Biomethane & Bioeconomy Synergies Report

Prepared by

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The Biomethane for Carbon and Community is co-funded by the Government of Ireland and the European Union through the EU Just Transition Fund Programme 2021-2027.

Partner Organisations

Partner/ Organisation Name	About
Comhairle Contae Thiobraid Árann Tipperary County Council	**Tipperary County Council (TCC) (Lead partner of the Biomethane for Carbon and Community (BCC) project),** as the Local Authority for Tipperary, provides an extensive range of infrastructural and social services and plays an active role in the development of the county's enterprise, environment and climate action, transport social, arts, heritage and cultural affairs. It also functions as the regulatory body for certain matters at local level.
TUS	**The Technological University of the Shannon (TUS)** is a multi-campus institution prioritizing accessibility, inclusivity and innovation. Spanning seven campuses in Ireland's Midwest and Midlands, TUS fosters regional growth through education, research and collaboration. With over 15,000 students annually, TUS combines student-focused learning with industry partnerships, driving progress and shaping the future of education and innovation.
Irish Bioeconomy Foundation Growing Ireland's Bioeconomy Together	**The Irish Bioeconomy Foundation (IBF)** is a pioneering hub for transforming Ireland's natural resources into sustainable, high-value products. Based at the National Bioeconomy Campus in Lisheen, Co. Tipperary, IBF fosters collaboration among agribusiness, forestry, marine and energy sectors, driving innovative projects, creating synergies and building a globally competitive bioeconomy that supports local communities and sustainable development.

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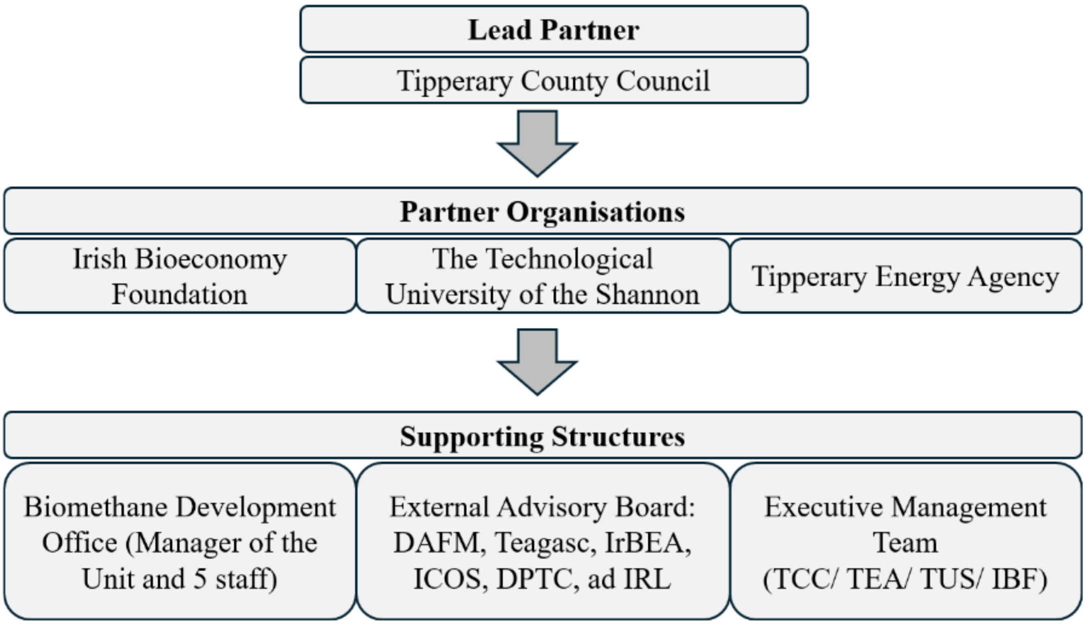
The Tipperary Energy Agency (TEA) is a not-for-profit social enterprise driving Ireland's energy transition. Funded through innovative engineering services, education and European grants, TEA enables local authorities, communities and businesses to deliver renewable energy and efficiency projects. With over 40 European projects completed, TEA bridges climate targets and results through innovation, collaboration and leadership.

Organisation Chart



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Biomethane for Carbon and Community Project

The **Biomethane for Carbon and Community (BCC) project** operates within a global, European, and national framework committed to achieving net-zero emissions and sustainable development. These interconnected efforts reflect an urgent response to climate change, emphasising the role of biomethane in reducing greenhouse gas emissions and advancing renewable energy solutions.

At the **global level**, the **Global Methane Pledge**, signed by over 100 countries, including Ireland, seeks to reduce methane emissions by at least 30% from 2020 levels by 2030. This initiative underscores the critical need to mitigate methane, a potent greenhouse gas, to limit global warming to 1.5°C. Biomethane, derived from organic waste, agricultural residues, and other renewable resources, offers a sustainable pathway to address this challenge.

The **European Union (EU)** has reinforced its climate leadership through the **European Green Deal** and the **Fit for 55 Package**, which aim to reduce net greenhouse gas emissions by 55% by 2030, compared to 1990 levels and achieve climate neutrality by 2050. The EU also emphasises integrating biomethane into its energy strategy, fostering circular economy principles and reducing reliance on fossil fuels. EU funding mechanisms, such as the **Just Transition Fund (JTF)**, support regions in transitioning to low-carbon economies, enabling projects like BCC to drive innovation and community-focused solutions.

In **Ireland**, the government has outlined its climate commitments in the **Climate Action Plan 2024**, targeting a 51% reduction in greenhouse gas emissions by 2030 and achieving net-zero emissions by 2050. **The Bioeconomy Action Plan** and **the National Biomethane Strategy** recognise biomethane's role in meeting renewable energy targets, decarbonising agriculture, and supporting a sustainable energy transition. Biomethane offers opportunities for rural development, biodiversity enhancement, and sustainable land use, aligning with Ireland's broader bioeconomy ambitions.

At the **regional level**, **Tipperary** stands at the forefront of Ireland's renewable energy efforts, supported by initiatives like the **Tipperary Local Authority Climate Action Plan 2024 - 2029** and the establishment of **Decarbonising Zones (DZs)**. These zones focus on reducing emissions at the community level, fostering local engagement, and showcasing innovative energy solutions. Tipperary's **National Bioeconomy Campus**, located at Lisheen, is a hub for research, innovation, and commercialisation in the bioeconomy and biomethane sectors. It exemplifies how local and national efforts can converge to create a sustainable and resilient future.

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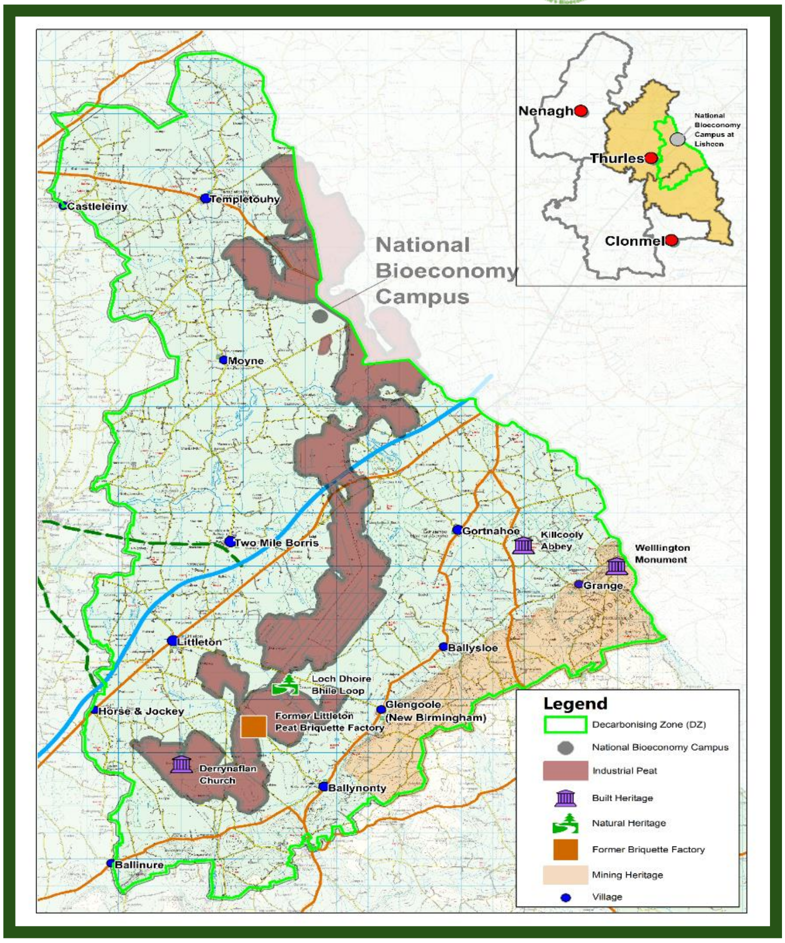

Figure 2: Tipperary Decarbonising Zone

The **BCC project** integrates these global, European, and national priorities to deliver tangible outcomes for the JTF region and beyond. By conducting a **feasibility study** on biomethane development, the project identifies resources such as agricultural slurry and organic waste and assesses applications such as gas injection and direct supply. Through **capacity-building campaigns**, it raises awareness among communities, farmers, and other stakeholders, enabling widespread participation in the biomethane economy. Collaborative efforts with farming stakeholders promote sustainable agricultural practices that balance biodiversity and energy production, while community and cooperative models foster inclusivity and shared ownership.

By situating its objectives within these broader frameworks, the BCC project not only contributes to Ireland's climate goals but also sets a replicable model for other regions. Its integration with the **National Bioeconomy Campus** and alignment with the **Tipperary DZ** ensures that it serves as a pivotal step toward a greener, more sustainable Ireland, while reinforcing global commitments to combat climate change.

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Acknowledgment

We would like to express our gratitude to everyone who contributed to the finalisation of these 'Planning, Permitting and Policy Guidelines' for Biomethane as part of the Biomethane for Carbon and Community (BCC) project. This document showcases the collaborative efforts of all stakeholders dedicated to achieving the objectives of the Biomethane Development Office..

We would like to express our gratitude to the Government of Ireland and the European Union (EU) for their support, particularly through the EU Just Transition Fund (JTF), which has funded the BCC project. We also thank the Eastern and Midland Regional Assembly and Pobal for their strategic guidance in achieving our objectives and ensuring effective reporting for the BCC project.

We would like to express our gratitude to the Advisory Board Members, whose strategic oversight and expertise have been crucial to the success of the BCC project. The members of the board include.

- Matthew Halpin, Assistant Agricultural Inspector at Department of Agriculture, Food and the Marine (DAFM);
- Sean Finan, CEO of Irish BioEnergy Association (IrBEA);
- John Brosnan, Bioeconomy Executive at Irish Co-operative Organisation Society (ICOS);
- Anne Marie Henihan, Centre Director at Dairy Processing Technology Centre (DPTC);
- James Claffey, Deputy CEO at Irish Rural Link (IRL);
- Barry Caslin, Energy & Rural Development Specialist at Teagasc.

We recognize and appreciate the significant contributions of the BCC project partners—Tipperary County Council (Michael Moroney, Clare Lee, Elaine Cullinan, and the entire TCC team), the Technological University of the Shannon (Seamus Hoyne, Mercedes Alonso-Gomez, Deirbhile Tuohy and Yvonne Doyle and the entire Sustainable Development Research Institute SDRI team), the Irish Bioeconomy Foundation (Stephen Napier, Gearoid McDermott, Sean O'Grady, Naveen Kumar and the entire IBF team) and the Tipperary Energy Agency (Lisa Vaughan, Mary Buckley and the entire TEA team)— whose expertise, insights and commitment to innovation have been essential to our success. The collaborative efforts of local communities, farming stakeholders and industry representatives have also played a crucial role in shaping a project that is inclusive, impactful and of great significance to the region. We proudly extend our sincere appreciation to the dedicated team members of the BDO for their commitment to advancing the objectives of the BCC project.

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Table of Abbreviations

- AD – Anaerobic Digestion
- BDO – Biomethane Development Office
- CHP – Combined Heat and Power
- CPD – Continuous Professional Development
- CRU – Commission for Regulation of Utilities
- DAERA – Department of Agriculture, Environment & Rural Affairs
- DAFM – Department of Agriculture, Food & the Marine
- DZ – Decarbonising Zone
- EBA – European Biogas Association
- EPA – Environmental Protection Agency
- ERDF – European Regional Development Fund
- EU – European Union
- GHG – Greenhouse Gas
- GNI – Gas Networks Ireland
- ICCT – International Council on Clean Transportation
- IEA – International Energy Agency
- IED – Industrial Emissions Directive
- KPI – Key Performance Indicator
- LCA – Life-Cycle Assessment
- LPC – Leaf Protein Concentrate
- OFMSW – Organic Fraction of Municipal Solid Waste
- PFAS – Per- and Polyfluoroalkyl Substances
- RIV – Regional Innovation Valley
- SEAI – Sustainable Energy Authority of Ireland
- SME – Small and Medium-sized Enterprise
- TUS – Technological University of the Shannon
- VS – Volatile Solids
- WBA – World Biogas Association

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Abstract

This review explores the integration of biomethane into a circular bioeconomy framework, highlighting its potential as a complementary energy source within holistic multi-product value chains, rather than as a standalone solution. Biomethane can contribute most effectively to a wider circular bioeconomy in Ireland, with integration assessed through greenhouse gas performance, nutrient recovery, economic value creation, system resilience, and regional development potential. It contains a synthesis of recent European Union and Government of Ireland policy developments, technical literature, and case studies to assess opportunities, constraints and practical next steps.

Technical evidence indicates that integrating green biorefinery steps with anaerobic digestion improves both climate and economic performance. However, green biorefineries are only one part of a broader bioeconomy landscape. Other configurations—including fermentation-based biorefineries, nutrient recovery systems, thermochemical routes such as pyrolysis and gasification, and biochar-linked models—can also integrate with biomethane to create multi-product value chains that combine renewable gas, bio-based materials, circular fertilisers, and carbon-rich soil amendments (with the help of efficient-grade biochars).

Recent studies indicate that integrated systems combining protein extraction, anaerobic digestion, nutrient recovery and bio-based co-products can improve resource efficiency and reduce lifecycle emissions relative to single-output energy systems, although economic outcomes remain site- and market-dependent. For example, Protein extraction from fresh grass, followed by the digestion of the cellulose-rich press-cake with cattle slurry, closes nutrient loops and maintains feed value while supplying dispatchable renewable gas. Across related studies, typical biomethane pathways deliver 80–100% greenhouse gas (GHG) savings compared with fossil gas, while manure-rich fertiliser blends can achieve net-negative results when avoided slurry methane, fertiliser substitution, and soil carbon gains are accounted for. The Danish and German experiences demonstrate how policy certainty, cooperative feedstock mobilisation and grid access can scale deployment quickly without compromising food systems.

Enabling conditions in Ireland are improving, but not yet entirely in place. Key bottlenecks include:

- high and variable costs for grid connection, which remain project-specific and can materially affect bankability; absence of final digestate/biofertiliser end-of-waste clarity, including treatment of pathogens, PFAS and nutrient products; and the need for stronger operator competence, project development support and delivery capacity.
- The significance of contaminants such as PFAS may vary by feedstock type and may be more pronounced in mixed-waste systems than in agri-only plants; however, regulatory clarity and appropriate monitoring remain important for market confidence and safe land application, the need for operator competence and project development capacity.

Regional initiatives—most notably the establishment of the National Bioeconomy Campus and Biomethane Development Office at Lisheen, located within the Tipperary Decarbonising Zone (DZ)—illustrate how clustered infrastructure and stakeholder collaboration, involving the Local Authority, Industry and Research Institutions and industry partners, can support and accelerate first-wave projects.

This review suggests that Ireland can significantly increase biomethane output and establish a credible export-aligned renewables sector if biomethane is embedded within farmer-led, residue-based bioeconomy networks. Priorities are finalising digestate standards, reducing connection costs, sequencing grid injection with offtake under the Renewable Heat Obligation and scaling skills and finance. This review provides an evidence-based sequence of actions for government and industry to deliver residue-first biomethane within a circular bioeconomy by 2030, while protecting water quality, soil health and biodiversity. With community engagement and participation at its core, public confidence seems achievable.

