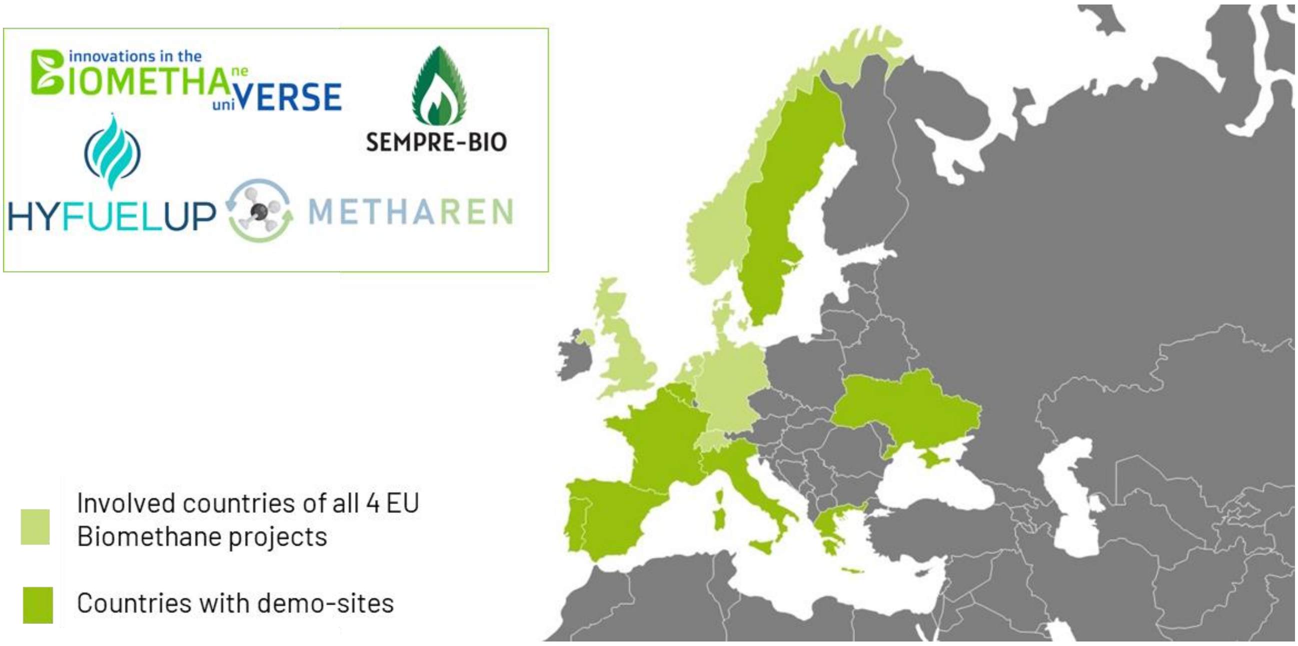

Figure 3: Cluster of Horizon Europe-funded projects on innovative biomethane production – involved countries and countries with demo-sites investigated in the 4 Biomethane projects (SEMPRE-BIO, BIOMETHAVERSE, HYFULEUP, METHAREN) (Source: DBFZ 06/2023)

In total, the consortium of all 4 Horizon Europe funded biomethane projects contains:

- 65 partners (67 in total, 2 twice)
- 14 countries (Spain, France, Belgium, Germany, Denmark, Norway, Italy, Greece, Sweden, Ukraine, Portugal, Switzerland, United Kingdom, Netherlands)
- 10 demonstration plants (demo-sites) in 8 countries (Spain, France, Belgium, Portugal, Greece, Italy, Sweden, Ukraine); in Italy and France 2 demo-sites

The consortium includes the most experienced biomethane experts from different stakeholder groups: universities, NGOs, associations, industrial partners and consulting experts in the field of biomethane.

Table 1: Statistics of 4 HE biomethane projects

HE Project	Number of countries	Number of partners	Number of demo-sites
SEMPRE-BIO	6	16	3
BIOMETHAVERSE	9	22	5
HYFUELUP	6	11	1
METHAREN	8	18	1
in total	**14**	**67**	**10**

Table 2 demonstrates the overview of innovative technologies and pathways investigated in 4 HE clusters on biomethane.

Table 2: Overview of 4 HE Biomethane projects – kind of innovative technology, TRL, used substrates, country of demo-sites

HE Project	No. Demo-Sites	Kind of innovative technology	TRL (by the beginning of the project)	TRL by the end of the project	kind of substrates	Country of demo-site
SEMPRE-BIO	Case I	Biogas methanation	4	7	sewage sludge (WWTP)	Spain
	Case I	Biomethanation (Sabatier reaction)	4	5	sewage sludge (WWTP)	Spain
	Case I	PEM electrolysis	3 - 4	5	sewage sludge (WWTP)	Spain
	Case II	Pyrolisis, syngas CO methanation	5	7	green waste /woody residues	France
	Case III	Cryoseparation (downsizing)	8	8	manure	Belgium
BIOMETHA-VERSE	Case I	In-Situ and Ex-Situ Electromethanogenesis	4	6 - 7	agro-industrial residues	France
	Case II	Ex-Situ Thermochemical/ catalytic methanation	5	7	livestock waste	Greece
	Case III	Ex-Situ Biological methanation	3 - 4	7	sewage sludge (WWTP)	Italy
	Case IV	Ex-Situ Syngas Biological methanation	3 - 4	7	wood chips, logging residues, municipal waste	Sweden
	Case V	In-Situ Biological methanation	4	6 - 7	chicken manure and agricultural residues	Ukraine
HYFUELUP	Case I	syngas /flue gas for catalytic methanation	4 - 5	6 - 7	Organic waste	Portugal
METHAREN	Case I	Gasification	4	7	Urban waste	Italy
	Case I	Methanation reactor	4	7	Syngas, CO_2 from biogas upgrading	Italy
	Case I	Flexible and innovative purification processes	4 - 5	7	Syngas, Biomethane	Italy
	Case I	Manage RES intermittency to ensure continuous production	4 - 5	7	Not apply	Italy
	Case I	Maximised energy and by-products recovery	4	7	Not apply	Italy

In METHAREN Project one demonstration plant in Italy will be in operation, however the analysis regarding the innovative technologies are investigated in cooperation with the involved country partners:

- Gasification and methanation reactor: France, Italy;
- Flexible and innovative purification processes: Germany, Portugal, Italy;
- Manage RES intermittency to ensure continuous production: Switzerland, Italy;
- Maximised energy and by-products recovery: France, Italy.

3.1. SEMPRE-BIO

3.1.1. Short project description

The European Commission, in March 2022, announced a target for the production of 35 bcm of biomethane within the EU by 2030. The EU produces 3 bcm of biomethane today. So plans to scale up require the mobilization of sustainable biomass feedstock. In this context, the EU-funded SEMPRE-BIO project will develop novel and cost-effective biomethane production solutions and pathways. Specifically, it will set up three European biomethane innovation ecosystems based in Adinkerke (Belgium), Baix Llobregat (Spain) and Bourges (France), which are representative of the different baseline situations for biomethane production across Europe. The project will design a process by which more innovators and entrepreneurs will be able to launch larger-scale and cheaper production of biomethane faster. (Cordis project description SEMPRE-BIO)

3.1.2. Overview of investigated innovative technologies and pathways

SEMPRE-BIO project will develop and scale-up 5 innovative biomethane production technologies which will be demonstrated through 3 case studies based in Baix Llobregat (Spain), Bourges (France) and Adinkerke (Belgium).

Case study I - Baix Llobregat (Spain): The demonstration plant (see Figure 4) will be installed in the Baix Llobregat wastewater treatment plant (WWTP) which treats sludge through anaerobic digestion, currently producing 700 m^3/h of biogas. This biogas will be upgraded to biomethane by an innovative combination of two different technologies: Proton exchange membrane water electrolysis (PEM) and CO_2 bio-methanation.

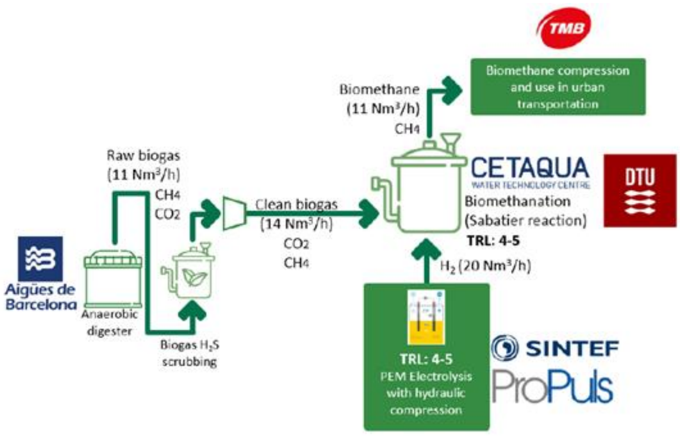

Figure 4: Schematic design of case study I in SEMPRE-BIO-Project

First, regenerated water from the tertiary system in the WWTP is treated through a reverse osmosis system to generate demineralized water, which is used in the PEM electrolyser to generate hydrogen. The hydrogen reacts with the carbon dioxide in the biogas in the presence of microorganisms. The biogas has been previously scrubbed of hydrogen sulphide to protect equipment. Finally, the resulting biomethane (95% vol) is scrubbed of volatile organic carbons and siloxanes, and later compressed for storage. The buses will directly be fuelled from this storage. The demonstration plant will allow the cost reduction in biomethane production by scaling-up biogas upgrading.

Case study II - Bourges (France): In this case, the input gas for methanation is syngas instead of biogas, which is the most common approach (case study I). The demonstration plant, depicted in Figure 5, consists of a combination of pyrolysis and bio-methanation to produce biogas from a novel feedstock, woody biomass, which is a non-digestable biomass. This innovative combination of technologies is a patent of TERRA in which the woody waste goes through a thermo-chemical pyrolysis process producing pyrolysis gas, bio-oil and bio-char. Then the pyrolysis gas is cleaned and turned into syngas, which in turn is injected into a bio-methanation reactor to produce biogas. The biogas is upgraded to biomethane after a membrane separation system and directly injected into the gas grid.

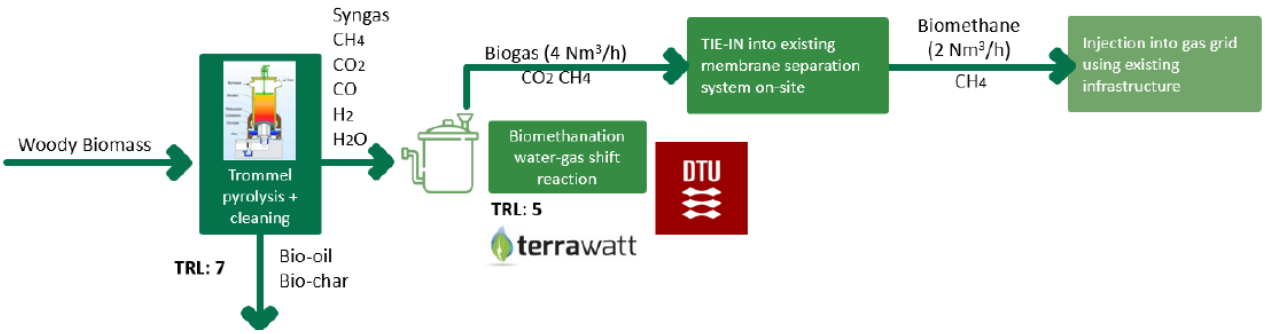

Figure 5: Schematic design of case study II in SEMPRE-BIO-Project

Case study III - Adinkerke (Belgium): Demonstration plant of case study III (see Figure 6) will be installed in the NV De Zwanebloem dairy farm which holds a permit for exploiting a biogas plant. The operator's goal is to co-digest manure and other agro-residues to optimize the process. The raw biogas produced in the anaerobic digestion will be upgraded through a cryogenic separation based on the phase separation due to the deep temperature decrease of the raw biogas mixture. The products of this cryogenic process are liquid biomethane, liquified carbon dioxide, water and hydrogen sulphide.

Two different technological configurations will be designed and constructed to obtain value-added products from the liquified carbon dioxide and hydrogen: 1) hybrid fermenter and 2) solar photobioreactor.

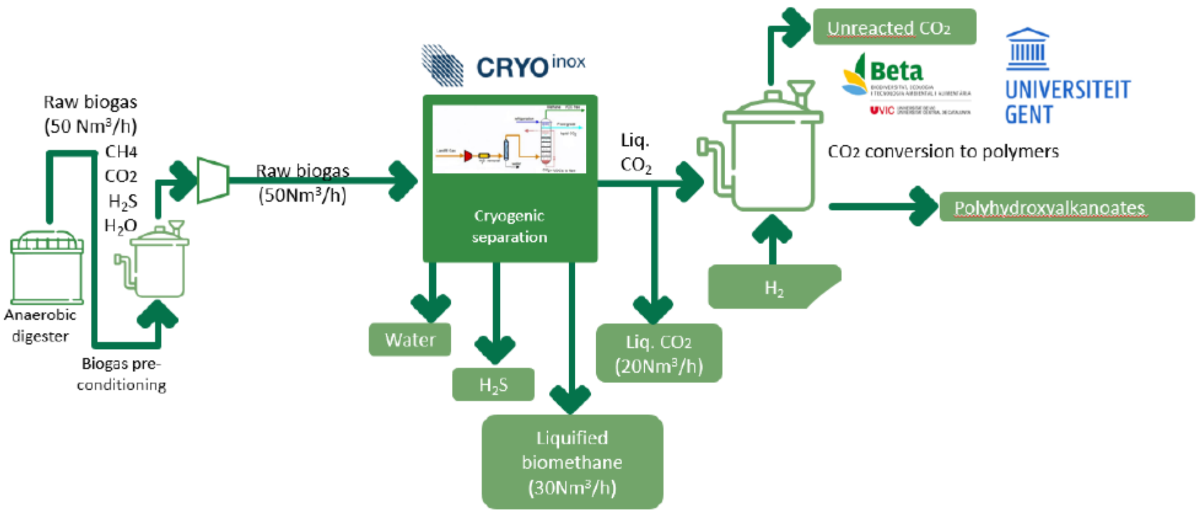

Figure 6: Schematic design of case study III in SEMPRE-BIO-Project

3.2. HYFUELUP

3.2.1. Short project description

The HYFUELUP project aims to develop and advanced technology for biomethane production using gasification and methanation. The biomethane produced will then be liquified and used for the decarbonization of long-distance road freight transport and maritime transportation. The project will demonstrate a flexible pathway for efficient and cost-effective biomethane production based on local renewable resources -crops, wastes, and by-products- (only low-cost biogenic wastes are used) through thermochemical technologies combined with renewable hydrogen. One demonstrator will convert biomass feedstocks to syngas (a mixture of hydrogen and carbon monoxide) and "clean" it. A second will employ dynamic hydrogen addition for methanation of the syngas (or flue gas). These will be integrated to demonstrate biomethane production at pre-commercial scale. This will allow accelerate the energy transition in the EU and increase sustainability in the transport and energy sector (replication is expected Europe-wide) and reduce greenhouse gas emissions (GHG) and improve competitive sustainable growth (higher than 90% GHG reduction, compared to use natural gas).

