

BRIDGING THE GAPS: RESEARCH AND INNOVATION

Priorities in The Biogas and
Biomethane Value Chain

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EBA
European Biogas
Association

Position Paper

Bridging the Gaps: Research and Innovation Priorities in the Biogas and Biomethane Value Chain

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Executive Summary

Biogas and biomethane occupy a unique position in the European energy system. As dispatchable, storable and grid-compatible renewable energy carriers, they are among the very few technologies capable of simultaneously advancing energy self-sufficiency and security, energy defossilisation and storage, climate neutrality, agricultural sustainability and circular economy objectives. In a context of accelerating defossilisation, biogases can play a targeted role in meeting Europe's security-of-supply and climate ambitions.

To map the research and innovation priorities that will determine whether this ambition is met, the European Biogas Association, together with its Scientific Advisory Board and a broad network of research institutions active across Europe, undertook a structured consultation process combining survey data, expert review and systematic analysis of the existing research landscape. The result is this position paper, offered not as a demand for resources, but as a scientific roadmap for where targeted R&I investment would generate the greatest technological, environmental and policy returns for Europe and its citizens.

The paper identifies five interconnected thematic pillars covering the full biogas and biomethane value chain, where further targeted research and innovation are still needed:

Closing the Circle – Biomass, Nutrients, Water and Soil: the circular potential of feedstock diversification, reduction of emissions, digestate valorisation and nutrient recovery, connecting biogas systems to agricultural sustainability, soil, human and animal health and European fertiliser sovereignty.

The Living Core – AD Biology and Process Performance: the biology and process engineering of anaerobic digestion, where advances in microbial science create compounding returns across every other research area in the value chain, including the fate of emerging pollutants, pathogens and antimicrobial resistance genes, contributing to the One Health concept.

From Energy to Molecules – Bio-based Fuels, Chemicals and other Products, Biogas Upgrading, CO₂ Valorisation: the opportunities that transform anaerobic bioprocesses into a biorefinery platform for advanced fuels, chemicals, novel biomolecules, biogenic CO₂

valorisation and negative emission services supporting the development of circular bioeconomies.

Knowing What We Measure – Digitalisation, Metrology and Standards: the digital and measurement infrastructure the sector needs, including robust metrology frameworks for accurate data and traceability, from AI-enabled process optimisation and digital twins to the harmonised standards that are prerequisites for market integration and credible environmental accounting.

Bridging Science and Society – System Integration, Deployment and Societal Dimensions: the systemic dimensions of deployment, including energy resilience and network interoperability, sector coupling, social acceptance, rural development and the mechanisms needed to bridge research results and commercial reality.

Five structural priorities have emerged across these five pillars: balanced investment across the full TRL spectrum; the deliberate incentivisation of cross-disciplinary and crosssectoral consortia; dedicated mechanisms for first-of-a-kind de-risking and technology transfer, to bridge the gap between demonstration readiness and commercial deployment; build the measurement infrastructure the sector needs; and recognise its multifunctional nature.