1. Introduction

Climate change represents one of the most pressing global challenges of the 21st century, driven by the increasing atmospheric concentrations of greenhouse gases (GHGs) resulting from human activities[1]. The build-up of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) is altering climate systems, with consequences for ecosystems, economies, and communities. While energy and transport have historically accounted for a large share of GHG emissions, agriculture remains vital to both national and local economies and is a significant source of GHG emissions. Methane production from ruminants and manure management are substantial sources of CH_4, and fertiliser use contributes to N_2O emissions.

In Ireland, the agricultural sector contributes approximately one-third of national GHG emissions, reflecting the country’s grass-based livestock systems and the critical role of the agri-food sector's within the economy. Delivering legally binding climate targets requires credible, sector-appropriate pathways that reduce emissions while maintaining food security and rural livelihoods[2]. This underlines the importance of credible mitigation pathways that work within Ireland’s livestock-based agricultural system while maintaining food production and rural livelihoods.

[1] *IPCC (2021). Sixth Assessment Report: The Physical Science Basis.*
[2] *EPA (2024). Ireland’s National Inventory Report 2024. Environmental Protection Agency, Wexford.*

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Recent national data and policy targets further reinforce the scale of this challenge and the role of biomethane in the solution[3]. According to the Environmental Protection Agency, Ireland's total greenhouse gas emissions have been approximately 55–57 $MtCO_2eq$ in recent years, with agriculture consistently accounting for around 37–38% of the total, making it the largest-emitting sector. Under the Climate Action Plan 2024 and associated sectoral emissions ceilings, agriculture is required to deliver a 25% reduction in emissions by 2030 relative to 2018 levels. Within this framework, renewable gas is identified as an important mitigation pathway. National policy, through the National Biomethane Strategy and wider climate policy, targets the development of up to 5.7 TWh of indigenous biomethane production by 2030, primarily from agricultural residues such as slurry and grass silage. This level of deployment is expected to contribute to emissions reduction—particularly through methane capture from manure management and displacement of fossil natural gas—while also supporting energy security and rural economic activity. However, delivery at this scale will depend on parallel progress in infrastructure, regulation, and project development capacity.

A circular bioeconomy approach supports this dual objective by treating biological resources and by-products as inputs for new value chains. In this framing, agricultural residues, manures and food waste are not waste but bioresources for producing energy, materials and chemicals. Bio-based technologies can therefore reduce emissions, displace fossil resources and create diversified income streams. Among these technologies, anaerobic digestion (AD) is one of the most established and immediately deployable options[4].

Anaerobic Digestion (AD) is a controlled, oxygen-free biological process in which microorganisms convert organic materials such as slurry, crop residues, the organic fraction of municipal waste, and sewage sludge into biogas and digestate**.** Biogas generally comprises 50–70% methane (CH_4) and 30–45% carbon dioxide (CO_2)**,** along with trace amounts of gases**,** such as nitrogen, hydrogen, and oxygen[5].

Biomethane is produced by upgrading biogas to remove CO_2, moisture and trace compounds. Biomethane is a renewable gas with the same functional properties as fossil natural gas. This equivalence is essential for near-term decarbonisation because biomethane can utilise existing infrastructure: it can be injected into the gas grid, subject to standards and metering, used in compatible boilers, engines, and turbines, and compressed or liquefied for transport applications. Unlike variable renewables, biomethane is storable and dispatchable, providing system flexibility as electricity generation increasingly relies on wind and solar[6].

[3] https://www.gasnetworks.ie/about/regulation/renewable-gas-policy/ireland
[4] *European Commission (2018). EU Bioeconomy Strategy – A Sustainable Bioeconomy for Europe.*
[5] *IEA Bioenergy (2021). Anaerobic Digestion: Technology Review and Greenhouse Gas Impacts.*
[6] *European Biogas Association (EBA) & Guidehouse (2023). European Biomethane Market Outlook.*

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Digestate is the residue left over after the biogas/biomethane is produced from feedstock. This residue is nutrient-rich, containing nitrogen, phosphorus, potassium and organic matter. When managed in accordance with regulatory standards and best practice, digestate can be used as an organic fertiliser, replacing a portion of synthetic fertilisers to support plant growth. At the same time, capturing methane from manure and other high-moisture substrates prevents uncontrolled emissions that would otherwise occur during storage or disposal. It also has an important nutrient management function, with potential to recycle nitrogen, phosphorus and potassium more efficiently within farming systems and reduce dependence on imported mineral fertilisers were applied under appropriate standards and controls

Life-cycle assessments consistently report substantial GHG savings for residue-based biomethane pathways relative to fossil gas[7]. Unless otherwise stated, cited GHG values should be interpreted within the stated system boundary (e.g., well-to-gate or cradle-to-grave), and compared against the RED III fossil natural gas comparator. The choice of system boundary has a significant influence on reported greenhouse gas performance and should be clearly understood when interpreting results. A **well-to-gate** boundary typically includes emissions associated with feedstock production, transport, processing and upgrading up to the point where biomethane is ready for injection or use, but excludes downstream use-phase emissions. In contrast, a **cradle-to-grave** boundary encompasses the full life cycle, including end-use combustion and avoided emissions, such as methane capture from manure storage or the displacement of synthetic fertilisers through digestate use. Under the Renewable Energy Directive (RED III), standardised lifecycle methodologies and fossil-fuel comparators are used to ensure consistency across renewable fuels. As a result, reported GHG savings can vary significantly depending on whether avoided emissions and co-product credits are included; manure-based systems may show substantially higher (and, in some cases, net-negative) savings under cradle-to-grave accounting than under more limited system boundaries.

In manure-dominant systems, total system effects can be net-negative when fertiliser substitution and soil carbon changes are fully accounted for. Real-world performance remains contingent upon the feedstock mix, plant design, operational practices, and compliance with environmental safeguards[8].

The role of AD is strengthened when situated within an integrated circular bioeconomy. In such systems, cascading use is applied: biomass is directed first to higher-value applications (food, feed, biobased chemicals and materials), with residual fractions then recovered for bioenergy.

[7] *Teagasc (2023). Life Cycle Assessment of Biomethane Pathways in Ireland.*
[8] *European Biogas Association (EBA) & Guidehouse (2023). European Biomethane Market Outlook.*

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Emerging green biorefinery models reflect this sequence. For example, proteins and other soluble components can be extracted from fresh grass, while the cellulose-rich press cake can serve as a suitable substrate for AD. This integration helps maximise value per tonne of biomass, reduce reliance on imported feed proteins, and close nutrient loops at both farm and regional scales.

Ireland's policy context is increasingly aligned with this approach. National strategies recognise residue-first pathways for biomethane development, the importance of circular value chains, and the need to protect water quality and soils through appropriate regulation of feedstocks and digestate[9]. Regional initiatives—such as locating the National Bioeconomy Campus at the site of the former Lisheen mine in Co. Tipperary and creating dedicated project development support illustrate how infrastructure, skills, and clustering can accelerate deployment while supporting Just Transition objectives in the Midlands. These developments are consistent with the broader European Green Deal, and its Just Transition Mechanism[10] and the REPowerEU policy[11]. These policies aim to accelerate the deployment of clean energy and enhance energy security, and the EU Bioeconomy Strategy, which promotes rural, bio-based innovation in line with cohesion objectives[12].

In summary, biomethane offers a practical means to reduce agricultural and waste-related emissions, enhance energy system flexibility, and support rural economies. Realising this potential requires delivery models that are circular by design, prioritising higher-value products where feasible, utilising residual streams for energy, recycling nutrients responsibly, and operating to robust environmental standards[13]. The remainder of this document examines (i) the technical and environmental performance of AD and biomethane within integrated bioeconomy systems, (ii) the evolving European and national policy frameworks, and (iii) regional implementation pathways that can scale deployment in a manner consistent with climate, environmental and economic objectives.

[9] *Government of Ireland (2024). National Biomethane Strategy.*
[10] *Just Transition Mechanism (2020). European Commission – Regulation (EU) 2021/1056.*
[11] *REPowerEU (2022). EU Plan to Reduce Dependence on Russian Fossil Fuels. European Commission*
[12] *Bioeconomy Action Plan (2023–2025). Department of Agriculture, Food and the Marine; Department of the Environment, Climate and Communications.*
[13] *European Commission (2018). EU Bioeconomy Strategy – A Sustainable Bioeconomy for Europe.*

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Scope and method. This report synthesises peer-reviewed studies, EU[14,15] and national policy documents, and Irish case studies. The report includes GHG results[16] relative to the RED III fossil natural gas comparator[17] where available and specify boundaries (e.g., well-to-gate), where figures are modelled rather than measured[18,19].

While the current analysis is national in scope, regional examples—particularly from Tipperary and the Midlands—are used to illustrate how integrated biomethane and bioeconomy systems may be delivered in practice. These should be interpreted as illustrative case studies rather than exclusive or prescriptive models.

This report is intended primarily for policymakers, regulators, project developers and regional stakeholders involved in the delivery of Ireland's biomethane and bioeconomy ambitions. Its purpose is to inform both policy development and practical implementation by synthesising technical evidence, policy frameworks and emerging delivery models. While it highlights best practice and international experience, the report is also designed to support near-term decision-making and project development in the Irish context.

[14] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652

[15] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001

[16] https://www.cscses.com/uploads/2016328/20160328110518251825.pdf

[17] https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

[18] https://www.ieabioenergy.com/wp-content/uploads/2022/12/2022_12_12-IEA_Bioenergy_position-paper_Final2.pdf

[19] https://www.europeanbiogas.eu/wp-content/uploads/2023/12/EBA-Statistical-Report-2023-Excerpt.pdf

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1.1 Anaerobic Digestion

Anaerobic digestion (AD) is a biological process in which microorganisms decompose organic matter such as slurry, crop residues, municipal biowaste, or sewage sludge in the absence of oxygen. The process takes place in sealed tanks in a controlled environment that ensures optimal temperature, pH, and retention time[20].

The outputs of AD are twofold:

- **Biogas**, a mixture of methane (CH_4), carbon dioxide (CO_2), and trace gases, which can be used directly for heat and electricity generation or upgraded to biomethane.
- **Digestate**, a nutrient-rich slurry containing nitrogen (N), phosphorus (P), potassium (K), and organic matter, which can be returned to soils as a fertiliser substitute.

In addition to generating renewable energy, AD reduces uncontrolled methane emissions from slurry storage, diverts organic wastes from landfill, and supports circular nutrient management.

For AD plants processing more than 100 tonnes per day of waste, facilities in the Republic of Ireland are required to hold an IED licence; smaller agri-led plants must still meet EPA permitting and Nitrates Programme obligations (see Section 3.2). In practice, regulatory requirements differ between larger waste-processing facilities and smaller agri-led plants, and this distinction is important for the feasibility of farm-scale and cooperative deployment models.

In the Irish context, AD regulation is differentiated by plant scale, feedstock classification, and environmental risk profile. Facilities processing more than 100 tonnes of waste per day are generally subject to EPA licensing under the Industrial Emissions Directive, reflecting the higher regulatory scrutiny required for larger and more complex waste-handling operations. Smaller agricultural AD systems, especially those using slurry, manure and related agricultural residues, may proceed under less intensive regulatory pathways, but they must still comply with planning requirements, relevant animal by-products rules, water-protection measures and the Nitrates Action Programme in relation to digestate storage and land application. As a result, smaller agri-led plants may benefit from a comparatively more proportionate regulatory route than large waste-processing installations, which is important for the feasibility of farm-scale and cooperative deployment models. However, this should not be understood as a fully streamlined approval framework: Ireland still lacks a dedicated, standardised permitting pathway for small-scale AD, and uncertainty around digestate end-

[20] *https://www.ieabioenergy.com/wp-content/uploads/2022/10/Task-37-End-of-Triennium-report-2019-2021.pdf*

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of-waste status, along with case-by-case regulatory interpretation, remains a material constraint on project delivery and bankability.

1.2 Biogas

Biogas is the gaseous product of anaerobic digestion. Its typical composition is 50–70% methane, 30–45% carbon dioxide, and small amounts of hydrogen sulphide, water vapour, siloxanes, and other trace elements. Depending on feedstock and process design, biogas can be used in different ways[21, 22]:

- **Raw biogas**: combusted in combined heat and power (CHP) engines for electricity and heat.
- **Upgraded biogas (biomethane):** purified to ≥97% CH_4 and injected to the gas grid or used as a vehicle fuel, subject to metering, gas quality, and certification requirements[23].
- **Biogenic CO_2**: captured during upgrading and reused in horticulture, food processing, or synthetic fuel production.
- **Grid flexibility:** because it is storable and dispatchable, biomethane complements variable wind/solar and supports security of supply[24].

By upgrading biogas to biomethane, a versatile, pipeline-quality renewable gas is obtained that can be seamlessly integrated into existing energy infrastructure.

1.3 Biomethane

Biomethane is a renewable, clean methane gas that is chemically identical to fossil natural gas. It is produced by biogas upgrading from anaerobic digestion of organic wastes or by methanation of the carbon-rich and hydrogen-rich syngas generated in biomass gasifiers[25]. The methanation or upgrading process removes a significant amount of water, hydrogen sulphide, carbon dioxide, siloxanes, and other trace compounds to produce a product that is typically more than 97% CH_4 and meets pipeline-quality calorific value and Wobbe index specifications. Ease of integration is one of the most advantageous aspects of biomethane. Its molecular makeup is identical to that of conventional natural gas. Biomethane can be used

[21] *IEA Bioenergy Task 37 (2021). Anaerobic Digestion – Technology Review.*
[22] *https://www.europeanbiogas.eu/wp-content/uploads/2023/12/EBA-Statistical-Report-2023-Excerpt.pdf*
[23] *https://www.europeanbiogas.eu/news/biomethane-standards-facilitating-renewable-gas-uptake/*
[24] *https://www.seai.ie/sites/default/files/publications/Energy-in-Ireland-2023.pdf*
[25] *https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomethane_en*

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interchangeably in current gas networks, stored in subsurface reservoirs, combusted in boilers, turbines and engines, or compressed/liquified for use as a fuel for transport[26].

The life-cycle footprint of biomethane can be very low, and in manure-rich systems, it can be net-negative because avoided slurry CH_4 and fertiliser displacement credits exceed process emissions[27]. Accordingly, it is a leading contender for decarbonising challenging-to-electrify uses, such as high-temperature industrial heat, backup power generation, and heavy long-distance haul. Where biogenic CO_2 from upgrading is reused (e.g., food-grade, horticulture, e-fuels), additional system benefits may accrue within the declared LCA boundary[28].

1.4 Circular Bioeconomy

The bioeconomy is the part of the economy which uses renewable resources from agriculture, forestry and the marine to produce food, feed, materials and energy, while reducing waste, in support of achieving a sustainable and climate neutral society[29]. Biogas and biomethane are integral components of the circular bioeconomy, where biological resources are used efficiently across multiple value streams. In this model, biomass is directed first toward its highest-value uses—such as food, feed, biobased chemicals and materials—before residual fractions are recovered for energy. This approach, known as the cascading principle, maximises resource efficiency, reduces waste, and strengthens rural value chains.

When applied to biomethane systems, the circular bioeconomy provides a range of environmental, social and economic benefits . In Ireland, these principles are reflected in initiatives such as Biorefinery Glas, Farm Zero C and regional demonstration activity around nutrient recovery, grass valorisation and integrated farming systems (projects discussed in Annex).

- **Nutrient recycling**: Digestate returns nitrogen, phosphorus, potassium, and organic carbon to soils, reducing reliance on synthetic fertilisers[30].
- **Emission avoidance**: Manure, sewage sludge, and food waste are diverted from uncontrolled storage or landfill, preventing methane release[31, 32].
- **Storable renewable energy**: Biomethane complements intermittent renewables such as wind and solar, providing dispatchable green gas for heat, power, and transport.

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[26] *https://www.europeanbiogas.eu/wp-content/uploads/2024/02/Greening-Gas-Grids-Navigating-Biomethane-Grid-connection-FINAL.pdf*
[27] *https://www.iea.org/reports/net-zero-by-2050*
[28] *https://teagasc.ie/wp-content/uploads/media/website/publications/2024/Research-Impacts-in-2023.pdf*
[29] *https://knowledge4policy.ec.europa.eu/publication/updated-bioeconomy-strategy-2018_en*
[30] https://www.epa.ie/publications/research/waste/Research_Report_375.pdf
[31] *https://www.epa.ie/publications/research/waste/Research_Report-432.pdf*
[32] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52019DC0640*

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- **Biogenic CO_2 recovery**: Upgrading produces high-purity CO_2 that can be used for e-fuels, horticulture, and food-grade applications[33].