3.2.2. Overview of investigated innovative technologies and pathways

One of the most interesting solutions for converting biomass and waste into energy or fuels is gasification, due to the high efficiencies offered compared to other processes. It is known that the use of residues and wastes is a potential strategy to obtain a high-quality syngas capable of being used in different applications.

During biomass gasification, a gaseous mixture called syngas is produced, which usually contains carbon monoxide, carbon dioxide, hydrogen, and small amounts of other gases. One of the HYFUELUP's solutions (Figure 7) is to use an advanced type of gasification known as sorption enhanced gasification (SEG). SEG is a process in which a biomass feedstock is converted into a gas in a gasifier reactor and carbon dioxide is simultaneously captured *(in-situ)* via the use of a sorbent in a combustor or calciner. The sorbent properties such as the type and activity are crucial for the success of this process. Limestone ($CaCO_3$) has been widely used due to its excellent carbon dioxide capture capacity and relatively low price point. The reactor temperature also needs to be set at a specific point for optimal carbon dioxide capture while also maintaining the $CaO/CaCO_3$ equilibrium. Oxy conditions are also investigated in an analogous process known as Oxy-SEG.

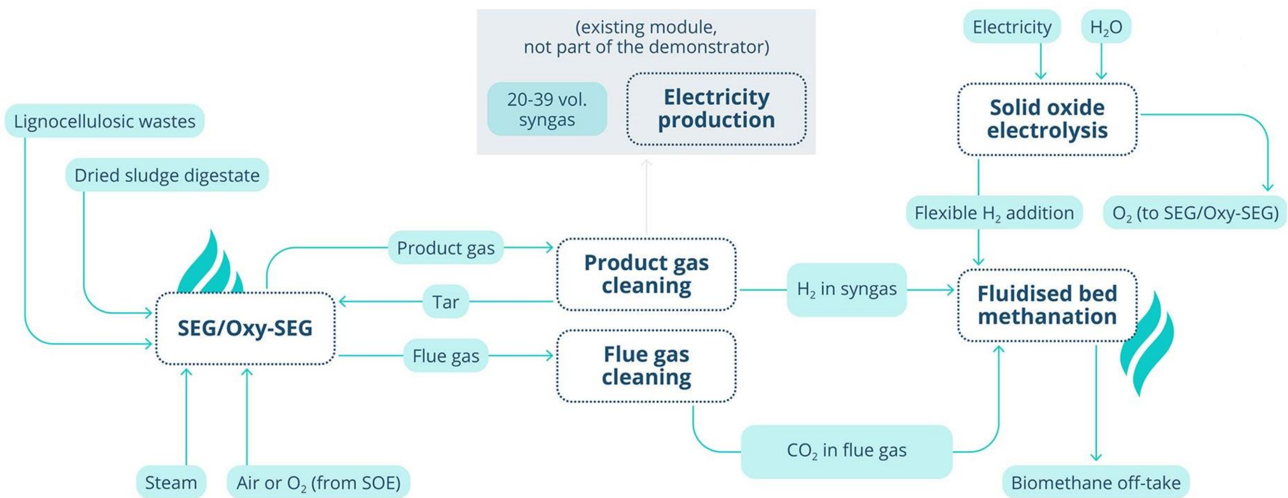

Figure 7: General process scheme of the HYFUELUP process. (Reference: https://hyfuelup.eu/)

Gasification is only one part of the concept, though. The syngas produced needs to be transformed into biomethane and prepared for off-take and distribution. After gas cleaning, where the syngas and flue gas are mainly decontaminated from solid particles, tars, and sulphur, methane synthesis is performed through catalytic methanation, a process also investigated in HYFUELUP due its flexibility and high potential for producing synfuels, namely biomethane.

This methanation is used to convert the carbon monoxide and carbon dioxide present in the syngas with non-stoichiometric feed gas compositions from SEG. Moreover, the dynamic integration with hydrogen from solid oxide electrolysis is explored to convert and utilize as many elemental carbon as possible. The additional hydrogen supply for methanation thus enables a high carbon efficiency compared with other processes with a relatively compact design of equipment and process chain. After obtaining a relatively pure biomethane stream, the gas is liquefied at near-atmospheric pressure by cooling it to very low temperatures. The liquefaction process requires the removal of non-methane components such as hydrogen, carbon dioxide, water, and other contaminants from the produced biomethane. In most cases, CO_2 levels are reduced to the ppm level before distribution to final markets.

3.3. BIOMETHAVERSE

3.3.1. Short project description

The EU-funded BIOMETHAVERSE project aims to diversify the technological basis for biomethane production in Europe, increasing cost-effectiveness and contributing to the uptake of biomethane technologies. To this end, five innovative biomethane production pathways will be demonstrated in five different European countries: France, Greece, Italy, Sweden and Ukraine. In the BIOMETHAVERSE demonstrators, CO_2 effluents from anaerobic digestion or gasification and other intermediate products will be combined with renewable hydrogen or renewable electricity to increase the overall biomethane yield. All demonstrated production routes consider a circular approach for energy and material use. The demonstrated technologies will reach TRL 6-7. (Cordis project description BIOMETHAVERSE)

3.3.2. Overview of investigated innovative technologies and pathways

In-Situ and Ex-Situ Electromethanogenesis (EMG): an electrochemical/biochemical route to produce biomethane from CO2 and renewable electricity

The anaerobic digestion plant of ENGIE is located at **Eppeville**, in **Hauts de France** region, covers a 2.5 ha surface and produces 1,815,000 m^3 of CH_4 per year (18 GWh, gas consumption of 5,000 persons). Around 230 Nm3 h^{-1} are injected into the natural gas grid. Biogas is produced from 30,000 tons y^{-1} of agro-industrial and agricultural residues. The plant has a 6,000 m3 digestion volume with a hydraulic retention time higher than 50 days. The digestate is valorized through land-spreading (6,000 ha, 31 farms).

Two configurations are planned with in the project:

- The first configuration has the electrodes in the digester (single chamber), which is then called a bio-electrochemically-improved anaerobic digester (1c-AD-BES). The electrodes increase the overall biogas production of the AD plant by fostering both oxidative and reductive processes in AD. A 1c-AD-BES will be implemented to produce biogas with a biomethane content of up to 70-80%.
- The second configuration, the classic EMG reactor, has two compartments (double chamber) separated by a proton exchange membrane (2c-AD-BES). Here, water is split on the anode, and CO_2 is reduced to CH_4 on the microbial cathode under the applied voltage. A 2c-AD-BES can be used for the biogas upgrading to high-purity biomethane (>95%) and power-to-gas applications, by bio electrocatalytically converting the remaining biogas CO_2 share.

Ex-Situ - Thermochemical/catalytic Methanation (ETM)

The Biogas Lagadas S.A. (BLAG) plant is located in **Kolchiko – Lagadas,** in **Central Macedonia Region**. The BLAG plant exploits around 80,000 tonnes of livestock waste per year, yielding 8,400 MWh of electricity and 75,000 tonnes of organic soil improver suitable for fertilizing 5,000 acres of agricultural land. The plant has a capacity of 290 m³ CH_4/h^{-1}. The BLAG's biogas plant has 2 fermenters with 4,500 m^3 active volume for biomass (each one) and 10,000 m^3 of biogas buffer capacity. The total flow is 500 m³h^{-1} at 100 mbar. The CHP generator produces 1MW$_e$.

The technology concerns the conversion of CO_2 contained in the biogas to biomethane, through its reaction with renewable hydrogen in a catalytic reactor.

$$CO_2 + 4H_2 \xrightarrow{catalyic\ reaction} CH_4 + \ 2H_2O$$

The catalytic reactor can handle a mixture of methane and carbon dioxide (raw biogas); thus, no separation of the biogas is required before conversion. The reaction takes place at high pressure and temperature.

The individual stages of the whole process include:

- Cleaning and compressing step of the biogas
- catalytic methanation reaction,
- dehumidification of the final biomethane stream.

The final product is biomethane already reaching pipeline quality gas standards (e.g., 96-98 vol-% CH_4), no further upgrading is necessary.

Ex Situ Biological Methanation (EBM)

Gruppo CAP, as integrated water service manager for the Metropolitan City of **Milan area (Lombardy Region)** operates 40 wastewater treatment plants of different sizes and capacities over a 1,500 km^2 area. Among those, anaerobic digestion is already widely implemented as a technology to reduce sewage sludge and produce biogas for local energy production. The demo site is situated at one specific WWTP (Bresso-Niguarda), located within the **Municipality of Milan** in the neighbourhood of Niguarda. Biogas produced via sewage sludge AD is already converted into biomethane via physical upgrading and sent to the natural gas distribution grid. Considering that Bresso-Niguarda WWTP has a treatment capacity of about 300,000 people equivalent, corresponding to 2,200 m^{3}h^{-1} of inflow from sewer, it currently produces about 90 m^{3}h^{-1} of biomethane.
CAP, in collaboration with partners Politecnico di Milano, SIAD and CIC, will implement an integrated demo plant, to achieve a more sustainable biomethane production, in a holistic approach that includes biogas upgrade side by side with several approaches to increase biogas production.

The demonstration plant will be implemented to one of the 2 parallel AD lines, the second one will be kept as such to have a direct comparison of the overall biomethane yield improvement and production cost reduction achievable by applying the integrated technologies. It will be composed of four units:

(1) sewage sludge ozonolysis, which will serve as pre-treatment to enhance the feedstock digestibility and thus the biogas yield, (2) ex-situ biological upgrading, to convert carbon dioxide in methane and boost the yield, (3) microalgae cultivation on the liquid fraction of digestate and (4) co-digestion of pre-treated sludge, microalgae, and selected substrates.

The purpose of sludge treatment using ozone is to increase the anaerobic biodegradability of the substrate and its capacity to produce biogas while reducing the digestate to be disposed of. In the scientific literature, several experiences are reporting the application of this technology on a laboratory and pilot scale. These experiences generally describe significantly positive effects on anaerobic digestion. However, pilot-scale experiments are extremely rare. Biological ex-situ upgrade operates at mild conditions and represents a promising and rapidly evolving technology, in terms of reactor configurations and process volumetric intensity. Key aspects are the gas transfer efficiency and the dynamic response to variable and even null H_2 load. The *ex-situ* upgrade prototype will run biological hydrogenotrophic conversion of biogas to biomethane by Archaea present as suspended biomass and as biofilm, the latter attached on hollow fibers tubular gas transfer membranes.

In this innovative configuration, H_2 and biogas are supplied by two devices: to the biofilm by diffusion through the lumen of the membrane and, to the suspended biomass, by gas sparging. This configuration combines the scheme of a previously tested *ex-situ* reactor (V = 500 L) with the gas transfer membrane biofilm reactor, a technology already known and applied at full scale in other sectors.

Ex-Situ Syngas Biological methanation (ESB)

The demonstration site is an existing 6 MW gasification plant owned by the company CORTUS. The plant is situated in **Höganäs, Region of Götaland**. The gasification technology employed is referred to as the *WoodRoll®* process. This involves drying, pyrolysis and gasification stages to convert raw biomass to synthesis gas (mixture of CO + H_2) in a CO/H_2 ratio of approximately 1:2. Additionally, the gas contains CO_2 (14%) and some CH4 (1%). The current feedstock is wood chips with 40% moisture. However, the plant could run on fuel with up to 45% moisture without pre-drying which enables the conversion of woody waste products such as logging residues or municipal yard-trimmings. The produced syngas is used as a green energy input for steel powder manufacturing by an adjacent industry.

The specific type of biological methanation intended for demonstration in this case converts syngas (CO, H_2, CO_2 and some CH_4) from thermal gasification and/or pyrolysis via biological methanation to biomethane in a Trickle Bed Reactor (TBR). This reactor is fed by syngas and a nutrient solution which can be in the form of digestate from a co-located conventional biogas plant or reject water from municipal wastewater sludge dewatering.

The syngas meets a selectively adapted mixed culture biofilm on carriers and a continuous flow of nutrient-rich solution. The CO and H_2 are consequently converted to CH_4 and CO_2. The TBR design allows for a high exchange rate between the gas and liquid phase. If it is desirable to also utilize the remaining CO_2 and produce a final gas mix of very high CH_4 content, an additional source of H_2 from an electrolyser can be added to the input syngas.

This reaction between the additional H_2 and CO_2 would happen in the same TBR facilitated by the same mix culture biofilm, resulting in higher utilization of invested CAPEX and the elimination of a conventional upgrading step. The demonstration plant will be equipped with a small electrolyser able to provide external H_2 volumes from renewable electricity to achieve stochiometric balance for the conversion of all CO_2 to methane. The planned trials will demonstrate biological methanation of syngas both without and with the addition of external H_2.

In-Situ Biological methanation (IBM)

The biogas plant in **Ladyzhin**, **Vinnytsia region,** has an installed electric capacity of 12 MW, producing biogas from 330 t d^{-1} of chicken manure and other agricultural residues, producing 85,000,000 kW of electricity per year. Plant configuration consists of twelve reactors (9 main digesters and 3 post digesters) with 90,000 m^3 volume each.