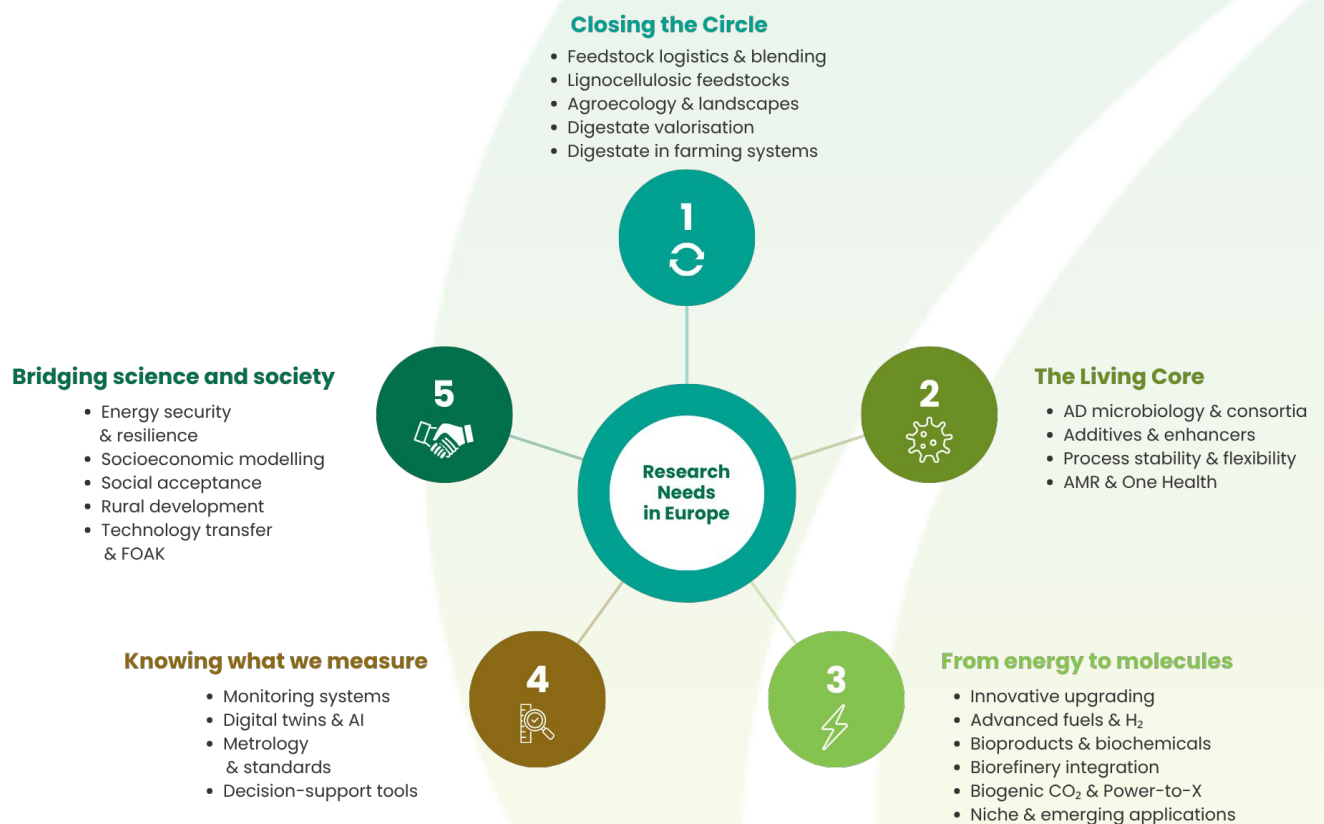


Figure 1. Key research and innovation topics in Europe's Biogas and Biomethane Value-Chain

CONTEXT AND RATIONALE

Biogas and biomethane are among the few renewable energy technologies capable of simultaneously addressing energy security, climate neutrality, agricultural sustainability and circular bioeconomy objectives. Achieving these goals is not simply a matter of deployment: it is an invitation to deepen and accelerate the science and innovation that will make large-scale production technically robust, economically viable and environmentally credible. A set of interconnected research and innovation priorities span the efficient mobilisation of sustainable and diverse feedstocks, the full valorisation of digestate and biogenic CO₂, the maturation of several advanced conversion routes, the harmonisation of measurement and emissions standards, and the integration of biogas systems into broader energy and agricultural frameworks.

This position paper presents the results of that process, not as a list of demands, but as an offer of scientific expertise and a roadmap for where R&I investment would generate the greatest technological, environmental and policy returns for Europe and its citizens.

METHODOLOGY

The research priorities presented in this paper are the result of a structured and multi-layered consultation process, combining quantitative survey data, expert review and systematic analysis of the existing EU-funded research landscape in the biogas and biomethane sector.

A survey was distributed to research institutions and universities actively working across the biogas and biomethane value chain throughout Europe. Respondents were invited to assess research needs across the full technology readiness level (TRL) spectrum, from fundamental science to near-market demonstration, and to identify the areas they consider most critical to advance in the coming years to unlock the full potential of the sector. The survey covered nine thematic areas, ranging from feedstock systems and anaerobic digestion fundamentals to digitalisation, biogenic CO₂ valorisation and system integration.

Survey findings were complemented by a qualitative review conducted with EBA's Scientific Advisory Board, whose members provided additional depth and context on emerging topics, cross-cutting priorities and areas where scientific consensus is strongest. This expert layer was particularly valuable in identifying research themes that are gaining momentum in the scientific community and are expected to become strategically central and impactful.

Finally, the identified priorities were assessed against the landscape of Horizon Europe and Horizon 2020 funded projects, and considered in alignment with the positions of established European research alliances and sector-specific evidence bases – including EERA,

EURAMET and related European research initiatives, as well as the findings of the Biomethane Industrial Partnership Task Force 5 reports on research priorities and deployment needs across the biogas and biomethane value chain – to ensure coherence with the broader EU research community's recommendations. The result is a prioritised map of research and innovation needs organised into five thematic pillars, structured to guide investment decisions across the full innovation chain.