Life-cycle assessments confirm substantial climate benefits; typical biomethane pathways achieve 80–100% GHG savings relative to fossil natural gas[34,35]. When manure-rich feedstocks are used, savings can exceed 100%, indicating a net-negative footprint. This occurs because avoided slurry methane emissions, reduced synthetic fertiliser production, and soil carbon improvements offset more emissions than the system generates. For clarity, we use the cascading order: Food/Feed → Materials/Chemicals → Energy → Soil, unless a higher-value route is not technically or economically feasible[36].

1.4.1 Cascading use

The concept of cascading use aims to increase biomass utilisation by reusing, recycling and finally for energy production at the end of the lifecycle. This aims to get the most value from the biomass. The National Bioeconomy Action Plan (2023–2025)[37] and the National Biomethane Strategy (2024) recognises and encourages the cascading use of biomethane[38]. These policies emphasise residue-first deployment and prioritising higher-value uses of biomass before energy recovery[39]. Implementation occurs through project design, regulation and market instruments, not the strategies alone[40].

- **Food & feed** — Extract proteins and digestible fibres first (e.g., from grass juice or side streams) to displace imported soymeal, with associated land-use and deforestation-avoidance benefits.
- **Materials & chemicals** — Channel remaining carbohydrates and lignocellulosic fractions into fermentation or polymerisation routes, extending carbon residence in long-lived products such as bioplastics.
- **Energy/fuels** — Direct low-value or mixed residuals (press cake, slurry, sewage sludge, food waste) to anaerobic digestion or gasification for biogas/biomethane production.

[33] *https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomethane_en*
[34] *https://www.sciencedirect.com/science/article/pii/S0959652624033857*
[35] *https://guidehouse.com/-/media/new-library/services/sustainability/documents/2024/biogases-towards-2040-and-beyond.ashx*
[36] *https://www.ieabioenergy.com/wp-content/uploads/2021/10/Mubareka_Giuntoli_Grassi.pdf*
[37] *https://assets.gov.ie/static/documents/bioeconomy-action-plan-2023-2025.pdf*
[38] *https://www.gov.ie/en/department-of-climate-energy-and-the-environment/publications/national-biomethane-strategy/*
[39] https://knowledge4policy.ec.europa.eu/publication/updated-bioeconomy-strategy-2018_en
[40] *https://www.ieabioenergy.com/wp-content/uploads/2021/10/Mubareka_Giuntoli_Grassi.pdf*

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- **Soil amendment** — Return mineral nutrients and stable carbon to land via compliant digestate or biochar, closing nutrient loops and rebuilding soil organic matter.

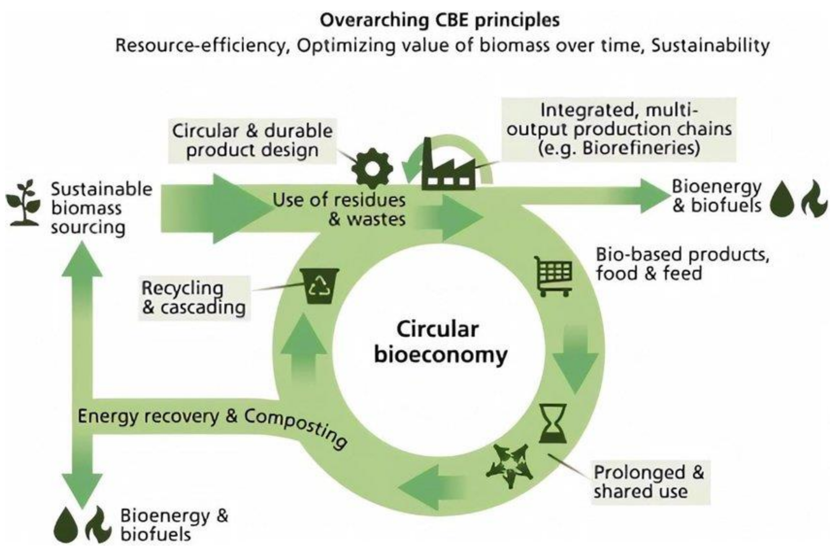

Figure 1: Integrated principles of circular bioeconomy[41]

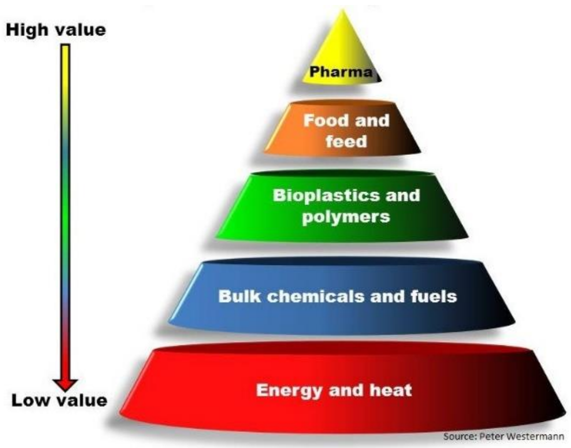

Figure 2: The Biomass Value Pyramid[42]

[41] https://www.researchgate.net/publication/359543043_Application_of_biological_systems_and_processes_employing_microbes_and_algae_to_Reduce_Recycle_Reuse_3Rs_for_the_sustainability_of_circular_bioeconomy

[42] https://www.researchgate.net/figure/The-Biomass-Value-Pyramid-shows-the-entire-cascade-of-value-adding-products-which-can-be_fig1_233424554

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1.5 Green Biorefinery

Green biorefineries are an important example of how biomethane can be integrated into a wider circular bioeconomy, alongside other models, including nutrient recovery, fermentation-based biorefineries, residue valorisation, and biochar-linked systems. A green biorefinery is a processing concept that converts freshly harvested green biomass—such as grass, clover, alfalfa, or leafy crops—into a variety of high-value products through gentle, low-energy fractionation, instead of using the biomass solely for animal feed or energy[43].

This method separates it into different streams, including protein-rich juice, fibrous press cake, and nutrient liquids, each with its own potential valorisation pathway[44]. From these streams, it is possible to produce animal feed proteins, amino acids, organic acids, fibres, biogas, fertilisers, and even bio-based chemicals and materials.

The benefits of green biorefineries:

1. enables efficient nutrient recovery in forms that are directly marketable for feed and food, preserving protein quality while reducing reliance on imported soy.
2. provides a cascading use of biomass—where high-value nutrients are captured first, followed by the utilisation of residuals (such as cellulose-rich fibres) for energy recovery through anaerobic digestion or further refining processes.
3. reduces emissions from silage storage, contributing to climate mitigation, while also promoting rural diversification by creating new income streams for farmers. Overall, green biorefineries are acknowledged as a cornerstone of the circular bioeconomy, linking sustainable agriculture with innovative bioproduct markets[45].

Green biorefineries rely on rapid, low-energy mechanical fractionation of fresh biomass (within 24 hours post-harvest), intentionally separating nutrient recovery from energy recovery[46]. The green biorefinery method produces two products: juice and press cake. The juice offers the greatest opportunity for producing value-added bioproducts, and the press cake is used as animal fodder or as feedstock for anaerobic digestion. Immediate pressing minimises proteolysis, thereby preserving the amino acid profile for feed markets and avoiding emissions associated with ensiling. The residual press cake retains a cellulose-rich structure, making it ideal for biomethanation. However, the economic viability of green biorefinery systems in Ireland remains dependent on scale, market value for protein and fibre co-products, logistics, the maturity of downstream AD infrastructure, and the availability of

[43] Xiu, Shuangning & Shahbazi, Ghasem. (2015). Development of Green Biorefinery for Biomass Utilization: A Review. Trends in Renewable Energy. 1. 4-15. 10.17737/tre.2015.1.1.008.
[44] https://www.sciencedirect.com/science/article/pii/S0734975023000757
[45] linkinghub.elsevier.com/retrieve/pii/S0960852409006300
[46] linkinghub.elsevier.com/retrieve/pii/S1364032120303208

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supportive policy and financing conditions. In this respect, Ireland remains at an earlier stage than Denmark and Germany

Press Cake

The press cake fraction can be valorised in several ways. Its primary outlet is as a ruminant feed ingredient (fresh or silage), utilising its adequate fibre, residual protein, and minerals[47]. Where feed markets are saturated or where further valorisation is desired, press cake can be directed to anaerobic digestion to produce biogas/biomethane. Depending on the grass or crop used, press cake can also be processed into fibre-based products (such as mulch/fibre mats, packaging fibre, or compost blends). Or used as a component in organic fertilisers after sterilisation, to keep the structural carbohydrates remains in this fraction, it is also suitable as a co-substrate in farm- or community-scale AD plants[48].

Juice

The juice stream is the high-value fraction and should be prioritised in a cascading approach. It contains soluble proteins, amino acids, sugars, minerals, and bioactive compounds. The primary bioproduct is leaf protein concentrate (LPC), produced by coagulating and separating the protein, which can be used in monogastric feed, aquaculture feed, or—after further safety and quality validation of proteins. After protein extraction, the remaining 'brown juice' can be fermented to produce organic acids (e.g., lactic acid), ethanol, or other biobased chemicals, or it can serve as nutrient-rich process water for microalgae or yeast cultivation. The mineral-rich liquid phase can be concentrated and applied back to land as a biobased fertiliser, closing nutrient loops[49].

Following the cascading principles approach, biogas (including biomethane) should be produced last, as it is typically the least valuable bioproduct pathway. Energy recovery should therefore only occur after higher-value options—such as protein extraction, feed ingredients, fermentation products, and biofertilizer recovery—have been realised, to ensure the maximum value is obtained from the green biomass feedstock[50.]

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[48] *https://www.europeanbiogas.eu/wp-content/uploads/2023/12/EBA-Statistical-Report-2023-Excerpt.pdf*
[49] *https://teagasc.ie/news--events/news/building-trust-and-fairness-new-research-highlights-pathways-to-successful-bioeconomy-development-in-ireland/*
[50] *https://www.sciencedirect.com/science/article/abs/pii/S095965262035109X*

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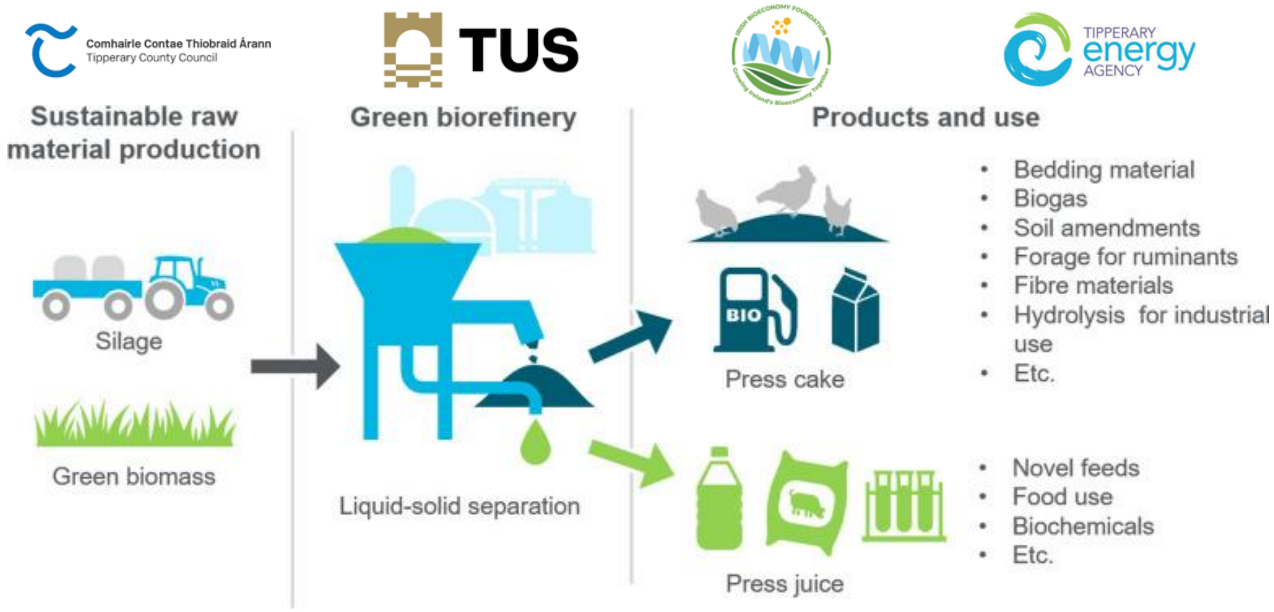

***Figure 3: Green Biorefinery approach*[51]**

Sustainability of Green Biorefinery

A recent LCA by Teagasc (methodology aligned with the SEAI National Heat Study) for the co-digestion of grass press-cake and cattle slurry reported 10.7 g CO_2-eq MJ^{-1} of biomethane[52]. Against the RED III fossil natural gas comparator (183 g CO_2-eq MJ^{-1}), this equates to ~94% savings, exceeding the ≥80% threshold from 2026[53].

Additionally, farm-gate nutrient audits from the Biorefinery Glas pilot project[54] revealed that integrating protein extraction with slurry co-digestion yields approximately 35kg of marketable protein for every kilogram of reactive nitrogen applied. This represents a 40% improvement in nitrogen use efficiency at the land level compared to traditional grass-silage systems.

The Environmental Protection Agency (EPA) Ireland has recognised the climate advantages of this approach. Still, it emphasises the need to address unresolved concerns regarding pathogens, PFAS, and other contaminants present in digestate. The significance of contaminants such as PFAS may vary by feedstock type and may be more pronounced in mixed-waste systems than in agri-only plants; however, regulatory clarity and appropriate monitoring remain important for market confidence and safe land application. In its submission regarding the draft National Biomethane Strategy in March 2024, the EPA

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[51] *https://pmc.ncbi.nlm.nih.gov/articles/PMC10913225/*
[52] *https://teagasc.ie/wp-content/uploads/media/website/publications/2024/Research-Impacts-in-2023.pdf*
[53] *https://www.seai.ie/sites/default/files/publications/National-Heat-Study-Summary-Report.pdf*
[54] *https://teagasc.ie/wp-content/uploads/media/website/publications/2021/Biorefinery-Glas.pdf*

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advocated for statutory safeguards before large-scale land-spreading can take place[55]. Until end-of-waste criteria are finalised, digestate markets remain conditional on meeting pathogen, PFAS, and micro-contaminant limits, as well as ensuring traceability under the Nitrates Programme[56].

To address these regulatory concerns, the EU Biomethane Action Plan commits[57] to establish a streamlined by-product and end-of-waste pathway that will allow compliant digestate to be used as fertiliser across the single market. This development is crucial for the success of multi-product bio-systems like Biorefinery Glas, where nutrient recycling is a central aspect of the business model[58]. Developments around RENURE and wider biofertiliser regulation could be particularly important for Ireland, as they may improve the marketability of nutrient products derived from anaerobic digestion and strengthen the business case for integrated biomethane systems

1.2 Integrated Bioeconomy Pathways beyond Green Biorefinery

While green biorefineries provide a clear demonstration of cascading use in practice, they represent only one configuration within a wider set of bioeconomy pathways that can integrate with biomethane. In parallel, fermentation-based biorefineries, thermochemical conversion routes and advanced nutrient recovery systems have emerged as complementary models that can utilise feedstocks, infrastructure and expertise of different actors with anaerobic digestion. Together, these pathways expand the range of products that can be generated from Irish biomass and residues, while maintaining a residue-first, circular approach.

Fermentation and biotech platforms

Fermentation can convert sugar- and protein-rich side streams—such as grass juice, food processing residues, or brown juice from green biorefineries—into organic acids, ethanol, bioplastic precursors, or microbial protein. Residual process streams that are no longer suitable for higher-value products can then complement efficient AD systems, ensuring that energy recovery remains the key step in a cascading sequence rather than the primary goal/objective.