Also, the complex has its own biogas pipeline that transfers biogas to the cogeneration unit located near the slaughter complex, in order to use heat to supply steam to the latter. During anaerobic digestion, different microorganisms convert organic residues into biogas. The process occurs in four different phases of which the last phase is methanogenesis. Two metabolic pathways of methanogenesis dominate in industrial biogas plants, i.e., acetolactic methanogenesis, where acetate is split into CO_2 and CH_4 and hydrogenotrophic methanogenesis where CO_2 is reduced with hydrogen to CH_4. Both processes run in parallel, however, the first route will be prevailing if no interventions are made because the naturally occurring amount of free hydrogen in the substrates is low. By injecting hydrogen directly into an AD reactor, the second route is stimulated and the activity of the hydrogenotrophic methane formers is increased. This results both in an overall increase of the biomethane yield per given amount of feedstock and in a higher methane concentration in the final biogas produced.

3.4. METHAREN

3.4.1. Short project description

The EU-funded METHAREN project will demonstrate a cost-effective, sustainable and circular biomethane production system enabling the management of the intermittent renewable energy sources. The newly developed systems will be retrofitted to existing biogas plants and will significantly enhance biomethane production through extracting value out of plant effluents. The project will demonstrate the cost effectiveness and sustainability of the whole production chain from feedstock to injection of biomethane into the grid. All developed systems will be integrated and tested in a pilot site before being operated and further optimised. METHAREN innovations could increase cost effectiveness by at least 20 %, enhance the carbon conversion rate from biowaste to methane more than 80 % and reduce harmful carbon emissions more than 50 %. (Cordis Project description METHAREN)

3.4.2. Overview of investigated innovative technologies and pathways

METHAREN is providing improvements beyond the state-of-the art along four main axes related to:

i) the biogas plant efficiency,
ii) flexibility and energy management for RES integration,
iii) the circularity approach for sustainable production,
iv) innovative business models and adapted policies.

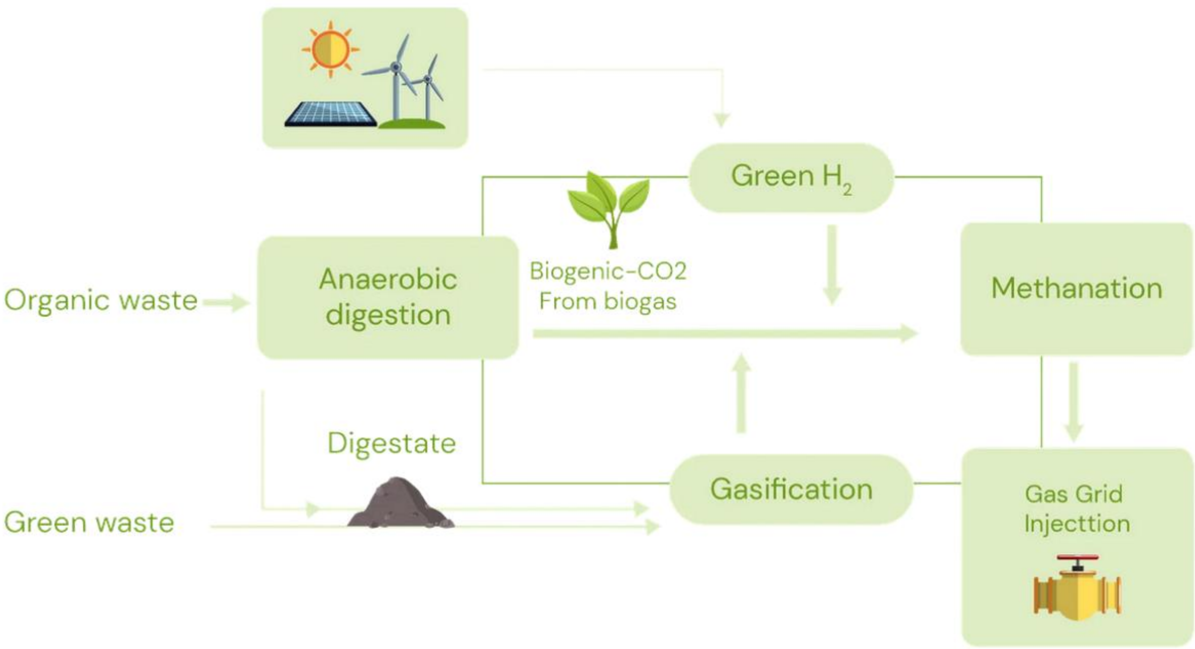

Figure 8: METHAREN global system

As shown in Figure 8, METHAREN aims to adopt a systemic approach through:

- The coupling of a methanation module with an existing biogas plant,
- Several innovative components or processes along the value chain integrated in a pilot plant,
- A high replicability potential of the solutions at European scale.

Adding a methanation module brings many benefits for the production process. It first increases the production yield of biomethane, enabling conversion of biogenic-CO_2 from biogas. This biogenic-CO_2 which represents 40 to 50 % of the biogas is usually returned to the atmosphere or, at best, stored but rarely used. METHAREN methanation process relies on the combination of this CO_2 with green H_2 produced from renewable power production as a power-to-gas process. This flexibility to pilot renewables intermittency is enhanced by a gasification module of waste residues. As the biogenic-CO_2, these wastes are so far discarded. In this process, they are gasified to provide a synthesis gas (syngas) which feeds the methanation reactor. Thus, METHAREN will considerably increase the production of biomethane by exclusively using effluents from biogas plants (biogenic-CO_2 and waste residues) and renewable energy sources (RES), without need for electric storage devices. This process has been designed to directly turn any electron coming from the RES into biomethane at any time, in an efficient way.

Gasification of wastes from biogas plant and coupling with methanation

Gasification is a globally endothermic thermochemical conversion process, performed between 750°C and 950°C, in the presence of a gasification agent, which, most frequently, consists of O_2, air, steam or their mixtures. Different kinds of carbon-based feedstock can be processed (e. g., woody biomass, agricultural residues, different kinds of wastes coming from household or industry). The produced syngas contains high value molecules such as H_2 and CO which can be used either for production of heat/electricity, or for synthesis of other final desired molecules, such as CH_4. Among different reactor technologies, the co-current fixed bed reactor is a proven technology and can be used on several diversified feedstock as long as they are properly prepared. When syngas is intended to be used in the synthesis of gaseous or liquid products (such as CH_4, or Fischer-Tropsch products), N_2 is not desired in the gasification agent to avoid any decrease in efficiency at the synthesis step due to the dilution effect or need for separation of N_2. The preferred options are then either gasification with O_2 (autothermal) possibly mixed with H_2O or CO_2, or gasification with H_2O only. The fixed bed technology proposed has been proven commercially for enriched air with O_2 up to 44% and demonstrated at pilot scale for up to 100% O_2, using a mix of O_2/H_2O.

The food wastes coming from municipal / household wastes are well adapted for anaerobic digestion, directly producing biogas. However, in the global production chain from food waste to biogas, some discarded fractions are produced, because of the presence of non-digestible fractions (plastic bags – increasingly made from compostable bioplastics – lignin materials etc.). Thermochemical processes, such as gasification, are then complementary to anaerobic digestion for valorisation of these residual fractions. However, gasification of these types of wastes brings several peculiarities: wastes with a high moisture and ash content and inorganic volatiles elements.

The biomass to bio-SNG conversion has been demonstrated on several sites: Gobigas project in Sweden, Bio-SNG project in Austria, GAYA project in France. However, in these cases, only woody biomass was considered as the feedstock, avoiding the three above-mentioned difficulties. In each case, gasification was performed in a dual fluidised bed gasifier. This fixed bed downdraft technology is a robust and well-known one. It is well adapted for small to medium scale reactors (up to about 5 MW_{th} corresponding to a feeding rate of 1-1.5 t/h). One of its advantages in comparison with the fluidised bed technology, is the easier operability. The tar content in the produced gas is rather low (under $1g/m^3$). However, this type of reactor uses most of the time air or enriched air as gasification agent.

The present project aims to fill this gap by designing and constructing a pilot scale gasification plant for transformation of residual waste fractions from the biogas plant into syngas that will be cleaned and conditioned to be used in a methanation reactor. The agglomeration issues that could occur due to the feedstock will be anticipated considering the detailed chemical analysis of this feedstock, building on the knowledge developed in previous projects. For gasification, the downdraft fixed bed technology will be considered, however using of mixture of O_2/H_2O as gasification agent.

Gasification process of various discarded residues

Optimization of the gasification process, evaluation of the syngas produced and identification of energy streams for assessment of overall energy integration enhancement with the methanation reactor and the whole biomethane production system.

Innovative methanation reactor

The catalytic methanation reactors are either state of the art technologies adapted from large scale stationary Coal- To-SNG systems, or new concepts designed to reach the specific requirements. This second type is spreading for smaller scale, more compact units to operate unsteady due to fluctuating availability of renewable hydrogen and variation of gas inlet composition. The methanation reaction is highly exothermic. The CO methanation is even more exothermic. A significant issue in methanation is therefore the efficient temperature control in the reactor in order to prevent thermodynamic conversion limitation and catalyst degradation caused e. g. by sintering.

Three basic concepts offer appropriate heat management:

(i) fluidized bed methanation,
(ii) Three phase methanation or
(iii) Cooled fixed bed methanation.

Innovative concepts are thus based on newly structured cooled fixed bed reactor. Due to their internal structure, these reactors feature better heat transfer capacities and overcome the drawbacks of temperature hot spots. Examples of such reactors are honeycomb reactors with catalyst coating and thermo-oil cooling envisaged for small-scale methanation applications. This technology has been successfully implemented in the Falkenhagen Power to Gas site, within the *STORE&GO European project*.
The methanation reactor proposed for the demonstration site of METHAREN is based on an innovative technology of millistructured tube and shell heat exchanger. It presents several advantages, in the frame of this project requiring high load flexibility, inlet gases composition variations, quick answer to variations, heat valorisation to increase the overall unit efficiency. The reactor compact design allows efficient heat management and a high conversion rate to optimise material and energy flows. It also operates with large flexibility in terms of inlet gases composition and flow rates.

Manage RES intermittency to ensure continuous production

Green H_2 production implies renewable energies, but when RES is not available, grid power consumption must be at least minimized. Yet, hydrogen must be produced constantly to satisfy the stoichiometry of the CO and CO_2 methanation reactions.

In METHAREN, the domain of applicability will be increased by expanding the boundaries of the system and including more technologies, such as the combination of gasification, methanation and a reversible SOEC system. It will also be improved by using real data from the demonstration pilot plant, which will allow fine-tuning of the models, identifying hotspots for improvement and anticipating bottlenecks from the experimental side.

The biomethane production system of METHAREN will be a complex integrated system. The Energy Management System (EMS) developed will cope with the different dimensions of constraints to ensure a continuous production considering also economic factors:

- Renewable energy intermittency which results in variations in H_2 availability for the methanation reaction;
- Different minimum operating levels of the components;
- Several integrations of the system between the components to recover energy and by-products.

4. Main barriers regarding increase of biomethane production in Europe

This chapter contains a short description of general barriers and challenges as well as key influencing factors which hinder the increase of biomethane production in Europe based on the survey response of involved project partner. The feedback is therefore only a sample, does not claim to be complete and has not been prioritized in the listing.

Technological barriers:

- Innovative, new technologies, different TRL to be approved, market uptake to be developed.
- Availability (logistics), different quality and costs of feedstock and digestate require different developed technologies
- Supply chains and logistics (especially for alternative feedstocks) to be developed.
- Focus mainly on AD, less on innovative gasification processes.
- Development of infrastructure (gas grids /grid injection/ number and/ or lack of CNG and LNG filling stations) in the countries are on different levels: grid expansion vs. grid reduction or reconstruction of pipelines in discussion.

Legislative barriers:

- Missing or not ambitious (in line with the potentials resp. EU regulations) national targets/ quotas for biomethane production and use (e.g. Spain, Sweden, Belgium, Ukraine)
- Missing support mechanism (e.g. FiT, quota) /legal framework, e.g. quotas for biomethane production and use)
- Complex regulations, less harmonized, faster amendments in shorter time (e.g. Germany)
- Focus on only one specific sector (e.g. Italy - transport sector shall remain the main utilization sector (due to the sustainability criteria to be fulfilled and country’s gas-driven vehicle fleet), Portugal – support for biomethane only and no for biogas, Sweden - support for other uses than transportation, France: general injection, not the use of biomethane)
- Often different legislation in different regions, different interpretation of laws (e.g. no support in Flanders/Belgium; state vs. autonomous legislation in Spain - example of the Biometagás plant La Galera in Tarragona with the connection to the transmission 60 bar line halted for over a year although the plant was already built and started because the jurisdiction was unclear whether being national or local); e.g. Denmark, Portugal, Spain – high spreading of waste; might be not allowed to export waste from one autonomous region to the other.
- Competition composting and AD for agro-industrial residues (e.g. Portugal)
- Taxation rules, i.e., based on volume instead of energy content (e.g. Sweden)
- Lack of overall strategy; which pathways using biomethane are prioritized (e.g. Germany)

Administrative barriers:

- Lack of planning security
- Long permitting processes (e.g. Germany, Spain, Italy, Sweden, Belgium)
- None or poor regulations on gas grid access
- Biomethane trading in EU: certification; missing (harmonized) mass balance principle
- Missing efficient and fully recognised system for cross-border trade of biomethane
- Guarantee of Origin style certificate system was developed outside an EU-wide framework, but not recognised by other states
- Very limited systems for administering the issuing and transfer of Proof of Sustainability in electronic databases (barrier to building trust in those systems)
- Certificate of Origin (CoO) Scheme represent biomethane from AD, so far, no synthetic methane and other renewable gases

Economic barriers:

- Missing or not sufficient feed-in tariffs/ premiums/ taxes
- Taxes on biomethane in comparison to fossil fuels, no benefit using biomethane: e.g. the same CO_2 tax on both natural gas and biogas (e.g. Denmark), tax exemption from excise and carbon duty for biogas/biomethane for transport and heating revoked (e.g. Sweden)
- Access to the gas grid: long distances to gas grid (higher costs); cost allocation between biomethane provider vs. gas grid operator (e.g. Germany); capping of costs for biomethane provider revoked / in discussion
- Export more attractive (e.g., 86 % of biogas produced in Denmark exported to Europe esp. to Germany and Sweden), increased biomethane imports but stagnating production
- Lack of private sector investments

Social barriers:

- Public image of biomethane unknown or negative, spreading the word needed (e.g. Belgium, Portugal)
- Outdated view of processes: composting of biowaste/ green cuttings/ residues instead of integrated processes (AD + composting)
- Possible pathogens in the digestate (e.g. Italy)

The main barriers to increase the biomethane capacity based on the survey response are summarized and classified according to the kind of barriers in Table 3 to Table 6. The overview contains the classification regarding the relevance for the short-term action to increase the biomethane capacity, the estimated timeframe and relevant stakeholder as well as the addressed level (EU, national, regional) to remove the barriers.