To further support navigation across this map, each research topic is accompanied by a visual indicator – a gauge symbol reflecting the nature and scale of the R&I investment needed. This classification distinguishes between topics where foundational or fundamental research is the primary need (emerging priorities), topics where investment should focus on scaling up and validating approaches that are already scientifically promising (growing priorities), and topics where the main barrier is bridging demonstration readiness and commercial deployment (scaling priorities). These categories reflect different points along the innovation continuum and should not be interpreted as a hierarchy of importance: a topic classified as scaling is not more deserving of support than one classified as emerging – rather, the nature of the investment required differs. All topics identified in this paper represent genuine and strategic research needs for the European biogas and biomethane sector.

RESEARCH GAPS AND INNOVATION NEEDS



1. Closing the Circle - Biomass, Nutrients, Water and Soil

The biogas and biomethane sector is uniquely positioned to act as a connector between agricultural systems, energy networks and nutrient cycles. Well-designed biogas systems can return nutrients, organic matter and energy services to the landscapes that supply them, creating genuinely circular flows that strengthen the energy and food systems simultaneously. The sector is also undergoing a fundamental feedstock transformation: moving from dedicated energy crops towards a diversified portfolio of agricultural residues, lignocellulosic materials, organic wastes and marginal land biomass, driven by sustainability requirements, land use pressures and the imperative to maximise the value of resources that would otherwise go unexploited. Realising the full circular potential of this

transition requires advances spanning agronomy, logistics, process engineering and soil science.

Efficient use of lignocellulosic feedstocks and pretreatment integration

Straw, woody residues, corn stover and other lignocellulosic materials represent a vast and strategically important resource for biogas production across Europe. Advancing energy-efficient pretreatment technologies – including mechanical, thermal, biological and hybrid approaches – and exploring their integration with dark fermentation, hydrothermal processes and pyrolysis would enable new product chains and significantly higher overall yields. Gasification offers a complementary thermochemical route for feedstocks that resist biological conversion, with the added strategic value that the hydrogen content of the resulting syngas can directly feed the biomethanation of biogenic CO₂, connecting feedstock processing and gas valorisation in a single integrated chain.

Biogas-enabled multifunctional agricultural landscapes and agroecology

Biogas systems can actively shape agricultural landscapes beyond their role as energy producers. Sequential and second cropping, cover crop integration, grassland management and the productive use of marginal or degraded land can deliver multiple co-benefits – soil health, biodiversity, reduced pesticide and herbicide inputs – while securing sustainable feedstock streams. Quantifying these co-benefits across European pedoclimatic zones and developing optimised cropping system designs for biogas-integrated farming would build the evidence base needed for incorporation into agricultural and rural development policy frameworks.

Feedstock logistics, blending and contaminant management

At operational scale, feedstock management involves challenges beyond laboratory conversion efficiency. Seasonal variability in biomass availability, the logistical complexity of mobilising and transporting diverse materials, optimal blending strategies for mixed feedstock inputs, and the management of potential contaminants – (micro)plastics, heavy metals, persistent organic pollutants – all represent areas where dedicated research would significantly reduce operational risks and costs for plant operators. Improved tools for feedstock characterisation, quality monitoring and supply chain optimisation are central to making the diversified feedstock base economically viable at scale. To fully secure the food waste valorisation chain, future research should also target the specific operational and downstream risks of depackaging, focusing on advanced technologies to mitigate the effects of contaminants in digesters and prevent microplastics accumulation in agricultural soils.

Digestate valorisation, nutrient recovery and fertiliser sovereignty

Digestate is the largest output of every biogas plant and, when fully valorised, one of its most strategically significant. Advancing digestate-based products beyond simple liquid and solid fractions – including digestate-derived fertilisers, biostimulants, hydrochars, biochar, sorbents, polymers, composites and peat substitutes – would open substantial new value streams and support circular economy objectives. Using digestate nutrient-rich fractions as growth media in high-value fermentations, for example for single cell protein and biopolymer production and algal cultivation systems, can substitute synthetic inputs. Phase separation of digestate into solid and liquid fractions also creates a practical opportunity: liquid effluent, carrying a minimal but agronomically relevant nutrient load, can be used for proximity fertigation or irrigation, avoiding the transport of large water volumes and significantly reducing digestate management costs. This is particularly relevant in regions facing growing water scarcity, including across the Mediterranean arc, where the integration of biogas plants with irrigation infrastructure could simultaneously address energy, nutrient and water management challenges. The recovery of nitrogen, phosphorus and potassium through post-treatment technologies of digestate and processes such as struvite precipitation, membrane filtration, biological acidification of manure and ion exchange offers a circular alternative to imported mineral fertilisers, strengthening agricultural sovereignty and supply chain resilience.