Thermochemical biorefineries,

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[55] *https://www.epa.ie/publications/corporate/submissions--observations/epa-submission-on-draft-national-biomethane-strategy.pdf*
[56] *https://eur-lex.europa.eu/eli/dir/2023/2413/oj*
[57] *https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230*
[58] *https://sword.mtu.ie/cgi/viewcontent.cgi?article=1803&context=allthe*

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Thermo-biorefineries, including gasification and pyrolysis, offer additional integration points with biomethane systems. Gasification produces a syngas that can be methanated to renewable methane, while pyrolysis yields biochar, bio-oil and syngas. Biochar can be combined with digestate to create enhanced fertiliser products with improved nutrient retention and soil carbon benefits, while syngas or biogenic CO_2 streams can potentially be linked to power-to-gas or e-fuels routes where required.

Nutrient recovery and Circular fertiliser systems

These are other critical interface technologies, such as ammonia stripping, struvite precipitation and digestate concentration, that can transform dilute nutrient streams into marketable fertiliser products, reducing dependence on imported mineral fertilisers and improving nutrient management at the catchment level. In integrated hubs, these systems can be co-located with AD plants, green biorefineries, and other bio-based processes, enabling shared use of storage, logistics, and quality control.

In practice, Ireland's bioeconomy is likely to evolve through regional cluster models that combine several of these pathways rather than through a single dominant model. In these models, biomethane provides dispatchable renewable energy and a sink for residual streams, while green biorefineries, fermentation platforms, thermochemical units and nutrient recovery technologies generate higher-value products and circular fertilisers. This multi-technology perspective is essential for designing resilient, farmer- and cooperative-led, and regionally appropriate bioeconomy approaches.

2 European Union Bioeconomy and Biomethane

Across Europe, the bioeconomy is emerging as a cornerstone of achieving climate neutrality, ensuring energy security, and promoting rural development. Countries in North-West Europe—including Denmark, Germany, and the Netherlands—have taken a leading role in demonstrating how biomethane and circular bioeconomy systems can scale at pace. Their success is underpinned by several common factors: high livestock density and abundant slurry and manure resources, strong agri-food sectors generating large volumes of residues, robust policy frameworks that incentivise renewable gas, and coordinated investment in infrastructure such as grid injection points and certification schemes. These countries have shown that when circular principles are embedded—such as cascading use of biomass, nutrient recycling, and integration with local industries—biomethane can deliver not only clean energy but also soil restoration, reduced fertiliser dependence, and diversified farmer incomes.

At the same time, differences in production systems matter: compared with Ireland, countries such as Denmark and Germany typically have more indoor-based livestock systems and more

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consistent year-round slurry collection, which can support anaerobic digestion at scale. For Ireland, these examples are particularly relevant as the feedstocks and demographics of Irish agriculture—grass-based dairy, cattle slurry, and rural farming communities—are closely comparable to those in Denmark and northern Germany. Yet while these countries have already developed thousands of anaerobic digestion plants and established biomethane as a mainstream energy vector, Ireland is still in the early stages of deployment. By learning from North-West Europe frontrunners, Ireland can accelerate its own transition, avoid past bottlenecks and tailoring proven models to local contexts. This includes adopting residue-led feedstock strategies, embedding biomethane within the broader bioeconomy, and aligning regional clusters with both EU and national policy frameworks.

2.1 EU Policy

A nested policy architecture now shapes biomethane deployment: EU-level targets define the ceiling, national energy strategies set the trajectory, and the new bioeconomy plan governs circularity and integration. Where EU targets are cited (e.g., 35 bcm by 2030 under REPowerEU), we treat them as strategic ceilings rather than guaranteed supply.

At the European level, biomethane has been elevated from a niche renewable option to a strategic pillar of energy security and decarbonisation. The turning point was the Russian gas crisis of 2022, when REPowerEU[59] positioned biomethane as a direct substitute for fossil natural gas. By doing so, the EU created a stronger political mandate and improved access to policy, innovation and demonstration support relevant to scale-up. Scientific and industry modelling confirms that biomethane can be delivered at scale from residues, wastes, and agricultural by-products without jeopardising food security (The Gas for Climate consortium projects)[60]. Between 2030 and 2050, Europe could sustainably mobilise between 41-151bn m^3 per year, mainly from residue-based anaerobic digestion. These volumes would account for a significant share of EU gas demand while meeting RED III sustainability criteria[61].

The EU policy framework also links biomethane with infrastructure modernisation. Projects of Common Interest (PCIs) under the TEN-E Regulation[62] now include gas grid upgrades, cross-border interconnections, and certification systems that will allow renewable gases to trade freely within the internal market. This provides Ireland with an opportunity to connect its domestic biomethane sector to wider EU decarbonisation pathways.

[59] *https://commission.europa.eu/topics/energy/repowereu_en*
[60] *https://gasforclimate2050.eu/wp-content/uploads/2023/12/Guidehouse_GfC_report_design_final_v3.pdf?*
[61] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023L2413*
[62] *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R0869*

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Key Points

- **Strategic target:** REPowerEU[63] sets a goal of 35 billion cubic meters of biomethane per year by 2030.
- **Sustainable potential:** Gas for Climate projects 41–151 bn m^3 by 2050, dominated by residues and waste-based AD.
- **Climate criteria:** RED III requires ≥80% GHG savings from 2026; biomethane pathways already exceed this.
- **Infrastructure:** TEN-E Regulation supports gas grid upgrades and certification for renewable gases.
- **Funding channels:** Funding channels such as Horizon Europe, CBE JU and the EU Innovation Fund can support research, demonstration and selected scale-up activities, though support for full commercial deployment remains more limited and project-specific.
- **Relevance for Ireland:** National target (5.7 TWh/y by 2030) contributes ~0.2% of the EU goal but positions Ireland to export renewable gas in the medium term.

For Ireland, further progress on certification and guarantees-of-origin alignment will be important to support market development and potential cross-border participation in renewable gas systems

2.1.2 Bioeconomy Synergies Initiative (BioSyn) Integration Dynamics

Bioeconomy Synergies Initiative (BioSyn) is a 2022–2024 research programme run under IEA Bioenergy Task 40. Its purpose is to shift the perspective on bioenergy projects from isolated, linear value chains to network-style bioeconomy systems in which biomass, bioenergy, biomaterials and nutrient services circulate between co-located plants. By mapping these exchanges and quantifying their economic and resilience benefits, BioSyn provides a

[63] *https://gasforclimate2050.eu/wp-content/uploads/2023/12/Guidehouse_GfC_report_design_final_v3.pdf?*

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framework for designing integrated campuses that maximise resource reuse, lower risk and cut greenhouse-gas emissions[64].

BioSyn moves beyond the classical "linear cascade" view of biorefineries and treats the plant as a **symbiotic network** in which the streams of mass, energy and carbon constantly circulate between unit operations. Value is therefore created not by any single step but by the quality of the exchanges that link them[65]. The campus-style integration examples are conceptual frameworks; site-specific feasibility and permitting still apply.

- **Resource exchange.** Products that would otherwise be side streams—such as the high-fibre grass press cake left after protein extraction—are deliberately specified as feedstock for the on-site anaerobic digester. This exchange turns a disposal cost into an energy-yielding revenue stream while closing the nutrient loop. In practice, such integration depends on value-sharing arrangements across the chain. For example, in grass-based systems, farmer participation may depend not only on payment for feedstock but also on whether part of the press cake, feed value, nutrient value or other co-products are returned to the farm

- **Flow-efficiency through co-location.** Locating upgrading, protein precipitation, and horticulture users on the same campus enables tight heat-and-carbon integration: the 40–60°C low-grade heat rejected from membrane or PSA upgrading can supply the evaporators that concentrate green-protein liquor, and the >98% pure biogenic CO_2 separated in the same step is piped directly to neighbouring greenhouse blocks[66],[67].

- **Economic resilience via diversification.** Whole-system modelling shows that a multi-product BioSyn campus (protein isolates, pipeline-grade biomethane, digestate pellets and bottled bio-CO_2) experiences ~20% lower revenue volatility over a ten-year horizon than a single-output biomethane plant, because adverse price swings in one market are damped by counter-cyclical income from the others[68]. Potential Irish-relevant value streams include biomethane, protein fractions, press cake for feed, digestate-derived biofertiliser products and, where regulation permits, RENURE-type nutrient outputs

- **Policy alignment.** The EU **Biomethane Action Plan** under the REPowerEU package commits, in its Actions 3.2.1–3.2.2, to (i) draft national valorisation roadmaps for bio-

[64] *https://www.ieabioenergy.com/wp-content/uploads/2025/03/IEA_Bioenergy-Task-40_Report_Synergies-for-bioenergy-supply-chains-in-bioeconomy-networks-1.pdf*
[65] *https://www.mdpi.com/2073-4360/17/12/1709*
[66] *https://www.sciencedirect.com/science/article/pii/S1364032121013034?*
[67] *https://bip-europe.eu/wp-content/uploads/2024/04/BIP_Task-Force-4.1_BioCO2-And-Biomethane_Apr2024.pdf*
[68] *https://www.europeanbiogas.eu/wp-content/uploads/2023/02/20230213_Guidehouse_EBA_Report.pdf*

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resources and (ii) streamline the by-product/end-of-waste assessment, removing a key regulatory hurdle for precisely this kind of industrial symbiosis[69].

Together, these integration dynamics push BioSyn from a collection of individual conversion steps to a resilient, circular-economy platform capable of maximising both financial returns and environmental performance. In Ireland, these principles are most visible in emerging cluster and hub concepts centred on co-location, shared infrastructure and integrated regional development.

In the Irish context, BioSyn should currently be understood primarily as a conceptual and analytical framework rather than a fully operational delivery model. While elements of these integration principles are emerging through cluster- and campus-based initiatives, large-scale commercial implementation remains in its early stages.

2.2 Denmark

Denmark is widely regarded as a European frontrunner in biomethane and circular bioeconomy, having integrated anaerobic digestion (AD) and green biorefinery concepts into mainstream agricultural and energy policy. The country's progress has been driven by strong state support, cooperative models, and a clear strategy to link farm residues, renewable energy production, and climate targets[70].

Since 2024, more than 50% of the gas in Denmark's national grid was renewable biomethane, with over 500 AD plants in operation. The policy trajectory aims for biomethane to cover most of the country's gas demand by 2030, subject to the delivery of support schemes and grid integration. This achievement is rooted in Denmark's agricultural profile characterised by high livestock density and abundant slurry resources combined with structured support schemes. Farmers are organised into cooperatives, ensuring steady feedstock supply chains and shared economic benefits[71].

Policy has been pivotal; feed-in tariffs, capital grants, and, most recently, a long-term subsidy framework for biomethane injection have given investors' confidence. The government's 2020 Climate Agreement and subsequent Green Gas Strategy enshrined biomethane as a central tool for meeting Denmark's legally binding 70% reduction target in greenhouse gas emissions by 2030. Importantly, Danish policy has also embedded the cascading use principle: priority is

[69] *https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX%3A52022SC023*
[70] *https://www.ieabioenergy.com/wp-content/uploads/2024/12/CountryReport2024_Denmark_final.pdf*
[71] *https://www.biogas.dk/wp-content/uploads/2024/05/Biogas-Outlook-2024-05-30-WEB-engelsk.pdf*

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given to food, feed, and material applications, while residual fractions such as slurry, manures, and food waste are directed to AD[72].

Beyond energy, Denmark has invested in green biorefinery pilots that valorise grass and clover into protein concentrates, fibres, and bio-based chemicals, with the residuals flowing to AD for biogas and nutrient recycling. These models mirror the Biorefinery Glas approach in Ireland, but on a larger and more advanced scale, demonstrating how grassland-rich regions can achieve multiple value streams from the same biomass.

For Ireland, Denmark serves as a clear reference point, sharing similar livestock systems, grass-based agriculture, and rural demographics, but with earlier policy alignment and infrastructure deployment. The Danish model shows that with coordinated incentives, cooperative feedstock mobilisation, and integration of bioeconomy principles, a rapid scale-up of biomethane is achievable without compromising food production or farm viability.

Implication for Ireland: Cooperative feedstock models and long-term injection support were decisive enablers; both are replicable.

2.3 Germany

Germany has established itself as a global leader in the bioeconomy, with a robust policy framework, substantial public and private investment, and extensive deployment of bio-based technologies. The country was among the first in Europe to publish a National Bioeconomy Strategy (2010, updated in 2020), which positions the bioeconomy as a cross-cutting pillar of its climate, innovation, and industrial policy. Implementation is supported by the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Food and Agriculture (BMEL), with funding streams for R&D, demonstration projects, and regional innovation clusters[73].

Germany also leads in the deployment of biogas and biomethane. With over 9,000 AD plants, around 12–13 TWh of biomethane is produced annually, prioritising high-value materials/chemicals over energy. Biomethane upgrading capacity is expected to expand rapidly, with more than 250 plants injecting renewable gas into the grid by 2024. The sector produces around 12–13 TWh of biomethane annually, supported by a combination of feed-in tariffs (EEG), renewable energy auctions, and guarantees of origin. Many German plants operate in integrated bioeconomy clusters, where residues from food, forestry, and farming are combined with nutrient recycling, biofertilizer production, and material valorisation. Examples of German practice illustrate how biomethane plants can be linked with wider

[72] *https://www.ifri.org/sites/default/files/migrated_files/documents/atoms/files/mathieu_eyl-mazzega_biomethane_2019.pdf*
[73] *https://www.bioeconomy-international.de/lw_resource/datapool/_items/item_169/summary_bioeconomy_strategy.pdf*

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nutrient recovery, industrial energy use and regional bioeconomy infrastructure rather than operating as stand-alone energy assets

The policy environment promotes cascading use and circularity. The updated Bioeconomy Strategy prioritises high-value applications (materials, chemicals, proteins) before energy recovery. It also links to Germany's National Hydrogen Strategy, where biomethane and biogenic CO_2 are expected to play a key role in e-fuel and synthetic methane production. Strong collaboration among research institutions, federal agencies, and industry has enabled Germany to establish a robust innovation ecosystem, ranging from regional biogas cooperatives to high-tech pilot plants and industrial-scale biorefineries.

For Ireland, the German model demonstrates how clear policy signals, infrastructure investment, and farmer-industry partnerships can rapidly expand biomethane capacity while integrating it into a broader circular bioeconomy framework.

Aspects	**Denmark (frontrunner)**	**Germany (major frontrunner)**	**Ireland (emerging)**
Biomethane/biogas maturity	Large AD fleet, strong biomethane injection, moving from CHP to grid gas[74].	A significant biogas sector, with hundreds of upgrading plants, and biomethane is well established[75].	Moving from pilots to first-wave deployment, aiming for ~140–200 plants[76,77].
Target/ambition	Contributes significantly to the EU's 35 billion cubic meters (bcm) biomethane goal by 2030[78].	Expected to remain a major contributor to EU biomethane volumes.	National target of up to 5.7 TWh of biomethane per year by 2030.
Feedstock approach	Focus on slurry, manure, and agri-residues via co-ops to protect food systems[79].	Mixed residues and some crops; strategy now stresses cascading, material-first uses[80].	Slurry as cornerstone, surplus grass as complement; energy crops capped[81].

[74] https://commission.europa.eu/topics/energy/repowereu_en
[75] https://biooekonomie.de/sites/default/files/files/2020-08/bmbf_national-bioeconomy-strategy_en.pdf
[76] https://www.gov.ie/en/department-of-agriculture-food-and-the-marine/publications/bioeconomy-policy/#irelands-bioeconomy-action-plan-2023-2025
[77] https://www.gov.ie/en/department-of-climate-energy-and-the-environment/publications/national-biomethane-strategy/
[78] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230
[79] https://commission.europa.eu/topics/energy/repowereu_en
[80] https://www.europeanbiogas.eu/
[81] https://assets.gov.ie/static/documents/62ec3306/Biomethane_Environmental_Sustainabilty_Charter.pdf

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Aspects	Denmark (frontrunner)	Germany (major frontrunner)	Ireland (emerging)
Incentives/supports	Long-term operating support and capital aid for biomethane injection.	EEG/feed-in, auctions and GO/certification underpin biomethane business models[82].	An initial €40 million biomethane capital support scheme was introduced as an early market stimulus; however, this scheme was time-limited and has now closed. Future capital support mechanisms are still under development and will be important in enabling the next phase of project deployment[83].
Grid access/injection model	Established injection sites and trading/certification systems.	Many upgrading plants are already injecting and using GO schemes.	Adopting the hub / CGI model (e.g. Mitchelstown) with specific PC5 mechanisms[84,85].
Regulation/safeguards	Mature fertiliser and waste rules enable the use of digestate under end-of-waste thinking. The development of standards and technical specifications, including the role of bodies such as NSAI, will also be important in supporting market confidence and interoperability[86].	Long experience with digestate and nutrient recycling in circular systems.	EPA stresses pathogen, PFAS, and traceability limits before full rollout of digestate[87].
Lesson for Ireland	Co-operative feedstock pooling and stable injection	Clear, durable policies, combined with infrastructure and farmer–industry partnerships,	Core architecture now exists (Strategy, RHO, PC5, hubs); delivery depends on digestate standards and

[82] *https://ecrn.net/wp-content/uploads/2019/05/COR-Opinion-on-Bioeconomy.pdf*
[83] *https://www.gov.ie/en/department-of-agriculture-food-and-the-marine/press-releases/minister-mcconalogue-announces-first-biomethane-capital-grant-letters-have-issued/*
[84] *https://www.gov.ie/en/department-of-climate-energy-and-the-environment/publications/national-biomethane-strategy/*

[86] *https://ecrn.net/wp-content/uploads/2019/05/COR-Opinion-on-Bioeconomy.pdf*

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Aspects	Denmark (frontrunner)	Germany (major frontrunner)	Ireland (emerging)
	support are decisive enablers[88].	drive scale. Examples of German practice illustrate how biomethane plants can be linked with wider nutrient recovery, industrial energy use and regional bioeconomy infrastructure rather than operating as stand-alone energy assets[89]	manageable connection costs[90].