Table 3: Classification of technological barriers on biomethane

Desciption of barriers	Relevance for short term action*	Estimated time-frame	Level	Main stake-holders
Innovative, new technologies, different TRL to be approved, market uptake to be developed	3	mid-term/ long-term	EU	industrial partners, R&D
Availability (logistics), different quality and costs of feedstock and digestate require different developed technologies	3	mid-term/ long-term	EU	industrial partners, R&D
Supply chains and logistics (especially for alternative feedstocks) to be developed	3	mid-term/ long-term	EU	industrial partners, R&D
Focus mainly on AD, less on innovative gasification processes	3	mid-term/ long-term	EU	industrial partners, R&D
Development of infrastructure (gas grids /grid injection/ number and/ or lack of CNG and LNG filling stations) in the countries are on different levels; grid expansion vs. grid reduction or reconstruction of pipelines in discussion, for planning security important	2	mid-term/ long-term	National/ Regional	energy supplier, network operator, policy makers

**(1=very important, 2=important, 3 = important, but long-term)*

Table 4: Classification of legal and administrative barriers on biomethane

Desciption of barriers	Relevance for short term action*	Estimated time-frame	Level	Main stake-holders
Missing or not ambitious (in line with the potentials resp. EU regulations) national targets/ quotas for biomethane production and use (e.g. Spain, Sweden, Belgium, Ukraine)	1	mid-term/ long-term	National	Policy makers
Missing support mechanism (e.g. FiT, quota) /legal framework, e.g. quotas for biomethane production and use)	1	mid-term/ long-term	National	Policy makers
Complex regulations, less harmonized, faster amendments in shorter time (e.g. Germany)	1	mid-term/ long-term	National	Policy makers
Focus on only one specific sector (e.g. Italy - transport sector shall remain the main utilization sector; Portugal – support for biomethane only and no for biogas; Sweden - support for other uses than transportation; France: general injection, not the use of biomethane	2	mid-term/ long-term	National	Policy makers
Often different legislation in different regions, different interpretation of laws (e.g. no support in Flanders/Belgium; state vs. autonomous legislation in Spain); e.g. Denmark, Portugal, Spain – high spreading of waste; might be not allowed to export waste from one autonomous region to the other.	2	mid-term/ long-term	National/ Regional	Policy makers
Competition composting and AD for agro-industrial residues (e.g. Portugal)	3	mid-term/ long-term	National	Municipalities
Taxation rules, i.e., based on volume instead of energy content	3	mid-term/ long-term	EU/ National	Policy makers
Lack of overall strategy; which pathways using biomethane are prioritized (e.g. Germany)	1	short-term/ mid-term	National	Policy makers
Lack of planning security	1	short-term/ mid-term	National	Policy makers
Long permitting processes (e.g. Germany, Spain, Italy, Sweden, Belgium)	1	short-term/ mid-term	National	Policy makers, administrative stakeholders
None or poor regulations on gas grid access	1	short-term/ mid-term	National / Regional	Policy makers, energy supplier
Biomethane trading in EU: certification; missing (harmonized) mass balance principle	3	long-term	EU	Policy makers
Missing efficient and fully recognised system for cross-border trade of biomethane	3	long-term	EU	Policy makers
Guarantee of Origin style certificate system was developed outside an EU-wide framework, but not recognised by other states	3	long-term	National / EU	Policy makers/ industrial partner

Very limited systems for administering the issuing and transfer of Proof of Sustainability in electronic databases (barrier to building trust in those systems)	3	long-term	EU / National	Policy makers, Software developer
Certificate of Origin (CoO) Scheme represent biomethane from AD, so far, no synthetic methane and other renewable gases	3	long-term	EU	Policy makers

**(1=very important, 2=important, 3 = important, but long-term)*

Table 5: Classification of economic barriers on biomethane

Desciption of barriers	Relevance for short term action*	Estimated timeframe	Level	Main stake-holders
Missing or not sufficient feed-in tariffs/ premiums/ taxes	1	mid-term/ long-term	National	Policy makers
Taxes on biomethane in comparison to fossil fuels, no benefit using biomethane: e.g. the same CO_2 tax on both natural gas and biogas (e.g. Denmark), tax exemption from excise and carbon duty for biogas/biomethane for transport and heating revoked (e.g. Sweden)	2	mid-term/ long-term	National	Policy makers
Access to the gas grid: long distances to gas grid (higher costs); cost allocation between biomethane provider vs. gas grid operator (e.g. Germany); capping of costs for biomethane provider revoked / in discussion (no planning security)	2	short-term/ mid-term	National / Regional	Policy, grid operators, biomethane provider, plant operators
Export more attractive (e.g., 86 % of biogas produced in Denmark exported to Europe esp. to Germany and Sweden), increased biomethane imports but stagnating production	3	mid-term	EU	Policy makers, Biomethane traders
Lack of private sector investments	2	mid-term/ long-term	National	Policy makers

**(1=very important, 2=important, 3 = important, but long-term)*

Table 6: Classification of social barriers on biomethane

Desciption of barriers	Relevance for short term action*	Estimated timeframe	Level	Main stake-holders
Public image of biomethane unknown or negative, spreading the word needed (e.g. Belgium, Portugal)	3	mid-term/ long-term	National / Regional	Policy makers, biogas associations, Consulting
Outdated view of processes: composting of biowaste/ green cuttings/ residues instead of integrated processes (AD + composting)	3	mid-term/ long-term	National / Regional	industrial partners, R&D
Possible pathogens in the digestate	3	mid-term/ long-term	National / Regional	Policy makers, plant operators

**(1=very important, 2=important, 3 = important, but long-term)*

The **country-specific barriers and perspectives** determined based on the survey results of the involved project partners are shown in the appendix 8.3. The country specific sheets on barriers and perspectives illustrate the main differences between the countries. Please note, the list of barriers based on different kind of stakeholders and demonstrate opinions of the involved project partners.

4.1. Framework

At the European level, multiple regulations shape the development of renewable energies, thereby the national deployment of biogas resp. biomethane sector is especially influenced by the legal norms transposed into the national law or by the exclusive jurisdiction at the member state level.

Main policies and regulations supporting biomethane are primarily driven at the member country level. The level and type of coordination varies by each member state.

Following barriers can be summarized according to the framework conditions (in general):

- Missing legal framework
- Long permitting processes for installations, planning of plants
- Long delivery times for materials, bottlenecks in delivery times and production
- Lack of skilled workers/ staff
- Infrastructure (gas grids /grid injection/ number and/ or lack of CNG and LNG filling stations), grid expansion vs. grid reduction/reconstruction of pipelines (transportation vs. distribution network level)
- Cost increases

The political aim for doubling of biomethane production by 2030, aiming to achieve a target of at least 35 bcm (350 TWh) of an annual biomethane production by 2030 as a part of the Biomethane Action Plan, among others through the incentives under the Common Agricultural Policy (CAP). In order to do so, more biogas must be produced and existing biogas converted to biomethane with the need for more incentives to build up new plants and provide biomethane by repowering existing plants in the EU (European Commission, 2022a).

The biomethane potential for Europe in 2023 per technology and country is shown in Figure 9.

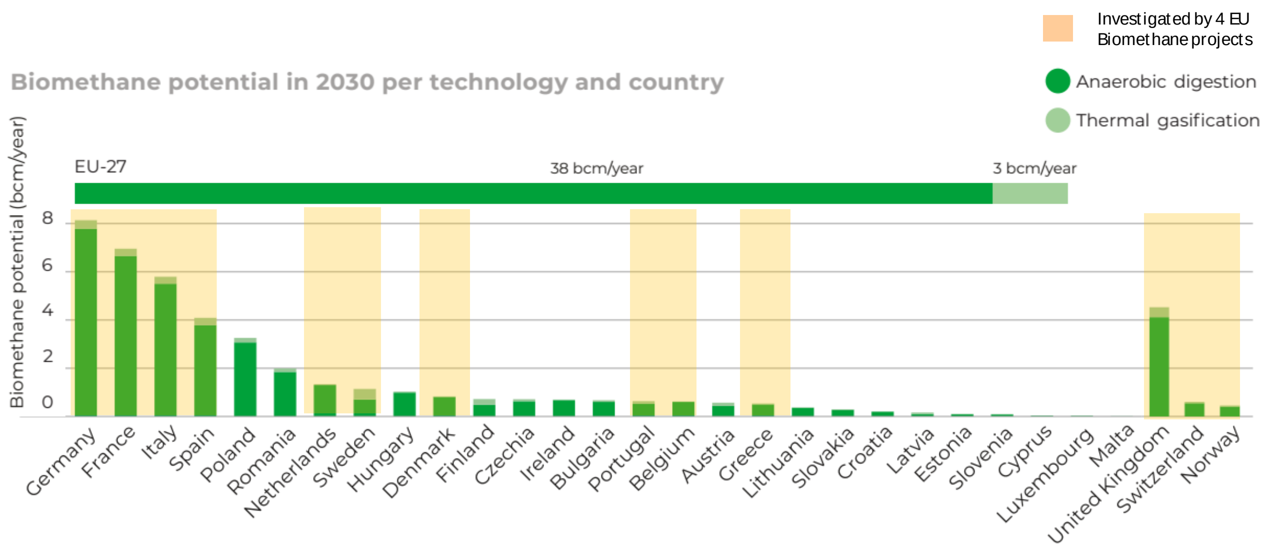

Figure 9: Biomethane potential in 2030 per technology and country (Source: Guidehouse Netherlands B.V (2022) - Biomethane production potentials in the EU, modified by DBFZ 5/2023)

4.2. Feedstock supply

This subchapter addresses some general aspects on feedstock supply and possible developments. Moreover country-specific aspects based on the survey responses (see appendix 8.3) are summarized as an overview.

4.2.1. General Aspects

For biogas resp. biomethane production a wide range of organic biomass can be used. Agricultural residues mixed with cattle or pig manure, organic waste, sewage sludge, landfills, forest biomass shall serve as future feedstocks for biomethane production. Unused resp. available substrates might be agricultural residues, biowaste, landfills and sludge from WWTP. The cultivation of energy crops is an exception and is mainly practiced in Germany and Austria. Against the background of low acceptance and political objectives on a national level, the focus is less on the cultivation of biomass and more on residual and waste materials for bioenergy production. Since biogas and biomethane are currently produced mainly from cultivated biomass in these countries, the question rises how to switch from energy crops to alternative substrates such as straw, catch crops, permanent crops, manure potentials, organic fraction of residual waste.

The *Climate Action Plan 2050 (BMUB 2016)* from 2016 heralded the focus on energy efficiency and bioenergy mainly from waste and residue materials in order to avoid land use competition attributing biomass only to a small extent by 2050 arguing that land will be needed for food provision. By tapping the still unused agricultural residue potential (straw, catch crops, not mobilized farm manure for AD), the volume could be increased to cover the current natural gas consumption.

A sustainable biomass uses via wider use of organic residues and (bio)wastes, agricultural co-products, material from landscape management for bioenergy production – addressing food and feed production. The (possible) utilization of specific substrates for biogas resp. biomethane production as well as the digestate treatment (return onto cultivated land) is partially linked to the European and German agricultural policy. At the European level, the Common Agricultural Policy (CAP) involves all EU member states supporting farmers. One of the CAP targets appears to be beneficial in particular with respect to the role of crop and feed residues within the future bio-economy identifying the favorable use of "food and feed residues, farm waste or other bio-based resources to produce textiles, natural packaging (replacing plastic), construction materials (reducing the use of energy-intensive materials such as steel and cement) or to produce a clean and affordable energy (e.g. through biogas production)" (European Commission, 2020).

With respect to the sustainable utilization of biomass, there are efforts towards further utilization of alternative substrates such as wild plants (cup plants) and agricultural residues (straw, chaff, sugar beet leaves) for biogas resp. biomethane production. Despite their positive environmental effects and cost reduction potentials, the limitations are set by the efficient process chain and availability at the regional scale for agricultural residues and harmonization of national and European legal frameworks for wild plants. More specifically, there should be an allowance for using wild plants from ecological conservation areas according to the second pillar of the Common Agricultural Policy (so-called greening measures) for biogas production. More attention to the anaerobic digestion of manure to be increased for biogas production can be complemented by the cultivation of field grass and clover for AD.

4.2.2. Examples /country-specific

Belgium's biogas potential shall be 15.6 TWh by 2030, 90% of which can be upgraded to biomethane, whereas the biogas potential specifically in Flanders can be amounted to 7.3 TWh by 2030 (Green Gas Platform, 2019). As future feedstocks for biomethane production manure (+/- 4.5 TWh), energy and intermediate/ sequential crops (+/- 4.5 TWh), followed by agricultural waste (+/- 3.5 TWh), industrial waste (+/- 1.5 TWh) and municipal waste (1 TWh) are expected (Regatrace, 2022). As unused resp. available feedstocks in Flanders manure (10 363 755 t), energy crops (1 338 953 t), agricultural waste (1 789 538 t), industrial waste (1 114 674 t), and municipal waste (1 197 263 t) can be counted (Green Gas Platform, 2019).