Digestate in real farming systems: soil, environment and climate

Understanding the agronomic and environmental performance of digestate under real farming conditions and across the diversity of European soil types, climatic zones and cropping systems, is essential to inform regulations and farmer adoption tools. The composition, agronomic value and regulatory compliance of digestate is directly shaped by what enters the digester. Establishing robust evidence on how feedstock characteristics – including methane yield and anaerobic degradability kinetics, lignocellulosic content, contaminant load and blending ratios – propagate through the system to affect digestate composition, pathogen load, heavy metals content and fertiliser value would create the scientific foundation for feedstock-specific digestate quality standards. Such standards would support both regulatory harmonisation across Member States and broader farmer adoption of digestate-based products. Research deepening our understanding of soil-plant-environment interactions following digestate application, including effects on soil health, carbon sequestration, nitrogen use efficiency, N₂O emissions, water retention and biodiversity, would directly support the sector's contribution to European climate and sustainability targets.



The Living Core – AD Biology and Process Performance

2. The Living Core – AD Biology and Process Performance

Long described as a black box, the anaerobic digester is today better understood as a living ecosystem, one of the most complex and scientifically rich microbial ecosystems in industrial use. The microbial communities that convert organic matter into biogas operate through intricate networks of metabolic interdependencies whose ecology, dynamics and responses to operational conditions represent an active and rapidly advancing frontier of scientific inquiry. This pillar addresses the biology and engineering of what happens inside the AD plant, from microbial community level to process stability and performance monitoring. Furthermore, it covers pathogen and AMR control, positioning the AD process as an active contributor to One Health objectives. It is also the area with the greatest potential for compounding returns: advances in AD microbiology and process dynamics amplify progress across every other pillar. Investment here is investment in the long-term competitiveness of the entire sector.

Microbial ecology, consortia engineering and metabolic pathways

The functional diversity of microbial communities in anaerobic digesters is vast and remains only partially characterised across plant typologies, feedstock combinations and operational regimes. Deepening knowledge of microbiome composition and metabolic function, and of the microbial drivers of process performance and stability under stress or novel conditions, would directly support plant optimisation, process resilience and next-generation AD design. Building on this, process optimisation, synthetic biology and microbiome engineering approaches could provide targeted tools for improving the predictability, functionality and robustness of AD and related gas bioconversion systems. Priority research areas include the design of robust microbial consortia, engineered enzymes, biosensors for early detection of process instability, and contained microbial conversion routes for biogenic CO₂, methane-derived intermediates and volatile fatty acids, developed with due attention to biosafety, containment and regulatory feasibility. As biogas plants are increasingly expected to provide flexibility services, the capacity to ramp production up or down without compromising biological stability is a key competitive asset. Equally promising are emerging operational frontiers such as low-temperature digestion and electrically and light-assisted AD, where understanding how microbial communities adapt and perform under these novel conditions would expand the geographic and

economic viability of biogas production across Europe, including in regions where conventional mesophilic digestion is not currently cost-effective.

Additives and biological enhancers

Additives and biological enhancers can help biogas plants get more value from existing and emerging feedstocks by improving process stability, mitigating inhibition, accelerating the degradation of recalcitrant materials and increasing methane yields. They can also support the use of hard-to-digest and future feedstocks that would otherwise be technically or economically challenging to process. Relevant research areas include operational conditions and cost-effectiveness of enzymes, bioaugmentation strategies, engineered microbial consortia, trace elements, micronutrients, buffers, natural mineral adsorbents, conductive carbon materials such as biochar and activated carbon, biodegradable biosurfactants and solubilising agents. Particular attention should also be given to their long-term effects on digestate quality, environmental safety and regulatory acceptability, so that these tools can support higher resource efficiency without creating new downstream risks.

Antimicrobial resistance, pathogen reduction and One Health dimensions

AD has a well-recognised role in reducing pathogen loads and antimicrobial resistance genes in organic waste streams – and deepening the scientific understanding of these processes would allow biogas to be positioned as an active contributor to One Health objectives, connecting energy production with human, animal and environmental health outcomes. Research on the fate of antimicrobial resistance genes across different operational conditions and feedstock types, and on the effectiveness of pathogen reduction under real plant conditions, would build the evidence base needed to integrate biogas into EU human and animal health and agriculture policy in ways that go well beyond its current recognition as an energy technology.