***Table 1**: Comparative overview – Denmark, Germany, Ireland · For clarity, energy values are presented primarily in TWh where possible; where bcm is used (e.g. EU-level targets), approximate conversions may be applied for comparison purposes: (1 bcm ≈ 10.5–11 TWh)*

3 Ireland Bioeconomy and Biomethane

Ireland is transitioning from pilots to early deployment; success depends on synchronised progress on feedstock co-ops, grid access, digestate standards, and market pull. Ireland's bioeconomy is gaining structure, but it is still in its early stages compared to its North-West EU peers. The Government's National Biomethane Strategy (2024) positions biomethane as an agri-led, residue-first solution aligned with climate, farming, and energy goals. The Strategy is paired with enabling measures (grid connections, certification, skills) and demand pull via a forthcoming Renewable Heat Obligation (RHO) to stimulate offtake for industrial heat users.

Gas Networks Ireland (GNI) is progressing the Mitchelstown Central Grid Injection (CGI) hub—part of the wider GRAZE project—to aggregate upgraded biogas from local AD plants and inject pipeline-quality biomethane into the national network. The Commission for Regulation of Utilities (CRU) Price Control 5 (PC5) framework is the regulatory framework governing Ireland's gas network for the period October 2022 – September 2027. PC5 framework now includes specific mechanisms and allowances to facilitate biomethane connections, signalling regulatory support for scale-up.

At the same time, the EPA has established clear guardrails to maintain social licence: larger waste-processing AD plants require IED licensing; digestate land use must comply with the

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[88] https://www.europeanbiogas.eu/
[89] https://research-and-innovation.ec.europa.eu/system/files/2023-10/ec_rtd_riv-bioeconomy-concept-note.pdf
[90] https://www.gov.ie/en/department-of-climate-energy-and-the-environment/publications/renewable-heat-obligation/

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Nitrates Programme and ensure traceability; and statutory limits/monitoring are sought for pathogens and PFAS before widespread land spreading. These safeguards are intended to align with EU-level end-of-waste pathways.

Why Ireland has lagged behind the EU/UK/NI pace

- Late policy certainty: Until 2024, there was no national deployment roadmap or durable market signal; Denmark and Germany had long-standing incentives and infrastructure, while the UK and Northern Ireland advanced earlier (albeit with mixed lessons). Ireland's Strategy and RHO are only now closing this gap.
- Planning and permitting uncertainty: inconsistent or prolonged approval pathways can add risk, delay and subjectivity to project development. Project development capability: Ireland requires stronger commercial consortia, more standardised development approaches, better risk mitigation and greater capacity to aggregate feedstock, technology, finance and offtake into bankable projects.
- Grid connection economics & infrastructure: High connection costs and limited injection points slowed early projects; CRU's PC5 decision provides mechanisms and allowances; real-world connection costs will be confirmed as the first tranche of projects proceeds.
- Regulatory uncertainty on digestate: The EPA's prudent stance on contaminants (e.g., PFAS) and pathogen controls—while necessary—created timing risk for business models reliant on fertiliser revenue until standards are finalised.
- Cooperative structures may be needed not only for feedstock mobilisation but across the wider value chain, including ownership, logistics, nutrient products and offtake.
- Project development capacity: Fragmented development know-how and finance pathways are only recently being tackled (support at Lisheen; regional clustering).

What Ireland can learn from EU frontrunners:

- Adopt cooperative feedstock models: Pool slurry/manures and agri-residues via farmer co-ops to ensure bankable volumes and stable quality—mirroring Danish practice—while prioritising residue-led pathways to protect food systems.
- Anchor hubs around Central Grid Injection point: Build clusters around injection hubs, synchronising AD commissioning with grid readiness and offtake contracts under the RHO.

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- Fast-track digestate standards: Align national end-of-waste criteria with EU approaches so compliant digestate can move as a fertiliser product, unlocking circular-nutrient revenues while meeting EPA safeguards.
- Create durable market signals: Implement the RHO at a trajectory that gives long-term revenue certainty for heat users and AD developers (with sustainability criteria and GOs), learning from EU schemes' stability features.
- Skill up the ecosystem: Expand CPD and operator certification to meet EPA expectations and reduce operational risk as plants scale.

In short, Ireland now has the policy architecture (strategy, RHO, and PC5 changes) and infrastructure blueprint (Central Grid Injection model) to close the gap—provided digestate rules, grid connections, and market pull are executed in lockstep.

3.1 Government of Ireland Policy

3.1.1 Bioeconomy Action Plan

The Government of Ireland launched its first Bioeconomy Action Plan during Bioeconomy Ireland Week 2023. The Action Plan 2023-2025 includes 33 key actions to accelerate the bioeconomy. The action plan critically focuses on bringing sustainable scientific practices, technologies, and biobased innovations and solutions into use on farms and in biobased industries in Ireland.

The Bioeconomy Action Plan (2023–25) positions biomethane not as an energy silo but as an anchor of circular, multi-product value chains. Governance sits at the Cabinet level, reporting through the Bioeconomy Implementation Group to align energy, agriculture, environment, enterprise, and skills. The Action Plan operationalises via seven pillars; for biomethane, Pillars 3, 4, 5, and 7 are most material[91,92].

Pillar 3 embeds cascading use and natural capital accounting, pushing projects to capture high-value nutrients and materials before energy recovery. Pillar 4 funds on-farm biorefinery demonstrations and provides project-development assistance, enabling farmer-led clusters. Pillar 5 connects ERDF, LEADER, and Shared Island resources to regional hubs and requires Local Climate Action Plans to feature bioeconomy actions. Pillar 7 scales education and CPD, creating the talent pipeline for projected 6,000+ jobs.

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[91] *https://www.gov.ie/en/department-of-agriculture-food-and-the-marine/publications/bioeconomy-policy/*
[92] *https://assets.gov.ie/static/documents/62ec3306/Biomethane_Environmental_Sustainabilty_Charter.pdf*

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Key Points

- **Governance:** The Action Plan places governance and coordination at the national level and highlights cross-departmental alignment, ensuring policies across energy, agriculture, environment, enterprise and skills interact to support the bioeconomy.
- **Pillar 3 (Nature/Climate/Circular):** Pillar 3 supports circular and cascading use of biomass and emphasises natural capital, encouraging bio-based projects to extract higher-value uses and materials before energy recovery.
- **Pillar 4 (Agri/Food/Forestry/Marine):** supports innovation in primary sectors and aims to bring new technologies and processes into use on farms and in bio-based industries, strengthening regional and sectoral participation.
- **Pillar 5 (Regions & Cities):** Focuses on building regional capability, community-based bioeconomy development and ensuring that local and regional plans integrate bio-based activities and opportunities for new enterprise.
- **Pillar 7 (Knowledge & Skills):** concentrates on education, skills and capacity-building, aiming to grow a workforce that can support emerging bio-based value chains and future industrial demand.
- **Strategic shift:** the Action Plan is the broader framing of the bioeconomy as a circular, multi-product system rather than a single-output energy model, which aligns well with Ireland's biomethane and biorefinery ambitions.
- **Integration:** The Bioeconomy Action Plan complements other national and EU-level policies – including the National Biomethane Strategy and circular economy frameworks – to create a more coherent policy environment for sustainable deployment of bio-based projects.

3.1.2 National Biomethane Strategy

Ireland's National Biomethane Strategy[93] (2024) translates EU ambition into a national build-out plan. It commits to 5.7 TWh per year by 2030, delivered through an estimated 140–200 AD plants distributed across regions to match feedstock availability and heat/gas off-take. The policy pairs capital support for first-wave projects with market pull via the Renewable Heat Obligation (RHO), creating early revenue certainty while grid and offtake infrastructure catch up.

Critically, the National Biomethane Strategy steers deployment toward pathway residues. Cattle slurry is positioned as the cornerstone feedstock (both for methane potential and nutrient recycling), with surplus grass silage as a managed complement. Purpose-grown energy crops are capped to avoid land-use conflicts and protect food systems. The strategy

[93] *https://www.gov.ie/en/department-of-climate-energy-and-the-environment/policy-information/biomethane*

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also signals enabling actions on grid injection, certification, and guarantees of origin, allowing biomethane to transition seamlessly into industrial heat and transport.

Key Points

- **Target & scale:** 5.7 TWh/y by 2030 via ~140–200 plants.
- **Funding**: An initial €40 million biomethane capital support scheme was introduced as an early market stimulus; however, this scheme was time-limited and has now closed. Future capital support mechanisms remain under development and will be important for enabling the next phase of project deployment.**Demand pull:** RHO rises from 2% → 10% by 2030, underwriting offtake.
- **Feedstock hierarchy:** Slurry first, surplus silage second; energy crops capped.
- **Feedstock safeguard:** Purpose-grown energy crops are capped to protect food systems and biodiversity; slurry remains the cornerstone.
- **Infrastructure enablers:** Grid injection capacity, metering/certification, GO systems.
- **Regional lens:** Clusters aligned with farm density, heat users, and valve upgrade plans.
- **Co-benefits:** Nutrient management, reduced emissions from manure, and farm income diversity.

3.2 EPA Regulatory Compliance

The Environmental Protection Agency (EPA) provides the compliance framework that maintains social licence for rapid biomethane growth[94]. In its 2024 consultation, the EPA clarified that AD plants processing more than 100 tonnes per day of waste require Industrial Emissions Directive (IED) licensing, ensuring proportional oversight of emissions, odours, and waste handling. On the land side, digestate application must comply with the Nitrates Action Programme,with electronic traceability to track nutrient movements and protect water quality.

In practice, regulatory requirements differ between larger waste-processing facilities and smaller agri-led AD plants, and this distinction is important for understanding delivery pathways in Ireland. While the IED framework provides structured oversight for larger installations, smaller farm-based or cooperative models operate under a more fragmented regulatory landscape, which can influence project scale, timelines and development approaches.

[94] *https://www.epa.ie/publications/corporate/submissions--position-papers/OES-EPA-Submission-on-Ireland%27s-Draft-National-Biomethane-Strategy-05Mar24.pdf?*

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While the climate case for co-digestion is strong, the EPA highlights unresolved risk parameters—namely, pathogens, PFAS, and related contaminants—and calls for the establishment of statutory limits and monitoring protocols before the widespread land application of co-digestate. The level of risk associated with these parameters may vary depending on feedstock type and is likely to be lower in agri-only systems compared to mixed or waste-derived feedstocks. However, regulatory clarity and consistent standards remain necessary across all pathways to support both environmental protection and market confidence. This prudential stance protects environmental outcomes and public trust while industry and policymakers finalise end-of-waste criteria and quality standards.

The sequencing of digestate standards with plant commissioning is crucial for ensuring bankability and public confidence. This uncertainty is not only a compliance issue but a commercial one, as developers and financiers require clarity on digestate outlets, nutrient product classification, and revenue certainty. In this context, the absence of defined end-of-waste criteria and operational pathways for biofertiliser products—including potential alignment with emerging EU developments such as RENURE—remains a material constraint on project bankability in Ireland. Delays in regulatory clarity around digestate, biofertiliser and RENURE-type products can affect project bankability by weakening confidence in nutrient revenue streams, land application pathways and long-term operating assumptions.

At present, Ireland does not yet have a fully standardised national end-of-waste or biofertiliser classification framework for digestate. In practice, approval for digestate recovery and land application pathways is often managed on a case-by-case basis, typically involving the Environmental Protection Agency. This introduces a degree of uncertainty for project developers, particularly in relation to long-term planning and investment decisions. Moving forward, greater clarity on digestate standards, monitoring frameworks, and regulatory pathways will be critical to enable consistent project delivery. This includes potential development of national standards (e.g. through bodies such as NSAI) and alignment with evolving EU-level end-of-waste and fertiliser frameworks. Progress in this area will be essential to move from a case-by-case approach towards more predictable and scalable deployment conditions.

Key Points

- **Licensing threshold:** AD plants processing >100 t/day of waste fall under IED licensing; smaller agri-led plants follow alternative regulatory pathways.
- **Digestate rules:** Must comply with the Nitrates Action Programme; traceability requirements are increasing, but no fully standardised end-of-waste framework currently exists.

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- **Regulatory reality:** Digestate use and recovery pathways are currently assessed on a case-by-case basis, creating uncertainty for developers.
- **Risk focus:** EPA highlights the need for statutory limits and monitoring for pathogens, PFAS and other micro-contaminants.
- **Compliance outcomes:** Protects air/water, manages odour, assures safe nutrient recycling.
- **Biofertiliser pathway:** National standards (e.g. via NSAI) and practical implementation of RENURE-type approaches are still evolving.
- **Bankability impact:** Regulatory uncertainty around digestates and nutrient products is a key constraint on financing and project viability.
- **Deployment implication:** Clear, standardised digestate and biofertiliser frameworks are essential for scaling biomethane in Ireland.
- **Next steps:** Progress national standards and align with EU end-of-waste and fertiliser frameworks to move from case-by-case approvals to predictable delivery pathways.

4 Tipperary and Midlands Bioeconomy and Biomethane

County Tipperary and the wider Midlands region are at the forefront of Ireland's transition from a fossil- and peat-based economy to a circular bioeconomy. The area combines three strategic advantages: (i) a strong agricultural base with high cattle and dairy density, (ii) legacy infrastructure from extractive industries such as peat and zinc mining, and (iii) designation as part of Ireland's Just Transition Zone, which channels EU and national funds into green industries, job creation, and rural revitalisation.

At the centre of this regional transition is the National Bioeconomy Campus at Lisheen, established on the site of the former Lisheen zinc mine. The mine, once symbolising a carbon-intensive industry, is now being repurposed as a hub for renewable gas, green biorefineries, and innovation clusters. The Campus hosts open-access pilot facilities, including the Biomethane Development Office (BDO), as well as a growing number of demonstration projects, such as biogas, biomaterials, and nutrient recycling. Its location in the Midlands makes it a natural anchor for Just Transition funding streams and a focal point for regional decarbonisation.

Tipperary County Council has embedded the bioeconomy into its Climate Action Plan 2024–2029, identifying Lisheen as a key innovation site and designating the Thurles–Lisheen corridor as a Decarbonising Zone. This framework commits to reducing local emissions by at least 50% by 2030, as outlined in the Plan's local pathway, through the deployment of renewable energy, energy efficiency measures, and support for bio-based enterprises. Biomethane and

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biorefining are central to the strategy, providing alternatives to fossil fuels, creating local jobs, and building resilience in rural communities.

The Midlands is increasingly recognised as Ireland's bioeconomy heartland. Alongside Lisheen, clusters are developing in Mitchelstown (Gas Networks Ireland's Central Grid Injection hub), Offaly (repurposing Bord na Móna's peatlands for renewable energy and biomass), and Laois–Westmeath (emerging AD and co-op initiatives)[95,96]. This regional alignment ensures that biomethane deployment is not only a climate solution but also a Just Transition pathway, replacing lost employment from extractive industries with new opportunities in green gas, agri-innovation, and circular value chains. Lisheen leverages Just Transition supports to convert legacy extractive infrastructure into circular bioeconomy assets[97].