In **Denmark,** biogas is expected to substitute 100% of the natural gas by 2030 (resp. 78% by 2030 and 92% by 2035). If using the full available biomass potential, the envisaged biomethane production will be 26.11 TWh by 2030 (Biogas Danmark, 2023a). With respect to the future feedstocks for biogas production, it is expected that 80% will be made up by agricultural waste, mainly by manure with the share of 64% and straw, whereas 20% will be represented by industrial and food waste. Denmark aims to phase out energy crops by 2030 at the latest. The deployment of feedstocks for biomethane production is expected to be similar to that of the biogas production. According to the calculations of the Technical University of Denmark, between 41.4% and 45.7% of substrates will be unused in case of production of 100 % biomethane from biogas. By comparison, between 56.1% and 59.3% of biomass potential will remain unused in the 75 % biomethane scenario. The future main sector for the utilization of biomethane will be industry with 55 %, followed by the transport sector with 20%, CHP and local use (outside of the grid) with 10% and the gas sector with 5 % (Biogas Danmark, 2023a).

In **Germany,** the biogas production comprises about 10 % of the total natural gas demand, with about 1 bcm biomethane (resp. 10 TWh_{HHV}) 1 % is already produced (Beil et al. 2019, Daniel-Gromke et al. 2019). Biogas and biomethane are currently produced mainly from cultivated biomass (energy crops). The trend towards more use of residual materials is present. The question is, how do to the transformation of pathways to switch from energy crops to alternative substrates (e.g. straw, catch crops, permanent crops, dual cropping, manure potentials, organic fraction of residual waste). By tapping the still unused agricultural residue potential (straw, catch crops, doubling the use of farm manure), the volume could be increased to around 20 % of the current natural gas consumption in Germany without additional energy crop cultivation (Stinner et al. 2022).

The official document 'Biogas Roadmap', approved by the Spanish Government in March 2022, aims to increase biogas and biomethane production in the coming years, with the goal of exceeding 10 TWh in 2030 in **Spain**. Focused on the anaerobic digestion of organic waste (agricultural, agri-food industries, municipal and sewage sludge), it will promote the use of biogas in two main ways: the production of electricity and useful heat – especially for industry–, and its use as a sustainable biofuel in mobility. The use in transport will facilitate meeting the objective of the National Integrated Energy and Climate Plan (PNIEC) 2021-2030, of reaching a share of renewable energy of 28% by 2030, as well as the European milestones of penetration of advanced biofuels which must reach at least 1% in 2025 and at least 3.5% of the total in 2030.

Whereas the total biomethane production in **Italy** might be 10 bcm/a by 2030, in case of AD of agri-food waste, sewage sludge, and food waste, theoretical production can be amounted to 700 Mm^3/a of biomethane and to 300 Mm^3/a of biowaste-based biomethane by 2030. Future feedstock in the waste sector shall be food waste, followed by minor shares of sludges and agri-food waste. Under the current legislation, with respect to the unused feedstock potential around 2Mt/y food waste and 1Mt/y of sludges and agri-food waste will be composted without any pre-AD step. However, mainly agriculture-based biomethane is expected due to the new Decree DM 15/09/2022 which in turn results in an increase of 600 Mm^3 biogas in the energy mix equivalent to 15% of the current production. Transport sector shall remain the main utilization sector due to the less restrictive sustainability criteria compared to the other sectors and the availability of country's gas-driven vehicle fleet.

In **Portugal**, the expected technical potential biomethane shall be 2 TWh/a by 2030. Manure, crops, biowaste, agro-industrial residues can be considered as future feedstocks. Further, by 2030 mainly injection into the gas grid, followed by the minor share used in CHP and even smaller share in the transport sector can be expected. However, specific targets are yet to be published and a biomethane action plan is also in the works for 2023.

Based on current regulations, **Sweden**'s biomethane potential and production target can be amounted to 10 TWh by 2030. However, the estimated techno-economic potential can be quantified as 30-37 TWh by 2030 incl. more agri-biomass, gasification of forest residues, and P2CH4 (Biogasmarknadsutredningen, 2019). In parallel to that, an increase of co-digestion plants based on manure in combination with biowaste, industrial organic waste, and agri-residues is expected. Consequently, future feedstock can include biowaste, sewage sludge, wastes and residues from industry, agriculture and forestry, non-food and non-feed crops to a minor share, and to the lesser part e-methane (Klackenberg, 2023a).

In the **Ukraine** based on the current legal framework the expected biomethane production can be amounted to 5-10 TWh/a by 2030 with 10 TWh/a being an upper edge if using the available biomass potential. The future biomethane plants (n=100–200 as expected by 2030) will run on manure/dung/litter, maize and wheat straw, sugar beet pulp, sequential crops, maize silage and organic fraction of municipal solid waste, however with the majority of biomethane plants being based on agricultural substrates. With respect to the future biomethane utilization sectors by 2030 due to the expected higher revenues, the Ukraine is counting on biomethane for export with 50 %, transport fuel with 25 %, electricity with 20 %, and gas with 5 %.

4.3. Cost effectiveness of biomethane production

The overall evaluation of the EU biomethane clusters will show which technology paths will prevail in the future. For this purpose, efficiency increases, emission reductions and cost evaluation of the innovative processes compared to the conventional biomethane paths will be examined and presented in more detail Based on this information, it can be derived which business models for biomethane can be served in the future, taking into account changing framework conditions(e.g. increasing CO_2 utilization by biogas upgrading processes, advanced gasification processes, advanced AD processes, using alternative substrates, challenges regarding kind of waste/residue).

The question on experiences of investigated innovative biomethane technologies are of particular importance and will be evaluated during the projects.

4.4. Cross-border trading in biomethane

4.4.1. Context

The appetite and need for renewable gas have been steadily increasing in the last few years. With the plans of the European Commission to deliver 35 bcm of biomethane by 2030, it is safe to say that renewable gases (lead by biomethane) have found their place.

While the production of biomethane has increased at a steady pace in many countries, this has largely been due to national level developments and an efficient and fully recognised system for cross-border trade remains a missing piece of the jigsaw, which previous EU funded projects e.g. REGATRACE, have found would unlock significant additional production and greenhouse gas (GHG) savings.

Documentation (via Guarantees of Origin (GoO) or Proof of Sustainability (PoS)) and cross border trade are essential to the growth of renewable gases for two reasons:

a) Because they are essential to the operation of support mechanisms such as biofuel/renewable fuel quotas which require tracking of gases from production to consumption as vehicle fuel.
b) They enable consumers to place a market premium on purchasing a renewable low carbon energy source and that value is transferred to the producer increasing the economic viability of producing those fuels/energy sources.

The relative immaturity of systems for trading of biomethane can be traced back to the fact that until the implementation of RED II in mid-2021 no European framework existed for Guarantees of Origin for renewable gas. At the same time while the Proof of Sustainability concept was envisaged in Article 18 of RED One, and voluntary schemes such as ISCC and REDCert have been certifying biomethane production and mass balance, the sector remained small and specialised relative to where it needs to be to fulfil the ambitious targets now in place.

The Guarantee of Origin style certificate system therefore developed outside an EU-wide framework, for example by Vertogas/VertiCer in the Netherlands and Energinet in Denmark, and have not generally been mutually recognised by other states in Europe. And while it has been possible to use Voluntary Schemes to prove the sustainability of biomethane production, the acceptance of the concept of cross border mass balancing of biomethane in the gas grid has either not been fully explored by relevant regulators or has in some cases been rejected e.g., Germany.

It has also been the case that there have been very limited systems for administering the issuing and transfer of Proof of Sustainability documents in electronic databases (which has been a barrier to building trust in those systems.

It is worth noting that developments during this time (2010 to 2020) were often driven by private actors e.g., large EU-wide companies, referring to non-governmental frameworks such as the Greenhouse Gas Protocol, as a framework for investing in biomethane purchases.

4.4.2. Recent Progress

In the last 2-3 years there have been several developments which have increased the potential for biomethane, and other renewable gases to be documented with GoO and PoS and be traded nationally and cross-border.

The most significant has been the development of EU legislation, namely the recast of the Renewable Energy Directive (RED), also known as RED 2018/2001/EU, or RED II in December 2018. Alongside the goal of seeing more ambitious targets for renewable energy in the EU, it also provides a clear framework for the documentation of all types of gaseous energy carriers.

Art.19 defines clearly a framework of the issuing of Guarantees of Origin and their mutual recognition:

> 1. *For the purpose of demonstrating to final customers the share or quantity of energy from renewable sources in an energy supplier's energy mix and in the energy supplied to consumers under contracts marketed with reference to the consumption of energy from renewable sources, Member States shall ensure that the origin of energy from renewable sources can be guaranteed as such within the meaning of this Directive, in accordance with objective, transparent and non-discriminatory criteria.*

With this introduction of guarantees of origin (GOs) for gaseous energy carriers, a network of issuing bodies from each member state is being rolled out, issuing standardised certificates which are mutually recognised by all other member states as a guarantee that energy was produced from a renewable energy source.

> *9. Member States shall recognise guarantees of origin issued by other Member States in accordance with this Directive. (RED II, 2018).*

While Articles 25 to 31, further clarify the rules that biomethane needs to follow to be rewarded as a biofuel. Statements supporting cross border mass balance are made and the intent to set up a EU wide database was stated;

> *European gas grids are becoming more integrated. The promotion of the production and use of biomethane, its injection into a natural gas grid and cross-border trade create a need to ensure proper accounting of renewable energy as well as avoiding double incentives resulting from support schemes in different Member States. The mass balance system related to verification of bioenergy sustainability and the new Union database are intended to help address those issues (Preamble – 123)*

These high-level developments have not meant that there are now issuing bodies for GoO in every member state or that PoS systems are fully developed the framework has been put in place for these systems to mature.

Cross-border Certificate Transfer

Another relatively recent development is the operation of the European Renewable Gas Registry (ERGaR) Certificate of Origin (CoOs) Scheme. While CoOs are documents that include almost the same kind of information as a GO, they can also be issued by competent bodies which are not yet, or will not be, mandated by a government to issue GOs.

Launched in June 2021, the ERGaR CoO Scheme has, so far, documented the cross-border transfer over 2 TWh of biomethane between its four System Participants: VertiCer (the Netherlands), AGCS (Austria), the German Energy Agency (dena, Germany), as well as GGCS (United Kingdom)[1]. The registries of Energinet (Denmark) and SPP Distribucia (Slovakia) joined the Scheme in October 2023.
The Scheme has enabled a level of cross-border trade, without waiting for all countries to appoint issuing bodies or the details of the updated EN 16325 standard to be agreed.

So far, the Scheme has been used to transfer CoOs that represent biomethane produced from anaerobic digestion but it is being updated to incorporate certificates representing synthetic methane and other Renewable Fuels of Non-Biological Origin (RFNBOs) in the future.

More recently the Association of Issuing Bodies (AIB) have started their gas scheme which will enable the transfer or Guarantees or Origin (GoOs) between appointed issuing bodies. It is expected that the first cross border transfers via that scheme will be sent soon.

Voluntary Schemes

The last few years have seen more and more biomethane certified under Voluntary Schemes.

The term "voluntary scheme" was outlined by RED II and describes a system to "help ensure that biofuels, bioliquids and biomass fuels are sustainably produced by verifying that they comply with EU sustainability criteria" (European Commission, 2023).
In order to be classified as such, these private organisations must undergo recognition by the European Commission.

The "Proof of Sustainability" documents issued by these schemes also form a key part of the evidence that a mass balance of renewable gas is achieved and that mass balance can be cross-border.

Voluntary Schemes for the certification of renewable gases are the following:

(1) REDcert
(2) International Sustainability and Carbon Certification (ISCC)
(3) Better Biomass
(4) 2BSvs

Union Database

RED II envisaged the creation of a Union wide database (UDB) for biofuels including liquid and gaseous fuels. As of early 2023 database had been launched and with testing phases and a roll out of full functionality over the year. The RED III will extend the scope and sets more requirements regarding the UDB.

---

[1] *ERGaR Website, 2023, https://www.ergar.org/ergar-schemes/coo-scheme-statistics/*

4.4.3. Remaining Challenges

While progress has been made in publishing and implementing legislation and in establishing and operating the schemes needed for cross border trade of renewable gases there is much more to be done. Example of these remaining challenges include:

- Issuing bodies need to be appointed in more countries.
- Where issuing bodies have been appointed, they need to finalise their rules and develop their IT infrastructure
- EN 16325 which will define how GoO schemes will operate still needs to be finalised (and it is very delayed)
- Issuing bodies and voluntary schemes have more work to do to engage with the facilitators of cross border trade (ERGaR CoO Scheme and AIB Gas Scheme) and ensure they are compatible with those schemes. At the same time those Schemes need to grow and mature and support new issuing bodies and certificate schemes to join.
- The Union Database is still at an early stage and several aspects are still unclear for the industry.

There is an overarching challenge in understanding how all of the above developments fit together and support the development of cross border trade, without creating conflicts or the opportunity for double counting.

Processes for trade, where they do exist, remain complex and lack efficiency which limits investor and consumer confidence.

All the while the focus is on the product that is most common in the market, being biomethane from anaerobic digestion. While there has been a significant discussion around hydrogen this has focused on its chemical form of H_2. So, there is still a gap in exploring and understanding certification and trade of intermediate products such as synthetic methane and a risk of it falling between the cracks.

5. Challenges and perspectives of innovative biomethane technologies

In the following, the challenges and perspectives of the innovative technologies of the 4 EU biomethane projects are presented in an overview.

Main challenges of all biomethane projects:

- Demonstration and analysis of innovative technologies to produce biomethane
- More efficient and cost-effective than the current technologies
- To identify cost reduction potential and to optimize these technologies
- to be able to use other /alternative substrates (like woody biomass) to increase the possible use of further substrates for additional biomethane production /gasification

5.1. SEMPRE-BIO

In the dynamic realm of sustainable energy, the SEMPRE-BIO project boldly undertakes a transformative challenge. At its core, the project strives to revolutionize biomethane technologies, addressing a multifaceted challenge that encompasses various pivotal aspects.