From Energy to Molecules – Bio-based Fuels, Chemicals and other Products, Biogas Upgrading and CO₂ Valorisation

3. From Energy to Molecules – Bio-based Fuels, Chemicals and other Products, Biogas Upgrading and CO₂ Valorisation

Biogas and biomethane are increasingly recognised not merely as energy carriers but as versatile molecular platforms to produce advanced fuels, chemicals, proteins, novel

biomolecules and negative-emission services. Every molecule of methane and every tonne of biogenic CO₂ produced at a biogas plant carries value beyond combustion, and the technologies that condition, refine and transform these gas streams determine how much of that value can be captured. Investing in this pillar means investing in European industrial competitiveness, energy system flexibility and the credibility of the sector's contribution to carbon neutrality. It is also where the biogas and biomethane sector most directly connects with the broader European bioeconomy, the hydrogen economy and the emerging carbon removal market.

Innovative upgrading, gas cleaning and emissions control

Innovative and energy-efficient upgrading technologies – including biological and hybrid systems and micro-upgrading units below 90 Nm³ CH₄/h – would extend the viability of biomethane production to smaller and more diverse plant configurations, broadening the geographic and economic reach of the sector across Europe. Advanced gas cleaning for hydrogen sulphide (H₂S) removal via chemical scrubbers, bioscrubbers, biofilters or activated carbon adsorbers, siloxane elimination and trace contaminant management are equally important, including for product gases from gasification routes. A particularly high-value research priority is the detection, measurement and mitigation of methane slip and fugitive emissions across the full chain – upgrading units, storage infrastructure and digestate handling – where advances in measurement precision and modelling would directly strengthen the sector's environmental integrity and support its participation in emerging carbon markets. Future work should integrate ground-level plant sensors with high-resolution methodologies (e.g. satellite imaging) to develop predictive, AI-driven Leak Detection and Repair (LDAR) protocols that proactively safeguard the sector's climate accounting.

Conversion to advanced fuels and energy carriers

Biogas and biomethane are strategically well-positioned as feedstocks to produce renewable hydrogen via reforming, e-methane for energy storage, sustainable aviation fuel (SAF), methanol and other synthetic hydrocarbons through catalytic and biological methanation routes. Gasification of difficult lignocellulosic feedstocks provides an additional and complementary pathway: the hydrogen content of the resulting syngas can directly feed the biomethanation of biogenic CO₂, creating an integrated thermochemical-biological conversion chain of strategic interest for hard-to-abate sectors. Research should focus on the efficiency, scalability and cost-competitiveness of these pathways, and developing robust lifecycle assessment frameworks within regulatory contexts such as ReFuelEU and the Renewable Energy Directive.

Bioproducts, novel biomolecules, carboxylate value networks and biorefineries

Beyond energy applications, methane and the intermediate products of anaerobic digestion can serve as feedstocks for high-value bio-based compounds with significant market potential. Microbial protein from biogas, carboxylate value networks based on volatile fatty acids from two-phase AD, and novel biomolecules from digestate streams all represent opportunities at the intersection of biotechnology, chemistry and circular economy. Advancing the biological and biochemical understanding of these conversion routes, demonstrating their technical feasibility at relevant scales, and assessing their economic viability within European bioeconomy conditions would open revenue streams that fundamentally change the business case for biogas plant investment. Lignocellulosic feedstocks also offer a wide range of opportunities beyond energy – including the recovery of cellulose, lignin and phenolic compounds as marketable bio-based products. Integrating AD with complementary biological, chemical and thermochemical processes – including high-value fermentations and algal cultivation systems using digestate or its nutrient-rich fractions as a nutrient medium – can then maximise resource efficiency and unlock multiple value streams from the same biomass input. Identifying the most viable integrated biorefinery configurations and developing the process-engineering knowledge to implement them at scale would position European biogas operators as active participants in the wider bioeconomy, not just suppliers of a single energy product.

Biogenic CO₂ valorisation, CCU/CCS and Power-to-X

Every biomethane upgrading plant produces a concentrated stream of biogenic CO₂ that represents a resource of growing strategic importance. The full spectrum of valorisation options – biological and catalytic methanation with green hydrogen, both ex-situ and in-situ including bioelectrochemical systems and electromethanogenesis, conversion to fuels, chemicals and greenhouse inputs, and permanent geological storage for carbon dioxide removal – deserves dedicated and coordinated research attention. Of particular importance is the role of biogenic CO₂ in sector coupling and Power-to-X chains, including its potential as feedstock for green ammonia and other hydrogen carriers. Developing robust methodological frameworks for negative emission accounting would also allow the sector to participate credibly and competitively in European and international carbon markets.