4.1 National Bioeconomy Campus, Lisheen

The Lisheen site in County Tipperary was once among Europe's largest zinc and lead mines, operating from 1997 until its closure in 2015. During that period, it played a central role in local employment and industrial output but also represented a carbon- and resource-intensive development model. Following decommissioning, the site was identified as a strategic asset within Ireland's Just Transition Zone, recognising both the need to support local communities after mine closure and the opportunity to repurpose the existing infrastructure for sustainable industries. Beyond physical infrastructure, the Campus plays an important role in stakeholder and farmer engagement, skills development, project demonstration, and the testing of integrated regional bioeconomy models that link anaerobic digestion, nutrient recovery, biorefinery functions, and low-carbon enterprise.

At present, the Campus primarily serves as a convening platform, bringing together stakeholders from across Ireland's emerging bioeconomy value chains—including dairy, tillage, forestry, waste management, technology providers, and rural enterprises—and facilitating structured dialogue among industry, farmers, researchers, policymakers, regulators, and funding bodies. This coordination role is essential in a sector where value chains are still forming and where regulatory, financial and technical uncertainties require shared problem-solving. Through workshops, stakeholder roundtables, and early-stage project scoping sessions, the Campus provides a neutral environment where farmers and cooperatives can explore opportunities, understand policy signals, and engage directly with agencies such as DAFM, SEAI, EPA, Enterprise Ireland, and the Just Transition Fund. As the Campus develops further infrastructure and demonstration capacity, these convening

95 https://www.gasnetworks.ie/network/biomethane/mitchelstown-cgi
96 https://bnmenergypark.ie/
97 https://www.energyireland.ie/bord-na-mona-completes-its-brown-to-green/

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activities will evolve into more formalised farmer-focused training, Continuous Professional Development (CPD) pathways, and hands-on demonstrations of integrated AD and green biorefinery models, ensuring that future skills development is grounded in real technologies and regional feedstocks.

Tipperary County Council's Local Authority Climate Action Plan 2024-2029 outlines a vision to transform the former mine into the National Bioeconomy Campus, Ireland's flagship hub for circular bioeconomy innovation[98]. This redevelopment positions Lisheen as a centre for open-access pilot facilities, research-industry partnerships, and demonstration projects across renewable gas, green biorefineries, and bio-based materials. The Just Transition designation makes it eligible for EU and national funding streams, ensuring that investment flows into rural diversification, green jobs, and climate-positive enterprises rather than extractive industries.

The National Biorefinery Pilot Plant (NPBB), located inside the campus, now hosts a range of cutting-edge technologies to advance Irish bio-innovations from TRL4 to TRL7 using local feedstocks such as dairy residues, forestry side streams, and organic waste. BioScaleUp is a project funded by the Government of Ireland and the European Union through the EU Just Transition Fund Programme 2021-2027 to develop the facility through a targeted project. BiOrbic Research Ireland Centre for Bioeconomy has been a key partner in the project linking academic institutions, industry partners, and farmer co-operatives, strengthening Ireland's capacity to turn research into market-ready solutions.

Lisheen's location and infrastructure make it a strategic anchor for future biomethane deployment. Its central position in the Midlands allows for the clustering of anaerobic digestion projects, while local agriculture provides an abundant supply of slurry and grass residues. In July 2024, the site also became home to the Biomethane Development Office (BDO), a dedicated support network that promotes biomethane development in the midlands. Together, the Campus and the BDO ensure that Lisheen is not only a symbol of Ireland's Just Transition but also the nerve centre for scaling bioeconomy and biomethane solutions.

4.2 Biomethane Development Office (BDO)

The Biomethane Development Office (BDO) is a key initiative under the "Biomethane for Carbon and Community" (BCC) project, co-funded by the Government of Ireland and the EU Just Transition Fund (2021-2027). The BCC project is a collaborative initiative involving Tipperary County Council and its partners, the Technological University of the Shannon, the Irish Bioeconomy Foundation and the Tipperary Energy Agency. The BDO aims to drive

[98] *https://www.tipperarycoco.ie/sites/default/files/2025-06/The%20first%20Tipperary%20County%20Council%20LACAP%20Progress%20Report%202024_1.pdf*

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biomethane development and decarbonisation efforts across Ireland, particularly in Tipperary.

5.4. NaringTech Bioproducts Campus

The NaringTech Bioproducts Campus, located at the former Lisheen Mine site in Derryville, Tipperary, received planning permission in November 2022 for a 10-year "BioProducts Campus" development[99]. The project encompasses a fully integrated facility including a compost and growing-media plant, anaerobic digestion units, and a biorefinery, with capacity to process up to 80,000 tonnes per year of organic waste materials. The site will produce a suite of outputs, including compost, renewable electricity, bioenergy, biomethane, and biofertilisers, supported by infrastructure such as digesters, digestate storage, biomass boilers, and solar arrays.

5.5 All-Island Bioeconomy Summit

The 4th All-Island Bioeconomy Summit & Awards took place on 13 May 2025 at the Johnstown Estate Hotel in Enfield, Co. Meath[100]. The Summit convened key stakeholders across the island—government, industry, academia, farmers, and community groups—to explore synergies between biomethane, green biorefining, and the development of a circular bioeconomy.

Over 200 delegates attended the Summit, which featured parallel sessions on themes such as "Synergies Between Biomethane and the Bioeconomy", marine bioeconomy, and best-in-class innovations. A free shuttle train service was also organised for delegates travelling from Dublin to Enfield.

The event hosted the Irish Bioeconomy Awards, recognising outstanding contributions in the sector. A highlight was Arigna Group, which received the Bio Achievement of the Year 2025 award for its transformation from fossil-fuel legacy operations to renewable solutions, including biochar production.

Minister Martin Heydon opened the event, emphasising that the bioeconomy offers a pathway to replace fossil-based products, valorise farm residues, strengthen the role of primary producers in value chains, and create new rural jobs.

Relevance: The Summit's themes mirror this report's focus on **biomethane-bioeconomy synergies** and **regional clustering**.

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[99] *https://www.eplanning.ie/TipperaryCC/AppFileRefDetails/2260395/0//AppFileRefDetails/5124572/0?*
[100] *https://bioeconomy.ie/*

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Agenda

Where is the Bioeconomy Going?	
10.00	**Welcome, Mary Coughlan (Master of Ceremonies)**
10.05	**Ministerial Address: Martin Heydon,** Department of Agriculture, Food and the Marine
10.20	**Whistle Stop Overview of Bioeconomy Developments in Ireland & Northern Ireland** Percy Foster, Managing Director, Foster Environmental
10.35	**Panel Discussion: Where is the Bioeconomy Development Going in Europe?** • Dr. John Bell, Director for Healthy Planet, DG Research and Innovation, European Commission • James Cogan, Public Affairs Director, Clonbio • Dr. Anne Kokel, EU Project Leader from Bioeconomy4Change, France • Stef Denayer, Stakeholder Relations Manager Pilots4U, Belgium
11.05	**Tea & Coffee Networking Break in Exhibition Hall**
11:30	**Alan Dillion, Minister of State, Department of the Environment, Climate and Communications with special responsibility for Circular Economy** **All Island Bioeconomy Awards** **Bio Achievement of the Year** / **Top Bioeconomy Young Talent** **Biobased Product of the Year** / **Best Biomethane Development**

	Synergies Between Biomethane and the Bioeconomy	Best in Class	Blue Bioeconomy
	Moderator: Mary Coughlan	**Moderator: Ian Archer, BioConnect**	**Moderator: Máire Ní Éinniú, Údarás na Gaeltachta**
12:00	**Renewable Heat Obligation / National Biomethane Strategy** Sean Kinsella, Principal Officer, Department of Environment, Climate and Communications	**Ireland's First Phosphorus Recovery Facility at the Ringsend Wastewater Treatment Plant** Dara White, Uisce Éireann	**Ocean Knowledge Strategy – National & EU Funding available** Dr. Fiona Grant, Marine Institute
12:20	**Northern Ireland's Biomethane Journey within the Agriculture Policy Landscape** Jonathan McFerran, Deputy Director, Green Growth, Department of Agriculture, Environment and Rural Affairs	**Europe's Largest Biochar Facility in Roscommon** Cathal Fitzgerald, Arigna Group	**Clustering and Blue Economy Innovation** Dr. Helena McMahon, Circular Bioeconomy Cluster
12:40		**Biogenic $C0_2$ and Nutrient Extraction from Digestate** Gary Logue, Greenville Energy	**Bord Iascaigh Mhara, Supporting the Blue Bioeconomy** Cliodhna Griffin, Bord Iascaigh Mhara
13:00	**Panel Discussion: Foresight on Developing Synergies Between Biomethane and the Bioeconomy on the Island of Ireland.** **Moderator:** Stephen Robb, Renewables Editor, Irish Farmers Journal Sean Finan, Chief Executive, Irish Bioenergy Association Padraig Fleming, Biomethane Programme Manager, Gas Networks Ireland Prof Vincent O'Flaherty, University of Galway, Co-founder GlasPort Bio Jenny Grant, Head of Organics and Natural Capital, REA Tony Breton, Chief Executive, Cré- Composting and Anaerobic Digestion Association of Ireland PJ McCarthy, Chief Executive, Renewable Gas Forum of Ireland		

Figure7: All-Island Bioeconomy Summit agenda

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Figure 8: Photos from All-Island Bioeconomy Summit

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5.6 RuralBioUp

RuralBioUp was an EU-funded Horizon project (2022–2025) designed to strengthen bioeconomy capacity in rural regions by supporting small-scale bio-based innovations[101]. It's aim was to build local ecosystems, involving farmers, clusters, policy actors, researchers, and civil society, that can co-design and scale bio-based value chains tailored to regional contexts.

Key features include:

- Establishment of nine Regional Hubs across six EU countries (including Ireland), each hub guiding Action Plans across 18 value chains tailored for rural bioeconomy uptake.
- Support mechanisms such as mentoring, coaching, training, networking, and study visits, targeting innovators and clusters in rural areas to adopt or scale bio-based solutions.
- Development of a digital One-Stop-Shop tool to provide regional actors with information on available biomass, nutrient cycling, business models, and financial opportunities.
- In Ireland specifically, the Irish Bioeconomy Foundation (IBF) is responsible for managing the national hub. The Irish hub has already organised study visits, including trips to the National Bioeconomy Campus in Tipperary and operating biorefinery/AD sites, such as Green Generation in Kildare, to expose stakeholders to real-world bioeconomy operations.

Target outputs include supporting ≥1,000 innovators and achieving ≥50 collaborations, with a digital One-Stop-Shop to sustain the initiative post-project.

In summary, RuralBioUp plaued a catalytic role in Ireland's bioeconomy by bridging knowledge gaps, fostering collaboration, and operationalising small-scale bio-based models that align with biomethane and circular bioeconomy strategies.

5.6.1 Training webinars

As part of the RuralBioUp project, IBF organised a series of technological training webinars[102] to strengthen knowledge transfer, raise awareness, and build capacity around emerging bio-based solutions. The purpose was to expose rural communities, innovators, and stakeholders to practical technologies already being deployed in Ireland and Europe, helping them to understand potential applications, environmental benefits, and business opportunities in the circular bioeconomy. These sessions also supported the RuralBioUp objective of

[101] https://ruralspot.eu/search-resources/

[102] *https://www.youtube.com/channel/UC5X6yvIKNcZUMPn2WzxDVCA*

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mainstreaming small-scale biorefineries and showcasing technologies that can valorise local feedstocks.

The webinars can be found on the RuralBioUp YouTube channel: https://www.youtube.com/@RuralBioUp. IBF hosted five webinars on the topic of Technological Trends in the Bioeconomy.

- **Name:** Pyrolysis for Feedstock Valorisation
  Presenter: Sean O'Grady
  Webinar Link: https://www.youtube.com/watch?v=vZIlkzyjh_M
  This webinar explored how pyrolysis technologies can convert agricultural residues, forestry by-products, and food waste into high-value products such as biochar, bio-oil, and syngas. The session highlighted practical case studies from Irish innovators and international pilots, demonstrating how pyrolysis contributes to carbon sequestration, renewable energy production, and soil enhancement.
- **Name:** Technologies Used in Green Biorefinery
  Presenter: Dr. Gaurav Rajauria
  Webinar Link: https://www.youtube.com/watch?v=iGzFmmtYO6Y&t=188s
  The green biorefinery session focused on how freshly harvested biomass, such as grass and clover, can be fractionated into protein concentrates, fibre-rich press cake, and nutrient liquids. Presentations outlined how this cascading use of biomass reduces reliance on imported soy proteins, provides high-quality animal feed, and leaves residues suitable for anaerobic digestion, creating multiple value streams for farmers.
- **Name:** Novel Biochar Application
  Presenter: Dr Alma Siggins
  Webinar Link: https://www.youtube.com/watch?v=PPV0xOvyBOs&t=328s
  This webinar presented innovative uses of biochar beyond its traditional role as a soil amendment. Speakers discussed how biochar can be used in water filtration, as a livestock feed additive to reduce methane emissions, and as a carrier for microbial inoculants. The session emphasised biochar's role in carbon credit schemes and its potential for developing new farmer-led business models.
- **Name:** Use of Anaerobic Digestion in Biorefinery
  Presenter: Pooja Bajarh
  Webinar Link: https://www.youtube.com/watch?v=OHSeyb9NGKA&t=182s
  This session examined the integration of anaerobic digestion (AD) into broader biorefinery concepts. It showed how digesters can act as a central platform for valorising slurry, silage residues, and food waste, while providing renewable energy in the form of biogas or upgraded biomethane. Presenters highlighted the benefits of

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nutrient recycling through digestate use and outlined EPA compliance considerations for future deployment.

- **Name:** Biomethane Production
  Presenter: Ajay Sutrakar
  Webinar Link: https://www.youtube.com/watch?v=SrXtc08XLkc
  The biomethane production webinar provided an overview of upgrading technologies, grid injection models, and policy enablers such as the Renewable Heat Obligation. Irish case studies were shared to illustrate the pathway from pilot-scale AD to commercial biomethane plants, underscoring the role of biomethane in decarbonising hard-to-electrify sectors and contributing to Ireland's 2030 climate and energy targets.

5.6.1 Mainstreaming Small-Scale Biorefineries

Mainstreaming Small-Scale Biorefineries was a full-day event in June 2024, organised by the Irish Bioeconomy Foundation (as part of the RuralBioUp project), Munster Technological University (as part of the MainstreamBIO project), and CAP Network Ireland. The event was to showcase examples of small-scale biorefineries in operation in Ireland. The event started with a study visit to the National Bioeconomy Campus in Tipperary, where IBF team provided a tour of the pilot-scale facilities.

A networking event followed this in the Horse & Jockey hotel in Tipperary. The event included tea/coffee, followed by presentations from the event organisers, including Kevin Ryan (IBF), Dragica Grozdanic (MTU), and David Barry (CAP Network Ireland). Following the presentations, a sit-down meal was served at the hotel, allowing attendees to network and discuss the presentations. The group then proceeded to the final study visit of the day to Green Generation in Kildare. Green Generation uses anaerobic digestion to convert agricultural and food waste into bioenergy. They also use innovative technology to convert waste plastics into higher-value products.

After the visits, **key takeaways** included: (i) modular fractionation reduces transport of water, (ii) press-cake remains a high-BMP substrate, and (iii) operator competence is central to EPA compliance.

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Figure 9: Participants at Green Generation

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5.7 Primed

PRIMED is a Horizon Europe project (2024–2026) involving 13 partners from eight countries[103]. It aims to transform underused biomass from Europe's primary sectors—forestry, agriculture, and dairy—into sustainable, high-value bio-based products using advanced biorefinery technologies.

The project addresses three primary objectives:

1. **Boosting primary production value chains** by converting residues and low-grade biomass into marketable products.
2. **Supporting climate and sustainability goals** through reduced greenhouse gas emissions, improved nutrient recycling, and carbon sequestration.
3. **Revitalising rural regions** by generating new income streams, green jobs, and investment opportunities.