Optimizing Feedstock Management

Central to SEMPRE-BIO's challenge is the strategic optimization of feedstock. Diverse organic materials, including waste and woody biomass, as well as novel sources like green waste and wastewater, serve as the foundation for biomethane production. The project's vision is to create innovative systems ensuring a consistent, high-quality supply. This involves identifying alternative feedstock sources, implementing efficient utilization techniques, and concurrently reducing associated costs.

Enhancing Plant Efficiency and Operations

SEMPRE-BIO sets out to raise the bar in plant efficiency and operational excellence. Through cutting-edge technologies and streamlined processes, the project aims to not only reduce operational costs but also elevate the overall output. Plant modifications, innovative upgrading methods, and advanced operational strategies play pivotal roles.

Carbon Savings and Environmental Considerations

Factoring in carbon savings is a cornerstone of SEMPRE-BIO's challenge. The project emphasizes the reduction of greenhouse gas emissions throughout biomethane production, ensuring a significant positive environmental impact. It involves meticulous planning, emission control technologies, and a strong commitment to sustainability.

Monetizing Co-Benefits

SEMPRE-BIO is at the forefront of co-benefit exploration. By valorizing residual gas streams like CO2 and leveraging prior EU-level experiences, particularly in digestate biorefining, the project aims to boost economic potential. Through innovative technologies and strategic CO2 valorization, SEMPRE-BIO contributes to a circular bio-economy, fostering sustainability and economic growth, especially in rural regions.

Strategic Cost Reduction

A strategic reduction in both investment and operational costs forms a significant challenge. SEMPRE-BIO delves into the intricate balance of financial prudence and technological innovation. This involves not only identifying cost-effective solutions but also optimizing existing resources, ensuring every investment leads to maximal returns.

5.2. HYFUELUP

The HYFUELUP project will blend market knowledge with advanced academic and industrial perspectives to demonstrate the production of biomethane at scale. First, the flexible conversion of low-grade feedstocks via sorption-enhanced gasification will be validated, coupled with syngas or flue gas clean-up, in a demonstrator at TRL6. Then, a second demonstrator will also validate fluidized-bed methanation of either syngas or flue gas with the dynamic addition of hydrogen at TRL6, before both technologies are integrated into a third demonstrator to produce biomethane at scale and reach TRL7, including biomethane offtake and distribution.

HYFUELUP integrates a SEG*/Oxy-SEG process to turn biowaste into syngas or flue gas.

Syngas with high H_2 content (>65%) and a CO_2-rich flue gas suitable for catalytic methanation are obtained as a result. The process takes place in a main demonstration site located in Tondela (Portugal) and is especially suited to advance the features of traditional gasification processes and produce tailored gas streams for catalytic methanation.

The project will validate an innovative, competitive, and clean biomethane production technology based on this advanced waste gasification technology using local biomass mixtures – crop residues, lignocellulosic residues, and other low-cost biogenic wastes. The main ambition of the project is to show that it is possible to produce 100% renewable natural gas (biomethane) at competitive costs and with greater carbon efficiency utilizing different low-cost feedstocks. However, relevant bottlenecks will have to be solved to fully prove the feasibility of this first-of-its-kind value chain for biomethane production.

The main specific challenges related to the project concern technical choices, process integration, and the way feedstock supply chains are organized, namely:

- Retrofitting the existing circulating fluidized-bed gasifier and integrating the sorption system is a major technical challenge. Careful design is also required for the integration with tar cleaning and high OPEX can be expected depending on the technology of choice.
- Another challenge is that converting all available carbon to synthetic fuel (after in situ carbon capture) may be unfeasible due to the high hydrogen needs. Process flexibility in all steps is yet to be proven, and adaptation to renewable energy fluctuations will be key for the concept to reach its full technoeconomic potential.
- General process integration is another area that needs attentive planning to overcome potential challenges. Solid oxide electrolysis and catalytic fluidized bed methanation have yet to be integrated at this scale. The aim is to prove that an adaptable and dynamic process can be achieved.
- Biomass gasification often requires a rather costly value chain, which is difficult to develop fully in many regions. The use of low-grade feedstocks in HYFUELUP, with potential well-established supply chains, is already a positive development. However, the complexity of the value chain is still likely to be high and is yet to be proven locally.

It is essential to take forward steps towards solving these overall challenges for the industrialization of biomethane innovative technologies and large-scale production of clean renewable gas.

5.3. BIOMETHAVERSE

In-Situ and Ex-Situ Electromethanogenesis (EMG): an electrochemical/biochemical route to produce biomethane from CO2 and renewable electricity

Previous lab experiences showed that two parameters contribute to increase biogas/biomethane production in AD-BES: (i) the increased available surface for biofilm growth, due to electrodes presence, and (ii) the application of an optimal voltage for the stimulation of electro-active microbes. It is still an open challenge to optimize these two parameters together, to sum their beneficial effects in an upscaled AD-BES plant.

Next, feeding the 1c-AD-BES with an already digested feedstock represents a challenge, as some physical-chemical characteristics are sub-optimal (e.g., basic pH, low carbon/nutrients ratio, low biodegradability, and high viscosity). Moreover, inoculation of anode and cathode with proper electro-active biofilms represents a challenge as well, when targeting upscaled, industrial systems. The ideal solution is to cope with both electrodes' inoculation directly onsite, by direct voltage application (i.e., not using a potentiostat, which is quite common in lab experiments).

The key challenge of 2c-AD-BES is retaining high biomass in the cathode chamber and limited mass and electron transfer between microbes and electrodes. The potential solution is to develop novel electrode designs and more efficient and resilient biocatalysts in the cathode chamber. Recent work conducted at DTU showed that granular anaerobic sludge is an efficient cathodic biocatalyst, but the mass and electrons transfer from electrodes to the granular anaerobic sludge far in the cathode chamber need to be further optimized.

Thus, the aim is to optimize the mass and electrons transfer or more efficient methane production rate through novel electrodes materials and design and its interactions with microbes.

Previous work done showed that this approach is possible, but biofilm populations are highly sensitive to applied operation conditions (e.g., inoculum mixture, feedstock temperature, voltage). Especially on the cathode site, it is challenging to grow a specific biofilm catalyzing CO_2 reduction to CH_4. For these reasons, the current proposal foresees initial laboratory trials on digestate pre-treatment and electrodes surface treatment solutions for optimized biocatalyst-transducer interface and overpotential minimization.

Treatment protocols are aimed towards (i) enhancing electrical conductivity, (ii) increasing the surface area (iii) increasing the hydrophilicity (iv) doping positive surface charges, (v) incorporating porosity (micro-/nanostructures), and (vi) increasing biocompatibility and microbial adhesion.

Besides, the interaction between the cathode electrode, and novel viable biocatalysts such as granular sludge could be better understood and manipulated to boost biomethane production.

The process will be computationally modelled to identify critical electrode parameters limiting the heterogeneous electron transfer kinetics throughout the EMG process.

At lab scale, the aim is to:

- test continuous feeding conditions
- estimate an energy balance of the AD-BES processes
- perform a preliminary economic analysis.

Although it is clear from the literature that the energy produced in biomethane form, by such systems, is higher than the electricity input provided to the electrodes, a global balance including all auxiliary equipment, at pilot scale, is required.

Ex-Situ - Thermochemical/catalytic Methanation (ETM)

The most attractive configuration for the methanation section will be identified taking into consideration several factors, including but not limited to heat exchange, catalyst type, process temperature and pressure.

Essential aspects which must be considered amongst others are (i) catalyst deterioration and contamination (ii) safe distribution of H2 to the pilot unit and tank replenishment (iii) appropriate automation with the respective controller unit, and finally (iv) successful operation with regeneration cycles of the catalyst.

The catalyst has been extensively tested for the treatment of syngas produced from the gasification process, so relevant protocols and step-by-step methodology have already been developed and to be used for the biogas case study at TRL 7. In addition, renewable hydrogen has a significant contribution to the process. Hence, accurate and secure handling and provision are considered critical for the implementation of the project. The basic engineering includes a safety study for the hydrogen storage at biogas plant facilities, distribution through piping system to the upgrading plant and the blending stage. The hydrogen supply will be evaluated within the project.

Finally, the operation parameters, such as temperature, pressure, biogas composition will be controlled during the demo activities, in order to evaluate the process itself and recognize any deviations (lower biomethane yield than expected, lack of hydrogen, no ideal conditions for the catalyst). During the BIOMETHAVERSE project, all the aforementioned measures will be investigated to identify possible edge effects at scale for the transition of the biogas Lagada plant to a full-scale biomethane production plant.

Ex Situ Biological Methanation (EBM)

The challenging aspects that need to be considered during the EBM innovative technological pathway are:

- Feedstock pre-treatment via ozonolyzsis

The main challenge for the full-scale ozonolysis application is related to the design configuration of the contact reactor to avoid ineffective transfer yields and malfunctions related to clogging problems and to the degassing unit of the ozonated sludge to avoid inhibition phenomenon of the AD process linked to the oxygen presence. A critical element to be assessed is the ozonolysis effect on sludge dewaterability. The AD process is expected to mitigate the worsening of the sludge dewaterability after ozonolysis: if this is not the case, the polyelectrolytes optimal dosage will be evaluated and taken into consideration in the process economic viability.

- Ex-situ biological upgrading

Ex-situ hydrogen-promoted biological upgrading efficiency is highly influenced by the mass-transfer of hydrogen into the medium. This aspect will be investigated thoroughly in the pilot, optimizing finding best performing solution on a scaled-up commercial system.

- Co-digestion pilot

Fast and reliable analytical tools for supporting digester modelling are currently one of the main bottlenecks for process modelling integration at real scale facilities. Further investigation will involve multiple analytical techniques such as near infrared (NIR), X-ray fluorescence (XRF) thus the comprehensive characterization would be beneficial for providing biogas plants with feasible and affordable process control and optimization tools.

Ex-Situ Syngas Biological methanation (ESB)

TBR is a relatively under-utilized reactor type which makes a theoretical assessment of practical scale-up cost challenging since there is not much in the real world to compare with. The concept is dependent on both a local source of syngas and a nutrient solution. During the BIOMETHAVERSE project, there will be a need to identify possible edge effects at scale to enable the properly designing a full-scale plant.

In-Situ Biological methanation (IBM)

Important technical and safety aspects need to be considered during in-situ methanation. Process parameters, such as the concentration of volatile fatty acids and pH, the quality and quantity of biogas, the presence of residual H_2 in the biogas, the optimal H_2 flow rate, the optimal gas recirculation rate and the mixing ratio of hydrogen/raw gas, as well as potential erosion on the existing gas mixing system due to H_2 and potential diffusion of hydrogen through the roof membranes of AD reactors will be evaluated in the project.

5.4. METHAREN

The main challenges that the project wants to achieve are:

- The coupling of a methanation module with an existing biogas plant.
- To optimize the gasification module for using waste residues.
- Several innovative components or processes along the value chain integrated in a pilot plant.
- A high replicability potential of the solutions at European scale.

This implies that we have to find a balance between financial, market, regulatory authorities and technological aspects. Reducing the investment and the operational costs to optimize the uses of the biogas plants combined with the production of green hydrogen.

The main innovative points that the project wants to develop, are:

Design, supply and erection of an Innovative methanation reactor (compact and escable).

The methanation reactor proposed by CEA for the demonstration site of METHAREN is based on an innovative technology (patent FR1913378) of millistructured tube and shell heat exchanger. It presents several advantages, in the frame of this project requiring high load flexibility, inlet gases composition variations, quick answer to variations, heat valorisation to increase the overall unit efficiency. With this technology in the frame of METHAREN, a conversion rate above 90% in one pass for a range of pressure from 3 to 8 bar and for temperature of 280°C can be expected. To fulfil the requirements of the Italian natural gas network, the product gas must achieve a CH_4 content of >96%vol. Hence CH_4 rich gas from methanation is fed to subsequent membrane gas upgrading unit. Membrane systems are highly flexible regarding changing flow rates by adapting the available membrane area due to their modular design. The off gas containing H_2/CO_2 and few % of CH_4 will be compressed and directly recycled to methanation, while improving the overall conversion of CO_2 and H_2, by negating any losses of CO_2 and H_2.

The concept is based on a classical tube and shell heat exchange technology with conventional tubes diameter and dedicated designed structuration inserted within the tubes. The reaction takes place under a temperature monitoring along the reactive channel, ensuring a high conversion rate and high space velocity, a reduced catalyst deactivation and a high heat recovery. The concept of this technology has been demonstrated and validated at a TRL level 4 and will be here demonstrated in an industrial environment and at bigger scale to reach TRL7. The methanation reactor will also be tailored to operate in the most convenient ways to favour heat recovery opportunities in this specific context.

Design a flexible and innovative purification processes for a better efficient.

In the METHAREN project, carbon membranes will be used for the processing of biogas and synthesis gas for the first time. In contrast to the prior art, these membranes are robust against gas contamination (e.g., H_2S), pressure and temperature fluctuations. The membrane technology also has low operating costs, does not require chemicals, can be switched on and off almost at will and can be easily adapted to changing volume flows. For the fine cleaning of gases, the membrane technology will be supplemented by adapted adsorption processes, which can then be designed correspondingly smaller due to the pre-treatment with membranes.

Design and implementation for optimal integrated production process that can manage RES intermittency to ensure continuous production and maximized energy and by-products recovery.

In METHAREN, the domain of applicability will be increased by expanding the boundaries of the system and including more technologies, such as the combination of gasification, methanation and a reversible SOEC system. It will also be improved by using real data from the demonstration pilot plant, which will allow fine-tuning of the models, identifying hotspots for improvement and anticipating bottlenecks from the experimental side.

The biomethane production system of METHAREN will be a complex integrated system. The Energy Management System (EMS) developed will cope with the different dimensions of constraints to ensure a continuous production considering also economic factors:

- Renewable energy intermittency which results in variations in H_2 availability for the methanation reaction.
- Different minimum operating levels of the components.
- Several integrations of the system between the components to recover energy and by-products.