Niche and emerging applications

Beyond mainstream energy and chemical markets, biogas and biomethane have potential in domains that represent genuinely novel frontiers, where the distributed, circular and molecularly versatile nature of anaerobic bioprocesses offers unique advantages.

The role of anaerobic biotechnology in space exploration and colonisation is attracting growing institutional interest. Provision of life in off-Earth environments – including closed-

loop life support systems, waste valorisation, and the production of water, fuels, chemicals and feed or food from local mineral and carbon sources – represents a frontier where AD-based processes are particularly well suited. The microgravity and zero-gravity conditions of space environments also open new opportunities for biotechnological process design, enabling configurations that are not feasible on Earth and that could in turn inform the development of more compact, automated and resource-efficient systems for terrestrial applications.

Disaster recovery and critical infrastructure resilience represent a second high-potential frontier. The decentralised, modular and feedstock-flexible nature of biogas systems makes them well suited to provide essential services – energy, fuels, water treatment and food production support – under conditions where centralised infrastructure has failed or is unavailable. Research into the role of anaerobic bioprocesses in defence and civil emergency contexts, including rapid-deployment systems and integration with wastewater treatment and agricultural continuity, would build the evidence base for biogas to be recognised as a strategic asset in national and European resilience planning.

Finally, the development of compact, automated and highly integrated AD systems – capable of operating across diverse scales, feedstock types and connectivity conditions – represents a cross-cutting research frontier that connects space, defence and off-grid applications with the broader democratisation of biogas technology across Europe.



4. Knowing What We Measure – Digitalisation, Metrology and Standards

The capacity to measure, model and control what happens inside and around a biogas plant is a prerequisite for every other advance described in this paper. Metrology underpins this capacity, ensuring accuracy, traceability and comparability of data across processes, sites and markets as reliable measurement protocols are the foundation of credible environmental accounting. Digital tools are the engine of process optimisation at scale. Harmonised standards are the infrastructure of a functioning biomethane market. This pillar addresses the knowledge and measurement infrastructure that underpins the entire sector – and where targeted investment would generate returns that compound across all five pillars. It is also the area most directly connected to the sector's ability to demonstrate its environmental performance to regulators and society, scale operations and participate in carbon markets.

Robust and resilient monitoring and control systems

A large share of European biogas plants, especially in agricultural and rural areas, operate with very different connectivity conditions and levels of instrumentation. Developing monitoring and control systems that are robust under low-connectivity conditions, use a limited number of sensors and follow standard data architectures would greatly improve the information available to plant operators. Standardised data frameworks would also facilitate the aggregation of operational data across plant networks, which is a prerequisite for training the AI and machine learning models that represent the next generation of process optimisation tools.

Digital twins and advanced process control

Digital twin technology – computer models that track the real-time state of a physical plant – has significant potential to improve biogas plant operation. A well-developed digital twin can anticipate process disturbances, optimise feedstock blending in real time, predict maintenance needs and support operator decisions under uncertainty. Developing digital twins tailored to anaerobic digestion, validating them across diverse plant types and scales, and integrating them with existing SCADA and plant management systems would help move this technology from research into everyday use.

AI and machine learning for process optimisation

Artificial intelligence and machine learning are powerful tools for pattern recognition, predictive modelling and optimisation in systems with high variability and non-linear dynamics, such as AD. Developing and validating AI-based tools for real-time process monitoring, early warning of instability, feedstock characterisation and energy yield optimisation – especially tools that work with limited data and in plants of different sizes and sensor setups – would democratise access to advanced process intelligence across the European biogas sector, benefiting large industrial installations and smaller agricultural plants alike.

Decision-support tools for technology selection and sector coupling

As biogas systems become more integrated into broader energy networks – providing flexibility services, coupling with Power-to-X installations, operating as part of district heating schemes or contributing to grid balancing – operators and planners face increasingly complex investment and operational decisions. Developing practical decision-support tools that can assess the techno-economic performance of different configurations, simulate system behaviour under variable grid and market conditions, and guide investment decisions for both new installations and the retrofitting of existing assets would significantly reduce the information barriers that currently slow the uptake of more integrated and higher-value operating models.