PRIMED operates through Living Labs, which bring together local stakeholders—farmers, foresters, industry, policymakers, and researchers—to co-design and test circular bioeconomy solutions. In Ireland, the BioÉire Living Lab, led by IBF, focuses on forestry residues and dairy valorisation, with projects including:

- Development of **biochar-based soil enhancers and filtration systems** from undervalorised Sitka spruce (in collaboration with Lurra Bio).
- Exploration of **dairy sludge and side-stream valorisation** with Blue Creamery and academic partners (UCD).

Internationally, PRIMED showcases a range of technologies, including pyrolysis, anaerobic digestion, fermentation and cascading biorefinery models. Demonstration sites in partner countries validate both the technical feasibility and the economic models needed to scale small- and medium-sized bio-based enterprises.

Expected outcomes include the delivery of an open-access digital toolbox containing methodologies, reports, and guidelines to support replication of these models across Europe. By 2026, PRIMED aims to demonstrate that small-scale, farmer- and SME-led bioeconomy systems can compete with industrial models while delivering greater environmental and social benefits.

5.7.1 Catalonia Biomethane site visit

During the PRIMED consortium's visit to Catalonia, partners toured the Alcarràs Composting and Bioproducts Plant in the Segrià region, which was established in 2022. This facility was

[103] *https://primed-project.eu/*

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created by Alcarràs Bioproductors, a cooperative of 150 livestock farming families, to manage the large volumes of slurry and manure generated by nearly half a million cattle and pigs reared annually in the municipality. The plant combines livestock residues with green waste from parks and gardens to produce a high-quality compost fertiliser, which is marketed locally and exported primarily to France. With an annual processing capacity of around 27,000 tonnes, it represents a pioneering example of farmer-led circular bioeconomy development.

The initiative is part of the BioHub Km0 project and has been supported by the regional strategic plan for the economic transformation of Lleida, the Pyrenees, and Aran. Its cooperative governance model ensures that transport costs are shared fairly among participants, avoiding penalties for farms located further from the plant. Beyond providing an outlet for livestock waste, the facility supports sustainable nutrient management in the region.

Alcarràs is preparing to expand with a biogas facility that will convert manure and slurry into renewable energy. Electricity from the plant will be partly fed into the national grid and partly supplied back to local farms. The process will also yield denitrified water suitable for irrigation, adding another resource loop to the system. The consortium's visit highlighted Alcarràs as an excellent demonstration of farmer-driven innovation, where composting and forthcoming anaerobic digestion are embedded in a local circular bioeconomy strategy.

Implication for Ireland: The **co-op governance** for cost-sharing and transport logistics is directly transferable to slurry pooling for AD hubs.

Figure 10: Alcarràs Biomethane Plant, Catalonia, Spain, site visit

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5.7.2 Circular Bioeconomy in Tipperary event

The Circular Bioeconomy in Tipperary event took place at the Thurles Chamber Enterprise Centre. The event was held in person on the morning of 16 April 2025 and was co-located with another event, 'Decarbonising Tipperary', organised by Tipperary County Council. The Circular Bioeconomy in Tipperary initiative began with a networking session over tea/coffee, followed by a presentation by Kevin Ryan on ongoing work exploring how the circular bioeconomy can be utilised to decarbonise the Tipperary region. He discussed ongoing projects and the progress made to help the region gain an understanding of the circular bioeconomy and biobased solutions.

The group also had presentations from other projects working on bioeconomy in the area, including PRIMED, Biomethane for Carbon and Community and Pathways2Resilience. A break for more networking followed the presentations. After the break, the group participated in a workshop to assess how these ongoing initiatives can work together towards a Shared Future Vision of a Circular Bioeconomy in Tipperary.

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Figure 11: Circular Bioeconomy in Tipperary event

5.8 NPower

The Npower project aims to deliver a set of solutions that limit their N/P emissions and rebalance regional N/P flows, demonstrating innovative N/P recovery technologies, replicating sectoral best management practices, and designing region-specific governance measures. The team will form four regional clusters in Spain, Belgium, Finland, and Ireland, involving practitioners and policymakers. These clusters will ensure that the solutions developed are applicable across diverse European environments, with a focus on five key economic sectors.

6. Economic, Environmental & Social Impacts

Grass, like all biomass feedstocks, has an economic value, and the level of that value is determined by its use. Grass is a valuable resource with several valorisation strategies, including animal fodder, anaerobic digestion, and/or green biorefinery methods.

The traditional use for grass as cattle fodders ranges from €100 to €170 t DM. Grass can also serve as a feedstock in anaerobic digestion to produce biomethane. However, feeding grass directly into AD plants is not economically feasible, as the maximum return is approximately €165/t DM, making it more profitable as cattle fodder. These values should be treated as indicative only, as the relative economics of grass as fodder, feedstock, or biorefinery input depend on season, logistics, market prices, dry matter, and local alternative use

This can be coupled with anaerobic digestion, where the grass is fed to cattle, and the slurry produced can be fed into an anaerobic digestion plant, where the biomethane produced is an added-value product.

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Ireland is well-positioned to implement green biorefineries, with a temperate climate and 90% of enabling the beef and dairy industries to thrive. This can be compared to Denmark, which has a strong green biorefinery sector and some of the lowest grasslands in Europe, at 9%, but has targeted the location of biorefineries in these areas.

Recent techno-economic assessments align on a levelised cost of electricity (LCOE) of €50–110 MWh^{1} for Irish plants, with feedstock cost the dominant variable. Grid connection charges—currently €1.2–1.5 MW^{-1} — are under CRU review; modelling suggests a 50% reduction would lower the levelized cost by approximately €8 MWh^{-1}. On the social side, applying the European Biogas Association's multipliers yields 1,800 direct and 4,400 indirect jobs for the 5.7 TWh target. These figures are indicative and depend on the assumptions used regarding plant numbers, supply-chain localisation, and multiplier effects; they should therefore be interpreted as scenario-based estimates rather than precise forecasts.

Action Plan Pillar 7 embeds bioeconomy curricula across all levels of schooling, directly addressing the anticipated technician and operator shortfall.

Despite the economic benefits of AD coupled with green biorefineries, Ireland is lagging its EU counterparts, such as Denmark and Germany. Developments in green biorefineries in these countries have occurred because there was already an established AD sector where the green biorefineries were later established. For green biorefineries to be based in Ireland, there first needs to be a more developed AD sector than it currently is. Bioeconomy hubs or parks, such as Lisheen, where multiple biotech and AD companies are located, could help develop green biorefineries and AD. Initiatives such as the recently started ‘Comhar BIA’ project or the Collaborative Bio-industrial Alliance can help the sector by developing co-owned business models to help diverse partners develop collaborative regional biorefineries.

Social licence & community benefits. Projects should include odour and traffic management plans, covered storage, bioaerosol controls, and community benefit schemes (e.g., farmer co-op dividends, local heat uses). Transparent communication and trusted local engagement will also be essential, particularly where misinformation or inconsistent interpretation can delay otherwise viable projects.

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7. Research Gaps & Implementation Priorities

This review identifies five recurring barriers to the development of an integrated, residue-first biomethane sector in Ireland: digestate end-of-waste clarity, grid connection economics, operator competence, whole-cascade life-cycle assessment, and early-stage project finance. For an implementation-focused audience, it is useful to distinguish between actions that can be advanced largely within Irish Government control and those that depend partly on EU-level regulatory or standardisation developments. A phased roadmap is therefore needed to separate near-term enablers from medium- and longer-term deployment actions.

Research and validation priorities-Ireland's next R&D tranche could usefully focus on closing a set of recurring knowledge and implementation gaps that are already signposted in the Bioeconomy Action Plan and related policy documents:

Whole-cascade LCA and natural capital accounting- Measure 3.3.1 of the Bioeconomy Action Plan envisages the development of natural capital accounting approaches for bioeconomy value chains. Applied to biomethane, this would support whole-cascade life-cycle assessment capable of consistently allocating emissions, removals, and co-product benefits across agriculture and energy systems. Such work would help clarify where climate benefits are counted and improve the evidence base for integrated biomethane-bioeconomy systems.

Digestate end-of-waste standards- Action 3.2.2 points towards clearer waste-to-resource pathways for bio-based outputs. For digestate, this implies work to define robust quality criteria (including limits for pathogens, PFAS and micro-contaminants). This work is essential not only to protect soil and water quality, but also to improve confidence in digestate-derived biofertilisers and support future alignment with RENURE-type nutrient pathways where applicable.

Operator competence and CPD - Under Pillar 7, the Action Plan introduces a stronger focus on skills, training, and continuous professional development. For biomethane, this provides a route to structured CPD and certification for AD operators, planners and advisers. Strengthening competence across the system would reduce operational and environmental risks, improve consistency in project delivery, and directly address regulator concerns about poor practice at some existing or proposed sites.

Grid connection costs and economic tests-

Measures under Pillar 6 of the Bioeconomy Action Plan, together with the National Biomethane Strategy, highlight the importance of network access and fair connection charging. A key gap remains in understanding how different economic test designs, cost-sharing arrangements, and central grid injection models affect the viability of rural

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biomethane projects. This is particularly important for informing the design of future capital grants and ensuring that grid connection costs do not undermine otherwise viable projects.

Bankable first-wave finance models-

A further gap concerns the practical "nuts and bolts" of bankable project structures. Ireland still has limited experience with standardised templates for feedstock supply agreements, digestate or nutrient-product offtake arrangements, and biomethane sales structures, including offtake linked to the Renewable Heat Obligation. Research and pilot work in this area would help reduce transaction costs, improve lender confidence, and accelerate the emergence of repeatable project models.

In addition to these cross-cutting gaps, several applied research and validation priorities require targeted attention:

- Field trials on digestate agronomy, nitrogen efficiency and leaching
- Methane leakage monitoring and MRV systems
- Biofertiliser and RENURE-related standards, evidence generation and nutrient-product validation
- Commercial and logistical assessment of integrated hub and co-location models

A short implementation matrix could usefully rank these issues by both their likely impact on the delivery of a residue-first biomethane sector and their relative ease or speed of delivery. This would also help distinguish between those actions that can be advanced immediately through existing Irish instruments, such as the Biomethane Development Office, CPD structures under Pillar 7, or the CRU PC5 framework, and those that depend more heavily on EU-level end-of-waste and fertiliser policy developments.

7.1. Scaling, Deployment and Commercialisation Priorities

Alongside research and validation, Ireland now requires a stronger focus on deployment-oriented actions activities to first-wave commercial delivery within a broader circular

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bioeconomy framework. This includes a clearer emphasis on scaling and deployment towards commercialisation, as early progress will depend not only on technical validation but on the emergence of regionally visible, commercially credible models capable of wider replication.

Flagship regional bioeconomy-biomethane hubs should therefore be prioritised as anchor projects within key regions, based on co-location, shared infrastructure and multi-actor delivery. Such hubs could integrate anaerobic digestion, nutrient recovery, green biorefinery functions, biofertiliser production, and related bioeconomy enterprises to improve scale efficiency, resource circularity, and regional visibility. In doing so, they can help demonstrate how biomethane can operate not as a stand-alone energy project, more resilient regional bioeconomy.

Multi-actor and cooperative models: Future growth is also likely to depend on multi-actor delivery structures, including cooperative authorities, and end-users. In the Irish context, such arrangements may be particularly important for aggregating feedstock, coordinating investment, sharing risk, and ensuring fair distribution of value across the chain. Cooperative approaches may therefore be needed not only for feedstock mobilisation but also across the wider value chain, including ownership, logistics, nutrient products, and offtake.

Public funding to crowd in private capital: Public funding has an important role not only in supporting early capital expenditure, but also in de-risking projects sufficiently to crowd in private investment. This includes support for feasibility work, project development, enabling infrastructure, aggregation mechanisms and early commercial demonstration, alongside clearer long-term market signals that improve investor confidence. In this sense, public funding should be viewed not only as direct support, but as a strategic tool for unlocking commercially viable first-wave projects and attracting wider private finance into the sector.

Standardised approaches to finance and contracting could materially reduce the friction associated with early deployment. Priority areas include feedstock supply agreements, digestate and lenders' confidence and reduce transaction costs.

The success of integrated systems will also depend on stronger, more credible market signals not only for biomethane but also for biofertilisers and other circular bioeconomy outputs. This includes demand pull-through policy instruments such as the Renewable Heat Obligation, as well as continued monitoring of emerging EU-level market-building mechanisms and standards that could support future product uptake and cross-border alignment.

A phased commercialisation sequence: ; medium-term deployment priorities, such as regional hubs, market formation and grid integration; A phased commercialisation sequence. A clear, phased roadmap is essential to distinguish among near-term enabling actions, medium-term deployment priorities, and longer-term system transformation. In practical terms, implementation can be understood as a sequence:

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(i) finalise regulatory standards for digestate, grid injection and permitting, providing the regulatory clarity required for first-wave projects;

(ii) establish and resource flagship regional hubs with dedicated project-development capacity, enabling coordinated feedstock mobilisation, shared infrastructure and early commercial demonstration; align biomethane deployment with renewable heat and industrial decarbonisation policies to secure predictable long-term offtake;

(iii) deploy blended public–private finance instruments to de-risk early capital expenditure and support bankable first-mover projects; and

(iv) replicate successful models across regions, supported by continuous learning on environmental performance, nutrient management and social acceptance. Distinguishing clearly between near-term delivery (standards, skills, pilots, finance models), medium-term deployment (regional hubs, market formation, grid integration), and longer-term scale-up pathways linked to wider bioeconomy and energy-system transformation helps avoid conflating aspiration with implementable action and ensures a coherent, regionally anchored network of hubs and value chains.

Conclusion

This study highlights that agri-led biomethane systems achieve their highest economic and environmental performance when integrated with green biorefinery processes and other complementary bioeconomy pathways, including fermentation-based biorefineries, nutrient recovery systems, and thermochemical routes such as pyrolysis and gasification at different commercial scales. By prioritising the extraction of proteins and other high-value molecules before diverting residual biomass to anaerobic digestion, value is maximised across multiple product streams. Such cascading use of biomass not only preserves nutrient quality for food and feed markets but also enables substantial reductions in greenhouse gas emissions, improved nitrogen-use efficiency, and diversification of income sources for rural communities. These wider integration pathways ensure that biomethane functions as part of a multi-product, circular bioeconomy rather than a standalone energy technology.

Middle – policy, governance, and enabling conditions-Ireland now operates within a three-tier policy framework that provides strong foundations for this transition. At the EU level, REPowerEU and RED III set ambitious targets for sustainability thresholds for biomethane technology. At the national level, the *National Biomethane Strategy (2024)* translates these ambitions into a concrete deployment roadmap, targeting 5.7 TWh per year of residue-led feedstock by 2030. At the bioeconomy level, the *Bioeconomy Action Plan (2023–2025)* embeds biomethane within wider circular value chains, ensuring that nutrient valorisation, rural development, and regional clusters are prioritised alongside energy production.

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Governance and compliance mechanisms provide further assurance. The EPA regulatory framework safeguards environmental performance through licensing, digestate management rules, and monitoring requirements, while the Bioeconomy Implementation Group coordinates cross-sectoral delivery of the Bioeconomy Action Plan. On-the-ground learning is provided by the Biomethane Development Office, which serves as a demonstration hub for integrating anaerobic digestion, biorefinery steps, nutrient recovery, thermochemical and fermentation-based processes, and energy valorisation at scale.

To reach its targets, Ireland must still overcome several enabling challenges. These include reducing grid connection costs for biomethane injection, finalising digestates end-of-waste standards to ensure safe nutrient recycling and investing in skills and workforce development to support rapid industry expansion. Addressing these factors is crucial to ensuring that the 5.7 TWh/year biomethane goal is not only met but also achieved in a manner that delivers genuine climate, economic, and social benefits.

In conclusion, Ireland is uniquely positioned to become a lighthouse for integrated bioeconomy networks in Europe, particularly those that combine biochemical, thermobiochemical, and nutrient recovery technologies with anaerobic digestion. Ireland has a credible opportunity to build an integrated biomethane and circular bioeconomy system, but delivery at scale by 2030 will depend on timely progress in standards, infrastructure, skills, planning, finance and market development. If key enablers are delayed, a phased scenario based on regional flagship hubs and progressive build-out may be more realistic than a uniform national roll-out. By coupling green biorefineries and other bioeconomy processes with a farmer-led anaerobic digestion cluster, it reflects broader integration. By embedding deployment within a supportive EU and national policy framework, the country can demonstrate how a residue-based, circular bioeconomy can deliver climate mitigation, rural revitalisation, and strategic energy security. If the identified enabling conditions are resolved, Ireland's biomethane sector will not only meet national needs but also contribute to European decarbonisation pathways, showcasing a scalable model of sustainable bioresource utilisation ahead of the 2030 EU goalsThis integrated approach positions Ireland to demonstrate a scalable, multi-technology circular bioeconomy model that can be replicated across regions..