The intermittency of RES will imply a dual operating mode to ensure constant production of biomethane, running at full capacity when renewable energy is available and in reduced mode connected to the grid when it is not. The Energy Management System (EMS) will work at a bi-level system; the upper level (also known as the master level) receives market information on electricity prices and electricity carbon-content and is responsible for running forecasting algorithms for the upcoming hours of operation. The lower level (or slave level) runs optimization-based models to understand the ideal design and operation of the systems based on inputs from the upper level, and consequently supplying the latter with that information, which is further communicated to the control system, responsible to operate the pattern change in operation. The upper level oversees the main objective definition and potential trade-offs. The main objective is the minimization of the system's total cost. The secondary objective is the environmental impact. The upper level forces the lower one to provide a set of operation designs for selection which form, by the nature of the optimization algorithm used, a non-dominated solution set. From there the 'knee point' is selected, which is considered one of the possible best solutions.

6. Outlook

At the present time (M12), it is still too early to make concrete policy recommendations focussed on the investigated biomethane technologies, as the innovative technologies on biomethane are initially being evaluated in demonstration plants (demo-sites). The most promising technologies are likely to be those with TRL higher than 6-7. More precise statements can be made after analysis of the plant concepts and overall evaluations of the involved projects. It is therefore recommended that funding be provided on an open technology basis for the time being. The most important question in the future will be what quantities of green hydrogen and green gases can be made available at cost-effective prices. More detailed recommendations will follow as part of the next reports in M24 and M42.

7. Literature

AEBIG (2019): Informe Biogás 2019. https://www.bdo.es/en-gb/insights/international/energy-transition-spain-potential-in-the-biomethane

Beil et al. 2019: Efficient micro biogas upgrading plants (eMikroBGAA), final report: https://www.fnr.de/ftp/pdf/berichte/22401615.pdf

Biogas Danmark (2023a): Biogas Outlook 2022, retrieved 12/05/2023 from https://www.biogas.dk/wp-content/uploads/2023/01/Biogas-Outlook-2022-English_16-01-2023.pdf

Biogas Danmark (2023b): Danish companies pay CO2 tax on green biogas, retrieved 12/05/2023 from https://www.biogas.dk/fakta/dansk-co2-afgift-paa-biogas/

Biogasmarknadsutredningen (2019): Mer biogas! För ett hållbart Sverige, retrieved 12/05/2023 from https://www.regeringen.se/contentassets/19fc575360724f2492bea2cb9e25b7e8/sou_2019_63_webb_rev.pdf

Biomethane Industrial Partnership (2023): Task forces, retrieved 16/05/2023 from https://bip-europe.eu/about-the-partnership/

EBA (2022): Statistical Report 2022. Tracking biogas and biomethane deployment across Europe. retrieved 20/10/2023: https://www.europeanbiogas.eu/SR-2022/EBA/

Daniel-Gromke, J., Denysenko, V., Liebetrau, J. (2019): Germany's experience with biogas and biomethane. In: Mathieu, C. and Eyl-Mazzega, M-A (eds.), Biogas and biomethane in Europe: Lessons from Denmark, Germany and Italy, Études de l'Ifri, Ifri, April 2019. retrieved 18/10/2023 https://www.ifri.org/sites/default/files/atoms/files/mathieu_eyl-mazzega_biomethane_2019.pdf

Dena (2022): Marktmonitoring. retrieved 18/10/2023
https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2022/ANALYSE_Marktmonitoring_Bioenergie_2022_Teil_2.pdf

DFBEW (2023): Business models for biomethane - generation, applications, financing. Online conference German-French office for the energy transition on 11. May 2023.

EBA European Biogas Association (2022): Statistical Report 2022 - Tracking biogas and biomethane deployment across Europe

EBRD European Bank for Reconstruction and Development (2021): Biomethane zoning and assessment of the possibility and conditions for connecting of biomethane producers to the gas transmission and distribution systems of Ukraine, retrieved 19/09/2023 from https://saf.org.ua/wp-content/uploads/2022/02/BM-Zoning-Final-Report-version-2022-02-01.pdf

ERGaR Website (2023): ERGaR CoO Scheme Statistics. https://www.ergar.org/ergar-schemes/coo-scheme-statistics/

European Commission (2020): Commission Staff Working Document Analysis of links between CAP Reform and Green Deal, SWD (2020) 93 final, https://agriculture.ec.europa.eu/system/files/2020-05/analysis-of-links-between-cap-and-green-deal_en_0.pdf

European Commission (2022a): REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition, retrieved 15/05/2023 from https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

European Commission (2022b): Commission Staff Working Document – Implementing the RePowerEU Action Plan: Investment needs, hydrogen accelerator and achieving the bio-methane targets, retrieved 15/05/2023 from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230&from=EN

European Commission (2022c): European Commission and industry leaders launch Biomethane Industrial Partnership, retrieved 15/05/2023 from https://commission.europa.eu/news/european-commission-and-industry-leaders-launch-biomethane-industrial-partnership-2022-09-28_en

European Commission (2023): Voluntary schemes. Voluntary schemes set standards for the production of sustainable fuels and gases. Retrieved 23/10/2023 from https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/voluntary-schemes_en

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) (2016): Climate Action Plan 2050. Principles and goals of the German government's climate policy. Retrieved from 23/10/2023, https://www.bmuv.de/fileadmin/Daten_BMU/Pools/Broschueren/klimaschutzplan_2050_en_bf.pdf

Geletukha, G.; Kucheruk, P.; Matveev, Y. (2022): Prospects for biomethane production in Ukraine, retrieved 19/09/2023 from https://uabio.org/wp-content/uploads/2022/10/final-EN-Position-paper-UABIO-2022-09.pdf

Green Gas Platform (2019): Welke plaats voor injecteerbaar biomethaan in België?, retrieved 12/05/2023 from https://greengasplatform.be/assets/potentiel-biomethane-nl.pdf

Guidehouse Netherlands B.V (2022) - Biomethane production potentials in the EU. Feasibility of REPowerEU 2030 targets, production potentials in the MemberStates and outlook to 2050. retrieved 23/10/2023: https://www.europeanbiogas.eu/wp-content/uploads/2022/07/GfC_national-biomethane-potentials_070722.pdf

International Energy Agency (IEA) (2022): Support schemes for biomethane: background paper.

Inveniam (2023): personal communication.

Klackenberg, L. (2023a): Biomethane in Sweden – market overview and policies, retrieved 12/05/2023 from https://www.energigas.se/media/wm1osxcb/biomethane-in-sweden-230112.pdf

Klackenberg, L. (2023b): Personal communication.

Publications Office of the European Union, Innovative biomethane for REPowerEU – A projects info pack by CORDIS, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2830/817871; https://op.europa.eu/en/publication-detail/-/publication/c4651f9b-eaf2-11ed-a05c-01aa75ed71a1/language-en

Renewable Energy Directive II (RED II) (2018): https://lexparency.org/eu/32018L2001/ART_19/

Secretary of State for Energy, Spanish Ministry for the Ecological Transition and the Demographic Challenge (2022): Hoja de Ruta del Biogás. March 2022, retrieved 19/06/2023 from https://energia.gob.es/es-es/Novedades/Documents/00HR_Biogas_V6.pdf

Spanish Gas Association (Sedigas) (2023): A study of the capacity for biomethane production in Spain, 2023. retrieved 18/10/2023: https://estudio-biometano.sedigas.es/wp-content/uploads/2023/03/sedigas-report-potential-biomethane-2023.pdf

Stinner, W., Rensberg, N., Denysenko, V., Barchmann, T., Müller, J., Daniel-Gromke, J.: Alternative and sustainable substrates for biogas production Biogas technology as a tool for multifunctional agricultural systems. Presentation on 21.06.2022, DBFZ Annual Conference.

Technical University of Denmark (2023): own calculations.

Regatrace (2022): D7.2 | Final evaluation report, retrieved 12/05/2023 from https://www.regatrace.eu/wp-content/uploads/2023/01/REGATRACE-D7.2.pdf

8. Appendix

Country-specific status quo analysis of biomethane, main barriers, main regulations, perspectives in order to summarize the survey results for joint policy recommendations (from the point of view of the biomethane experts and research participants involved)

8.1. Questionnaire on country-specific main barriers, potentials & perspectives on biomethane

Table 7: Survey EU biomethane projects – Sheet "Main barriers"

Objective	Identification of **main barriers** which prevent **biomethane production in your country** (from the point of view of the biomethane experts and research participants involved)
Questions	What are in your opinion the main barriers which hinder the development of biomethane production in your country?
How to manage this sheet /comments	If you have relevant information, please fill in the sheet, add the source of your information /own estimation, reference year, and add the relevant weblink where we can find more information or actual literature.

Country

What are in your opinion the main barriers which hinder the deployment of biomethane production in your country? Please specify...

Do you know relevant literature, studies, weblinks etc. to find further information regarding main barriers - either country specific or in general, at the EU level? If so, please indicate the relevant weblinks.

Table 8: Survey EU biomethane projects – Sheet "Perspectives 2030"

Objective	Identification of country specific perspectives of **biomethane production in 2030** (from the point of view of the biomethane experts and research participants involved)
Questions	What are in your opinion the **perspectives of biomethane production** in your country?
How to manage this sheet /comments	If you have relevant information, please fill in the sheet, add the source of your information /own estimation, reference year, and add the relevant weblink where we can find more information or actual literature.

Country			
How much **biomethane** can be produced by **2030 (TWh per year)**, if available biomass potential will be used in **your country?**			
How much biomethane (TWh) do you expect by 2030 based on the current regulations?			
How many biomethane plants do you expect by 2030 based on the current regulations?			
What type of biomethane plants do you expect by 2030? (agricultural plants, biowaste plants, etc.)			
What **kind of substrates** will be used for **future biomethane plants in your country**?			
What amount of potential unused/ available substrates for biomethane production in your country do you expect?			
Which sector do you expect will dominate for biomethane utilization in your country by 2030?			
general commments:			
kind of sector	**expected % share**	**comment**	**Source**
CHP Electricity Gas Heat Transport fuel Industry other:			
Expected share of biogas production in the national natural gas demand in 2030			
Do you know relevant literature, studies, stakeholders, institutions to find further informations regarding country specific perspectives? If so, please indicate the relevant weblinks.			

8.2. Overview - Survey responses by EU biomethane projects

Table 9: Survey responses by EU biomethane projects (09/2023)

Project	Partner country	Number of respondent organizations	Name of respondent organization	Type of respondent organization
BIOMETHAVERSE	Italy	1	CIC	association
	Sweden	2	Energigas, RISE	association, research
	Ukraine	1	UABio	association
METHAREN	Italy	2	ACEA, Envipark	Industry, research and consulting
HYFUELUP	Portugal	2	BIOREF, Bioplat	Research and consulting
SEMPRE-BIO	Spain	3	CET, INV, UVIC	Research and consulting, consulting, academia
	France	1	DBFZ	Research institute
	Belgium	1	Biogas-E	association
	Denmark	1	DTU	academia

8.3. Country-specific barriers and perspectives on biomethane based on the survey results

The following is a brief summary of the country-specific feedback from the partner survey on the topic of main barriers and perspectives for biomethane production from the perspective of the project participants involved.

8.3.1. Belgium

Barriers	Perspectives
No explicit targets for biomethane	Biogas potential of 15.6 TWh by 2030 (90% of which can be upgraded to biomethane)
No support in Flanders	Biogas potential Flanders: 7.3 TWh by 2030
In 2021: cost differential with natural gas	Future feedstocks: manure (+/- 4.5 TWh) and energy and intermediate/ sequential crops (+/- 4.5 TWh), agricultural waste (+/- 3.5 TWh), industrial waste (+/- 1.5 TWh) and municipal waste (1 TWh)
Different legislation in different regions	Unused/ available feedstocks Flanders: manure (10 363 755 t), energy crops (1 338 953 t), agricultural waste (1 789 538 t), industrial waste (1 114 674 t), and municipal waste (1 197 263 t)
Regulation and permitting issues (i.e., Flemish Nitrogen agreement[2])	
Administrative burden for plant operators	
Uncertainty, public image (benefits not yet recognized)	
Missing link with Belgian energy and climate goals	

Sources: Biogas-E 2023 based on Green Gas Platform, 2019; Regatrace, 2022.

[2] Reduction of nitrogen emissions by 50% by 2030

8.3.2. Denmark

Barriers	Perspectives
need of subsidization	biogas is expected to substitute 100% of the natural gas by 2030 (resp. 78% by 2030 and 92% by 2035)
price of biomass	biogas production of 94 PJ (26.11 TWh) by 2030 resp. 51 PJ (14.17 TWh), of which 75% biomethane by 2030 or 55 PJ (15.28 TWh), of which 100% biomethane by 2030
lack of tax incentives for using biogas over fossil fuels - 86 % of biogas exported to Europe (Germany and Sweden)	future feedstocks: biogas (similar for biomethane) – 80% agricultural waste (of which 64 % manure), 20% industrial and food waste by 2030; 75 % manure (with 12 % pig manure) and 6 % straw by 2035; energy crops to be phased out by 2030
the same CO_2 tax on both natural gas and biogas (expected to rise by 2030 to DKK 750 per t CO_2)	Unused substrates by 2030: between 41.4% and 45.7% in the 100% biomethane scenario; between 56.1% and 59.3% of biomass potential unused in the 75% biomethane scenario
	main sectors for the utilization of biomethane by 2030: • industry with 55%, • transport sector with 20%, • CHP and local use (outside of the grid) with 10% respectively, • gas sector with 5%

Sources: Technical University of Denmark, 2023 based on Biogas Danmark, 2023a; Biogas Danmark, 2023b.