Metrology and standard methods

Metrology provides measurement standards and methods for accurate and comparable measurement data which are foundational to market integration, regulatory compliance and environmental accountability across the biomethane sector – and represents one of the areas where pre-normative EU research investment would generate the most immediate and far-reaching returns. Reliable sampling is the first critical step in the measurement chain, ensuring that data collected are representative, comparable and suitable for downstream analysis and decision-making, while requiring careful selection of sampling vessel materials to ensure chemical and physical compatibility.

Reliability and harmonisation of measurement methods, sampling procedures, and protocols for data collection, analysis and reporting are a priority across five interconnected dimensions: feedstock characterisation, digester biology monitoring, tracking of environmental pollutants, greenhouse gas emissions measurement and conformity assessment of biomethane. Developing and validating high-resolution and traceable measurement methodologies, standardised sampling strategies, establishing reference materials and inter-laboratory comparison frameworks, and feeding results directly into European and international standardisation processes would create the metrology infrastructure that the sector needs to demonstrate its environmental performance with credibility/assurance and precision. This is particularly urgent for methane emissions monitoring (e.g. Methane Pledge) and biogenic CO₂ accounting, where agreed and robust protocols are a prerequisite for the sector's participation in carbon markets and for the integrity of its contribution to European climate targets. Ensuring the quality of biogenic CO₂ and defining the purification requirements is essential to enable its use across applications such as food-grade supply and carbon capture value chain. Furthermore, pre-normative research should develop digital tracking methodologies to align the Union Database (UDB) with registries like ERGaR and AIB, ensuring transparent mass-balance accounting and enabling efficient cross-border markets.



Bridging Science and Society – System Integration, Deployment and Societal Dimensions

5. Bridging Science and Society – System Integration, Deployment and Societal Dimensions

Biogas and biomethane are embedded in energy markets, agricultural policies, rural economies, regulatory frameworks and social contexts whose complexity is rarely captured

in technology-focused research programmes. This pillar addresses the research needs that determine whether the technologies developed across the other four pillars actually reach society – and whether they do so in a way that is economically viable, socially accepted, territorially equitable and strategically coherent with the broader European Green Deal ambitions.

Energy security, resilience and strategic dimensions

As a domestically produced, distributed and storable energy carrier, biogases have a growing role in national and regional energy resilience strategies. For biogases to be recognised as a strategic energy asset, not only a renewable one, research into quantification of the security of supply at different scales, the modelling of behaviour under supply stress conditions, and the assessment of biogases integration into national resilience planning frameworks – including off-grid critical infrastructure and contexts with civil security implications – need to be undertaken.

Biogas in sector coupling and socioeconomic modelling

The specific contribution of biogas to energy system flexibility – flexible CHP operation, integration with Power-to-Heat and Power-to-X systems, demand-side management and grid balancing services – is one of the sector's most strategically valuable and most undermodelled dimensions. Developing high-resolution techno-economic models of biogas in sector-coupled energy systems, assessing the value of flexibility services under different market designs, and building the full socioeconomic modelling capacity needed to capture the interactions between energy markets, agricultural systems and rural development policy would give policymakers, investors and plant operators the analytical tools they need to make informed decisions at the pace that the energy transition requires.

Social acceptance and communication of multifunctional benefits

The deployment of biogas at scale depends not only on technical and economic viability but on genuine social acceptance and meaningful community engagement. Research on public perception, trust-building mechanisms, participatory governance models and the communication of the sector's multifunctional benefits – spanning energy security, agricultural sustainability, circular economy and environmental services – to farmers, rural communities and the broader public would provide the social science foundation that large-scale deployment requires.

Market integration, first-of-a-kind de-risking and technology transfer

Several advanced biogas technologies – including lignocellulosic AD, biological methanation and integrated biorefinery concepts – are approaching demonstration readiness and represent some of the most promising near-term opportunities for European industrial leadership in the biogas sector. Supporting their transition from research to

market through coordinated first-of-a-kind (FOAK) mechanisms, systematic technology transfer frameworks, and the establishment of living lab demonstrators that allow new process concepts to be validated under real operating conditions would address the financing and regulatory barriers that standard market mechanisms alone cannot resolve. This is the connective tissue of a functioning innovation system, and where the returns on EU research investment become most visible and most tangible for European citizens and industry alike.

DISCUSSION

The five pillars presented in this paper collectively point to a set of structural patterns that deserve attention beyond the individual topic level and that offer concrete guidance for the design of Framework Programme 10 and other European research programmes.