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Annex:

1. Rural BioReFarmeries

Rural BioReFarmeries[104] project is a newly launched EU-funded initiative under the Circular Bio-based Europe Joint Undertaking (CBE-JU), running from 2024 to 2028. Its goal is to demonstrate *small-scale, farmer-centric green biorefineries* that transform grassland and other green biomass into multiple valuable products such as animal feed proteins, fertilisers, biobased materials, and high-value compounds. By placing processing close to the farm and involving farmers directly, the project reduces transport costs, strengthens local supply chains, and ensures that rural communities benefit from new business opportunities. Demonstration sites in Ireland, Denmark, and the Netherlands will test these models and validate their technical, economic, and environmental performance.

The expected outcomes encompass both economic and societal aspects. Farmers will gain new income streams and reduce their dependency on imported feed and fertilisers, while rural areas will benefit from green job creation and increased resilience. Environmentally, the project aims to reduce greenhouse gas emissions, improve nutrient recycling, and increase the efficient use of land and biomass. Beyond the demonstrations, Rural BioReFarmeries will deliver ICT tools, logistics solutions, and replicable business models, paving the way for small, innovative, and farmer-led biorefineries to be scaled across Europe[105].

Linked actions: Supports **on farm biorefinery pilots** and **regional hubs** envisaged in **Action Plan Pillars 4 & 5**.

2. Biorefinery Glas

Biorefinery Glas was a European Innovation Partnership (EIP-AGRI) pilot project run in Ireland between 2018 and 2021, coordinated by Teagasc with industry and farming partners. Its core aim was to test the feasibility of "green biorefining" under Irish farming conditions, particularly using multi-species grass swards as feedstock[106]. A mobile screw-press system was deployed directly on farms to fractionate freshly harvested grass into protein-rich juice and fibrous press cake. The project attempted to demonstrate how such decentralised, low-energy processing could:

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[104] *https://www.mtu.ie/news/rural-biorefarmeries-demonstration-project/*
[105] *https://horizoneurope.ie/global-challenges-european-industrial-competitiveness/food-bioeconomy-natural-resources-agriculture-and-environment/rural-biorefarmeries-supporting-sustainable-agriculture-and-bioeconomy-development-and-building-resilient-rural-areas*
[106] *https://teagasc.ie/wp-content/uploads/media/website/publications/2021/Biorefinery-Glas.pdf*

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- Produce a local, sustainable protein concentrate for use in animal feeds, thereby reducing dependence on imported soy.
- Enable cascading use of biomass, with fibre residues valorised for anaerobic digestion or material applications[107].
- Deliver climate benefits through avoided ensiling losses and displacement of high-footprint protein imports.

Key Results:

Between 2018 and 2021, the Biorefinery Glas operational group processed 4,000 t of multi-species grass using a mobile screw-press. Scientific analysis reported protein yield 6.5–7.2 t LPC DM per 100 ha, a 40 % uplift over direct silage feeding systems[108].

- Anaerobic potential of press-cake averaged 510 ± 20 L CH_4 kg^{-1} VS, matching best-practice grass silage despite prior juice removal.
- GHG footprint fell by 0.12 t CO_2-eq t^{-1} fresh matter relative to conventional grass-silage AD, reflecting soymeal displacement and reduced ensiling losses.
- Farmer economics improved by €156 ha^{-1} net when protein and fibre revenues plus avoided fertiliser costs were combined.

While projects such as Biorefinery Glas demonstrate the technical feasibility of integrating green biorefinery and anaerobic digestion systems, their transition to fully commercial, scalable deployment in Ireland remains at an early stage. Key challenges include market development for co-products, capital costs, logistics and integration with downstream processing infrastructure.

[107] *https://dcapub.au.dk/djfpublikation/djfpdf/DCArapport193.pdf*
[108] *https://biorefineryglas.eu/*

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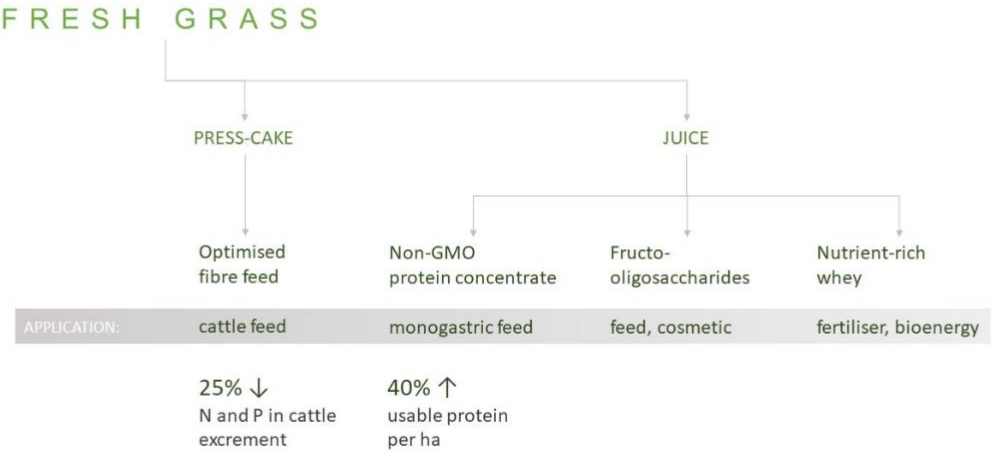

Figure 4: Biorefinery Glas process[109]Source: Teagasc & MTU, Biorefinery Glas Technical Report 2018–2021.

3. Farm4More

Farm4More is a multi-year demonstration project co-financed under the EU LIFE programme and supported in Ireland by the Department of Agriculture, Food and the Marine (DAFM)[110].

Its core objective is to reduce greenhouse gas (GHG) emissions in animal protein production by integrating green biorefinery and biochar technologies into grass- and seaweed-based feed systems[111].

Policy relevance: Demonstrates feed displacement, residue valorisation, and biochar routes aligned with the Bioeconomy Action Plan Pillars 3 & 4.

Key elements & process

- The project operates a pilot green biorefinery that processes grass silage and legume or seaweed silage into high-value protein and amino acid concentrates for monogastric livestock (pigs and poultry).
- Biomass is fractionated into a liquid juice and a solid press-cake. The juice is processed into protein concentrates, while the press-cake can be used as ruminant feed or as feedstock for anaerobic digestion.

[109] https://biorefineryglas.eu/
[110] https://informbioproject.ie/bbvc/life-farm4more
[111] https://www.farm4more.eu/about-the-project/

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- A novel seaweed ensiling method is being trialled to lower the carbon footprint of drying and preservation, making seaweed a viable supplementary feedstock.
- A biochar pilot plant is included, producing animal feed additives that can reduce enteric methane in livestock and/or improve soil carbon sequestration.

Consortium & scope

- Coordinated by University College Dublin (UCD) with partners in Ireland and Austria, including research institutes, marine specialists, and biorefinery R&D firms.
- The project runs across both countries to test the adaptation of the technologies in different feedstock contexts.

Outcomes & significance

- **Feed displacement & emissions reduction**: By producing high-protein feed additives, Farm4More reduces reliance on imported feedstuffs such as soy, cutting embodied emissions.
- **Residue valorisation**: The press-cake residue provides an energy-yielding feedstock for anaerobic digestion.
- **Seaweed feedstock diversification**: Ensiling methods enable coastal biomass utilisation for bioeconomy applications.
- **Techno-economic guidance**: The project delivers optimisation, cost modelling, and stakeholder engagement to support future scale-up and policy uptake.

Policy relevance: Demonstrates feed displacement, residue valorisation, and biochar routes aligned with the Bioeconomy Action Plan Pillars 3 & 4.

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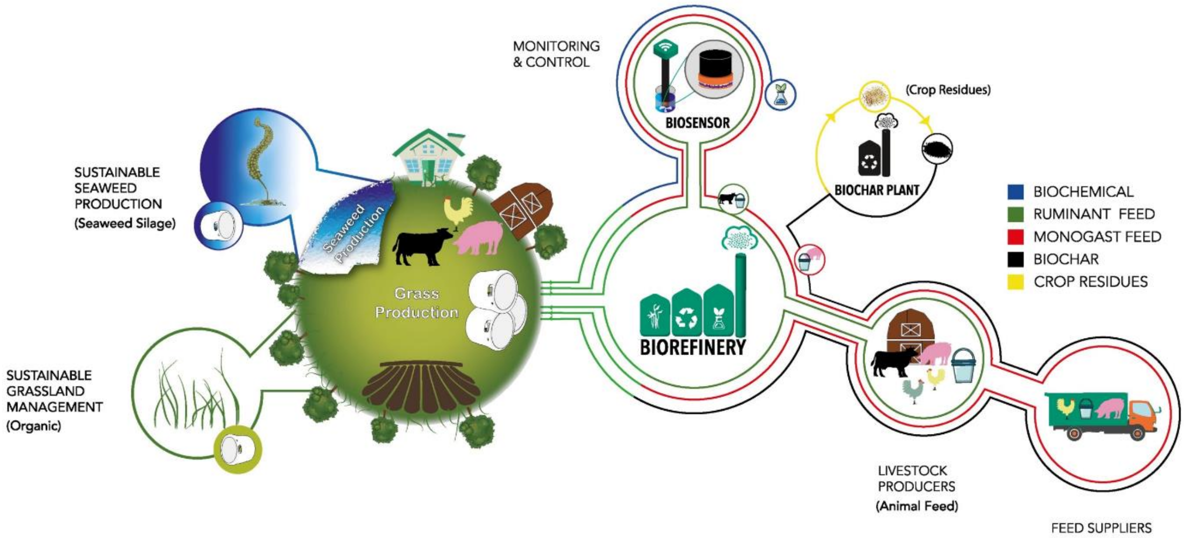

Figure5: Farm4More[112]

4. Farm Zero C

The project is an ongoing demonstration; results are indicative and farm-specific. Farm Zero C is a collaborative project based at Shinagh dairy farm in Co. Cork, aiming to demonstrate how a commercial dairy farm can reach net-zero greenhouse gas (GHG) emissions by 2027[113]. The initiative integrates multiple technologies, business models, and land-use practices to deliver deep emission cuts while sustaining farm productivity.[114]

One of the central strategies of Farm Zero C has been to build on the green biorefinery principles proven in Biorefinery Glas. Multi-species grass swards are grown to increase protein yields, biodiversity, and soil carbon sequestration. Harvested grass is then fractionated to separate protein-rich juice from fibrous press cake. The protein fraction is utilised as a high-value animal feed, displacing imported soy. At the same time, the fibrous residue serves as feedstock for anaerobic digestion, producing renewable energy as biogas or upgraded biomethane. This cascading use of grass ensures that the highest-value nutrients are captured first, while energy recovery is reserved for lower-value fractions, maximising overall resource efficiency[115].

By integrating green biorefining with anaerobic digestion, Farm Zero C not only reduces reliance on high-emission imported feed proteins but also provides a pathway to renewable

[112] *https://www.farm4more.eu/*
[113] *https://farmzerocproject.ie/*

[115] *https://www.carbery.com/sustainability/farm-zero-c/*

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energy self-sufficiency and closed-loop nutrient recycling. The approach mirrors Biorefinery Glas outcomes—improved nitrogen-use efficiency, reduced ensiling losses, and enhanced farm economics—while embedding them into a whole-farm decarbonisation model. The result is a practical demonstration that dairy systems can simultaneously reduce carbon emissions, diversify farmers' incomes, and valorise grass as a versatile bioresource.

Fig 6: Fresh grass is separated into press juice and press cake; juice yields protein concentrates and functional carbohydrates; cake and brown juice go to AD; digestate returns nutrients to soil; biomethane and CO_2 support energy/users[116].

5. SEAI FUNDED PROJECTS[117]

Agri Bio Circular Economy (ABC Economy)-

The ABC Economy project is focused on building new regional value chains for the circular bioeconomy in Ireland. It examines how different types of agricultural and organic biomass can be used more efficiently through cascading, first for high-value bioproducts and then for energy. The project works closely with local authorities and industry stakeholders to understand what resources are available in different regions and how they can be turned into viable bio-based products. A key feature of the project is its comprehensive supply chain sustainability analysis, which assesses where the most significant environmental benefits and

[116] *https://biorefineryglas.eu/*
[117]https://www.seai.ie/sites/default/files/2025-11/SEAI-DAFM-Policy-Brief.pdf

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trade-offs occur. ABC Economy builds on existing Irish and European research but goes further by combining life-cycle analysis, market assessment, and stakeholder engagement. The overall aim is to provide a practical blueprint for developing sustainable regional bioeconomy value chains in Ireland.

BioPyroC-

BioPyroC responds to two significant national challenges: managing agri-food waste and reducing greenhouse gas emissions. The project converts agricultural residues into valuable products, such as biochar, bio-oil, and syngas, through advanced pyrolysis. It also includes laboratory and field trials to assess how biochar performs in Irish soils, including its potential for carbon storage, soil health improvement and environmental safety. BioPyroC brings together biomass pretreatment, process optimisation, carbon accounting, and risk assessment to fully understand the economic and ecological benefits. The project positions pyrolysis as a pathway not only for waste reduction but also for building a carbon-negative bioeconomy model.

CABBBIE – Cascading Algal Biomethane Biorefinery System-

CABBBIE explores how biomethane production and microalgae can be combined to produce both renewable gas and high-value bioproducts. The project investigates low-carbon methods for upgrading biogas using microalgae and examines how the process can be adapted to the Irish climate and feedstocks. CABBBIE also examines technical performance, environmental impacts, business models and policy requirements to enable this biorefinery approach to scale up. The long-term goal is to support a future bioeconomy in which biomethane and bioproducts are produced locally and sustainably in rural areas.

EirAlgae-

EirAlgae brings together anaerobic digestion and microalgae production in a single biorefinery concept. The project looks at how digestate and biogenic CO_2 from AD plants can be converted into algal biomass rich in protein and omega-3 oils for use in animal feed. The ambition is to improve the environmental and economic performance of AD plants and contribute to food security, energy independence and Ireland's climate targets. The project focuses on the practical integration of both technologies and the market potential for the bio-based products produced.

EXPAND-

EXPAND focuses on the broader value of anaerobic digestion beyond biomethane. As Ireland plans up to 200 AD plants to meet its 2030 biomethane target, the project examines how digestate and biogenic CO_2 can become reliable products. The current project includes

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identifying value chains, potential markets, and technical or regulatory barriers. The project will evaluate how digestate can be optimised as a fertiliser and how biogenic CO_2 can be used or stored. The overall aim is to reduce costs in the AD sector and identify business opportunities that help the industry scale sustainably.

Enhancing and Assessing the Impact of Novel Circular Economy Sectors-

This project examines how emerging circular economy industries can scale up in Ireland. It conducts case studies that map value chains, identify market opportunities, assess the technical and commercial challenges, and analyse the knowledge needed to bring new products to market. It uses innovation frameworks, economic impact modelling and life-cycle assessment to understand the effects of new technologies on jobs, emissions, resource use and local communities.

BioAssess-

BioAssess develops and tests a framework to assess the environmental, economic and social consequences of using biomass for fuels and bio-based products in Ireland. It analyses different value chains by examining where the biomass comes from, what products it produces, and what it replaces. The project aims to help identify unintended effects and provide better evidence for policy and financial support mechanisms.

AgriRenew-

AgriRenew examines the extent of the farming sector's current engagement with renewable energy and bioeconomy projects. It identifies the main financial, social and technical drivers that influence participation, as well as the barriers that make adoption more difficult. The results help pinpoint where support or incentives are needed to increase farmer involvement in renewable and bio-based projects.

High-value BIO-based products from residual agri-food biomass via pyrolysis-

This project focuses on converting Ireland's large volumes of agri-food waste into high-value products using pyrolysis. It will investigate the potential of various residues to produce biochar and other carbon-rich materials and evaluate biochar stability in Irish soils and its ability to reduce greenhouse gas emissions. The aim is to show how pyrolysis can provide both carbon sequestration and residue valorisation solutions.

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