8.3.3. France

Barriers	Perspectives
Approvals processes take too long time Building permits are very important, with 3-5 years too long Heterogeneity and complexity of national biomethane markets in Europe	Currently 10 TWh /a Biomethane are fed into gas grid in France. Further expansion is planned; ~ 530 plants feeding biomethane into the gas grid, 85% of the sites feed into the GRDF grid, the rest into the 2 other grid operators.
Incentives necessary for Bio-LNG Support of the demand side and the production side needed	10 % biomethane in the gas grid by 2030 according to the Act on Energy Transition for Green Growth (LTECV) from 08/2015 resp. 7-10 % biomethane in total gas consumption by 2030 according to the Pluriannual Energy Programme (PPE) from 2019 share of renewable gas of 200-250 TWh in the energy system in 2050 according to the “Stratégie Nationale Bas-Carbone” from 07/2017 (EBA 2022)
Increasing production capacity, e.g. by using regional waste inwastewater treatment plants, is currently not allowed, but this could increase production capacity	Support mechanisms focused on waste use of biomethane will increase, especially from biowaste
Reduction of fixed costs for smaller plants (e.g. through price reductions for better competitiveness)	It will be easier for large biomethane plants, but also smaller and medium sized plants in region should be strengthened (support CAPEX) Investment always together with local authorities and stakeholders; Local projects with local feedstock and local partners would be important
Biogas PPAs should be used more, implementation of biogas certificates for utilization possibilities must be extended	Where there are no gas grids, the possibility of liquefaction of biomethane can also become an interesting market

Sources: DBFZ 2023 based on DFBEW 2023 and EBA 2022.

8.3.4. Germany

Barriers	Perspectives
National biogas resp. biomethane policy in Germany is rather fragmented, no clear biomethane strategy, which pathways using biomethane are prioritized (fuel, electricity, heat, material use)	Germany has a 8.4 GW biomass production target; however this target for 2030 applies to all installed biomass (incl. solid, liquid, gaseous) capacities 20 – 50 TWh_{HHV} as a possible biomethane production in the mid-term (need adapted framework)
Permitting procedure, especially for biomethane (upgrading plants), takes quite a long time and should be accelerated; so the permitting procedure for biogas resp. biomethane plants to be built takes 3 to 5 years (dena 2022)	Today's biogas production in Germany comprises about 10 % of the total natural gas demand in Germany, with about 1 billion m^3 biomethane (resp. 10 TWh_{HHV}) 1 % is already produced (Beil et al. 2019, Daniel-Gromke et al. 2019). With regard to the existing biogas plants (with on-site electricity generation) in Germany *DBFZ* estimates, that taking into account the current situation and price increases, about 20 to 50 % of the existing biogas plants could be retrofitted to provide biomethane in the mid-term (approx. 20 - 50 TWh_{HHV}). By tapping the still unused agricultural residue potential (straw, catch crops, doubling the use of farm manure), the volume could be increased to around 20 % of the current natural gas consumption in Germany without additional energy crop cultivation (Stinner et al. 2022).
a lack of planning security, complex regulations which are less harmonized with faster amendments in shorter time	switch from the FiTs under the EEG regime to more market-oriented support scheme/ market premium from 2012 on and demand-oriented biogas production
	increased use of biogas in the fuel but also heating and electricity sectors
	investment incentives to curb the power generation from biomass and installations of gas storage systems in order to compensate for fluctuating wind and solar power
	Biogas and biomethane are currently produced mainly from cultivated biomass; trend towards more use of residual materials is present; Transformation of pathways to switch from energy crops to alternative substrates (e.g. straw, catch crops, permanent crops, dual cropping, manure potentials, organic fraction of residual waste)

Sources: DBFZ 2023 based on dena 2022, Beil et al. 2019, Daniel-Gromke et al. 2019, Stinner et al. 2022.

8.3.5. Italy

Barriers	Perspectives
return of the investments (meeting sustainability targets for the whole funding period esp. for uses other than transportation sector)	theoretical production of 700 Mm^3/a of biomethane by 2030 (in case of AD of agri-food waste, sewage sludge, and food waste) (CIC 2023)
Biogas upgrading and purification process costs	300 Mm^3/a biowaste-based biomethane by 2030
Bureaucracy (incentives and grid management)	Agriculture-based biomethane due to the new Decree DM 15/09/2022, an increase of 600 Mm^3 biogas in the energy mix, corresponding to around 15% of current production (Envipark 2023)
Absence and deficiency of controls, lack of transparency of information	Total biomethane production of 10 bcm/a by 2030 estimated (ACEA 2023)
Public perception (biowaste in AD instead of material recycling, possible pathogens in digestate)	Transport sector shall remain the main utilization sector (sustainability criteria and country's gas-driven vehicle fleet)
	Expected plants: ~ 40 plants (biowaste sector) to be operating in 2030 (16 are already in operation), which would mean around 300 Mm^3/year. The highest increase should happen within 2023, since the incentives of the DM 2/03/2018 look more convenient than the ones of the DM 15/09/2022. (CIC 2023)
	Under the current regulatory/incentivising scenario, CIC expect that about 2Mt/y foodwaste and 1Mt/y of sludges+agri-food waste will simply be composted without any pre-AD step (CIC 2023)
	Future feedstock in the waste sector: food waste, followed by minor shares of sludges and agri-food waste

Sources: ACEA Pinerolese Industriale Spa (ACEA) 2023, Consorzio Italiano Compostatori (CIC) 2023, Environment Park SpA (Envipark) 2023.

8.3.6. Portugal

Barriers	Perspectives
Economic: Lack of public incentives for biogas (biomethane upgrading only) Lack of private sector investment Supply chains and logistics (collection of feedstocks)	Technical potential biomethane 2 TWh/a by 2030 3.1 TWh technical potencial in 2030 (only AD) and ca. 1.1 TWh implemented in 2030 (AD + gasification)
Technological: quantity and quality of feedstocks (also costs) focus mainly on AD	Future feedstocks: Manure, crops, biowaste, agro-industrial residues
Social: Lack of awareness and advantages of biomethane	By 2030, mainly injection into the gas grid, followed by the minor share used in CHP and even smaller share in the transport sector
Environmental: Sustainability of the value chain (market solutions for digestate, methane slips)	About 25-50 new plants in 2030 (20 and/or 40 GWh)
Regulatory: Lack of favourable regulations Lack of harmonization between public policies (competition composting and AD for agro-industrial residues)	

Sources: CoLAB BIOREF 2023.

Funded by
the European Union

8.3.7. Spain (1)

Barriers	Perspectives
Regulatory and legislative: the absence of a framework with ambitious incentives, quotas, and targets compared to the potentials in order to regulate the sectors other than the electricity; access to waste, framework capable of regulating uses of biomethane that are not related to strictly electrical applications, such as injection into the gas grid barriers hindering new plants and pipeline connection authorization procedures complex processing due to the different regulations and responsible bodies (state and autonomous)	Spanish Gas Association (Sedigas) considers that is possible to reach 38 TWh of biomethane per year in 2030. However, Spain's total biomethane production in 2021 amounted to 100 GWh. There are currently five, and at least twice as many biomethane plants are expected to be built and operated by 2030. Exporting pipelines to Portugal and France. We do not have data on how much biomethane will be exported. However, Spain has the potential to produce 163 TWh/year of biomethane, a figure that would cover around 45% of the national demand for natural gas
Administrative: obtaining permits and the delays, lack of a uniform processing process (currently 17 for each autonomous community, numerous regulations of various kinds)	Expected plant types in 2030: Anaerobic digestion based on sewage sludge; agricultural waste; biowaste or manure (cattle or pig). Biomass gasification and methanation combined with an upgrading technology through H2 and CO2 or syngas.
Economic and social: absence of specific incentives to support biomethane, taxes on generation and consumption, logistics costs (feedstock and digestate), high economic costs for the specific project; new business opportunities – normative vs. market demand	Future feedstocks: Energy crops, agricultural residues and/or mixed with manure, organic waste, sewage sludge, landfills, forest biomass among others. Unused feedstock potential: Agricultural residues, landfills, biowaste and WWTP.
	main sectors for the utilization of biomethane by 2030: • electricity and heat with 25% respectively, • transport fuel (CNG) 25 %, • CHP and gas with 10% respectively, • Transport fuel (LNG) 5%

Sources: Inveniam, 2023.

8.3.8. Spain (2)

Barriers	Perspectives
Regulatory and legislative: authorizing barriers coming from discrepancies between autonomous and state administrations regulatory barriers hindering new plants and pipeline connexion authorization procedures numerous regulations of various kinds and involves a large number of administrations (state, autonomous and municipal) National biogas and biomethane promoting policies arrived much later than in other European countries, thus forcing the administrations to establish novel measures under the pressure and agreements coming from the common European policy.	According to the Spanish Association of Biogas, Spain has a current biomethane production potential of 35.8 – 53.3 TWh per year, which would cover nearly 45 % of the national demand for natural gas. However, only 225 GWh/year of electricity are produced and about 105 GWh/year are injected into the gas system. Biomethane potential: 11 bcm (90 TWh) by 2030; Biomethane potential for Catalonia: 55 GWh by early 2020s The government's Biogas Roadmap (2022) has set a goal for biomethane of only around 1% of the gas consumed via the natural gas network by 2030, which is still very far from established European objectives and very low compared to Spain's production potential.
Administrative: origin guarantee mechanisms imposed by the administrations together with the Spanish gas grid manager (Enagas), bureaucratic steps	Currently, more than half of biogas plants are agriculture-based; Deployment of biowaste-based biomethane plants In addition to agricultural biomethane plants, there is also potential for the development of biowaste biomethane plants, which utilize organic waste from municipal, commercial, and industrial sources. Other potential sources of organic waste that could be used for biomethane production include sewage sludge, food waste, and forestry residues. Unused/ available substrates: Agricultural residues, landfills, biowaste and WWTP, 250 Mt of organic waste
Economic and social: considerable economic costs that promoters usually face when projecting new biomethane facilities, considering the installation itself plus quality	Acc. to AEBIG (2019): biogas production could cover around 10% of the national natural gas demand by 2030 Acc. to the Spanish Association of Natural Gas for Mobility (Gasnam) – 1 bcm of natural gas by 2025 in the transport sector, with a significant share coming from biomethane

Sources: BETA, 2023.

8.3.9. Spain (3)

Barriers	Perspectives
There continues to be an important bottleneck related to the use of digestate (solid-liquid fraction, etc.) from anaerobic biodigestion.	To make use of the biodegradable fraction of municipal waste, sewage sludge or liquid manure to produce biogas or biomethane. To explore innovative fraction technologies for this type of bio-waste, to optimize the process involved with anaerobic biodigestion and biomethane purification technologies for its direct use in internal combustion engines. To ensure the valorization of the digestate resulting from biodigestion.
The great dispersing in the territories of the raw materials (feedstock), combined with the need to produce where these raw materials are found (much more sustainable in environmental and economic terms) makes it necessary to have suitable and viable economically equipment for biofuel production (or bio-oil) and upgrading biogas for smaller installations.	Research into streamlining the costs of upgrading biogas to obtain biomethane compatible with injection into the gas grid or for vehicle use: Scaling significantly conditions the profitability of upgrading costs. The development of P2G stations (Power-to-Gas); The development of more efficient absorbents, (based on ionic liquids, etc.); The application of process intensifying technologies (modified membranes, micro-reactors, membrane reactors) to improve yields and reduce the production of by-products; The direct conversion of biogas into synthetic natural gas (without separating CO2), in hydrogen, or methanol.
Currently, the distance between the pilot plant (TRL4-TRL5) and the commercial 'flagship' plant (TRL8-TRL9) is very relevant.	Facilitate this progress and market scaling of the projects be feasible through financial instruments and risk-sharing mechanisms.

Sources: Bioplat, 2023.

8.3.10. Sweden

Barriers	Perspectives
Missing biomethane target	Estimated techno-economic potential 30-37 TWh by 2030 (incl. more agri-biomass, gasification of forest residues, P2CH4)
Long and costly permitting processes	10 TWh of biomethane by 2030[3] based on current regulations
Support for other uses than transportation	Increase of co-digestion plants (manure + biowaste/ industrial organic waste/ agri-residues)
Increased biomethane imports but stagnating production	Bio-LNG – potential large gas users in industry, long haul heavy road or maritime transport
Taxation rules, i.e., based on volume instead of energy content	Future feedstock: Biowaste, sewage sludge, wastes and residues from industry, agriculture and forestry, non-food/feed crops, e-methane
tax exemption from excise and carbon duty for biogas/biomethane for transport and heating revoked (2011 – 2023)	main sectors for the utilization of biomethane by 2030: • industry with 50%, • transport sector with 30%, • CHP with 10%, • Electricity and heat with 5% respectively
Missing mass balance principle (for EU ETS resolved but not for power reserve procurement or Klimatklivet[4])	90 – 100 biomethane plants by 2030

Sources: Klackenberg, 2023a; Klackenberg, 2023b; Biogasmarknadsutredningen, 2019.

[3] Swedish Biogas Market Investigation

[4] Klimatklivet = local climate investment programme

8.3.11. Ukraine

Barriers	Perspectives
Limited technical possibilities for supplying biomethane to the gas distribution system, especially in the summer	10 TWh of biomethane per year can be produced by 2030 if using available biomass potential
Absence of basic law on the production and consumption of biomethane in transport sector	5-10 TWh of biomethane per year based on current legislation by 2030
Absence of state goals and obligations regarding the share of biomethane use in transport sector	Future feedstock: manure/dung/litter, maize and wheat straw, sugar beet pulp, sequential crops, organic fraction of municipal solid waste, maize silage
Absence of technical requirements for the use of biomethane as motor fuel in transport sector	up to 100 TWh biomethane production potential based on unused/ available substrates
Lack of a mechanism for issuing Guarantees of Origin (GoO) for biomethane in transport sector	main sectors for the utilization of biomethane by 2030: • export with 50 %, • transport fuel with 25 %, • electricity with 20 %, • gas with 5 %
Negative trends in the market of natural gas consumption as motor fuel	100 – 200 biomethane plants by 2030, mainly agricultural
Reduction in the number of compressed natural gas (CNG) filling stations, lack of liquefied natural gas (LNG) filling stations	

Sources: Bioenergy Association of Ukraine (UABio) 2023. Geletukha et al. 2022; EBRD, 2021