The first is the strategic value of investing across the full TRL spectrum. The greatest long-term returns in the biogas and biomethane sector will come from a programme architecture that explicitly protects space for fundamental and applied research at low technology readiness levels, alongside the higher-TRL demonstration and deployment activities that have historically attracted the bulk of attention. AD microbiology, bioelectrochemical systems, metrology and advanced conversion routes are areas where foundational scientific advances today will translate into competitive technologies and credible environmental performance tomorrow. A balanced European research programme would ensure that the scientific foundations of the sector's long-term growth are not crowded out by short-term deployment priorities.

The second pattern concerns the potential of interdisciplinary and cross-sectoral research in this space. Many of the most promising innovation opportunities identified across the five pillars sit at the interfaces between disciplines and value chain stages – for example, the integration of biogas systems with Power-to-X infrastructure, the development of digestate-based bioproducts and novel biomolecules, the deployment of AI tools for process optimisation, the quantification of agroecological co-benefits. These opportunities require the convergence of expertise from microbiology, agronomy, engineering, biotechnology, computer science, economics and social science. European research funding calls that incentivise cross-disciplinary and cross-sectoral consortia – covering the continuum from fundamental research through pilot demonstration – would unlock research value that no single-discipline programme can generate.

The third observation concerns the critical importance of bridging research maturity and deployment ambition. The distance between laboratory results and commercial reality is precisely the space where coordinated EU investment generates its greatest leverage. FOAK de-risking mechanisms, living lab demonstrators and structured technology transfer programmes provide the innovation infrastructure that transforms scientific knowledge

into industrial reality, and that ensures European research leadership translates into European market leadership.

These structural patterns translate directly into five priorities for consideration in the design of future European research programmes:

Recommendations for the design of future European research programmes

1. Ensure dedicated funding for low-TRL research in biogas and biomethane

Fundamental research in AD microbiology and process optimisation, bioelectrochemical and other assisted and enhanced systems and advanced conversion routes is approaching a critical and scientifically fertile juncture. Future European research programmes would benefit from explicitly allocating funding for basic and applied research at TRL 1–5 in this sector, ensuring that the scientific foundations of long-term technological progress are developed in parallel with near-term deployment priorities.

2. Support coordinated calls spanning the full innovation chain

The most strategically valuable research opportunities in this sector sit at the interface of disciplines and value chain stages. Future European research programmes that explicitly require cross-disciplinary and cross-sectoral consortia – covering the continuum from fundamental research through pilot demonstration – would unlock innovation value that fragmented, single-discipline funding cannot generate.

3. Establish dedicated mechanisms for FOAK de-risking and technology transfer

Several advanced biogas technologies – including lignocellulosic AD, biological methanation and integrated biorefinery concepts – are approaching demonstration readiness. Structured FOAK support schemes and living lab demonstrators specifically designed to bridge the gap between research results and commercial deployment would address financing and regulatory barriers that market mechanisms alone cannot resolve.

4. Fund metrological and pre-normative research and harmonised standards for the biomethane sector

The development of agreed measurement protocols, sampling protocols and reference methods for gas quality, methane emissions, feedstock characterisation and biogenic CO₂ accounting is a prerequisite for market integration, regulatory

compliance and credible environmental performance claims. Future European research programme support for dedicated metrological and pre-normative research programmes, with explicit linkages to European and international standardisation bodies, would ensure that research results are translated into actionable standards within the programme timeframe.

5. Integrate biogas and biomethane into cross-sectoral research agendas

The multifunctional nature of biogas systems – spanning energy, agriculture, circular economy, One Health and carbon removal – means that relevant research priorities are distributed across multiple European research programmes clusters. Ensuring coherence and complementarity across clusters and avoiding duplication while maximising the systemic value of biogas-related investments, would significantly amplify the impact of EU research funding in this space.

FINAL REMARK | The EBA scientific community as a structured knowledge partner

The research needs identified across these five pillars were articulated by a broad and geographically diverse community of European research institutions, whose collective expertise spans the full biogas and biomethane value chain. The convergence of expert opinion around the priorities presented in this paper reflects a genuine and robust scientific consensus and an offer of structured collaboration to the European Commission as it designs the research agenda that will shape the sector's trajectory over the next decade. EBA, its Scientific Advisory Board and the contributing research institutions stand ready to engage as a knowledge partner throughout the FP10 and other future European research programmes' implementation process, bringing scientific expertise, sector intelligence and a pan-European network committed to helping ensure that biogas and biomethane make a measurable contribution to Europe's energy security and climate mitigation objectives.