WIRE

Waste biorefinery technologies for accelerating sustainable energy processes

Bridging Policy, Innovation and Industry for a Sustainable Biorefinery Future

Theo Zacharis

04 July, 2025

Working Group 4

7th Working Groups Workshop – Faro Portugal

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GREEK SCIENTISTS SOCIETY

Theo Zacharis

Greek Scientists Society

Bridging Policy, Innovation and Industry for a Sustainable Biorefinery Future

03-04 July 2025

Presentation Agenda

01 Present State of the Biorefinery Sector in Europe
- The Challenge of Fragmentation
- WIRE's Strategic Vision & Achievements

02 Bridging Knowledge and Application

03 Key Contributions to the Biorefinery Ecosystem

04 Impact & Future Opportunities

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1. Present State of the Biorefinery Sector in Europe

Where We Stand

- Europe has made progress in biorefinery R&D, but deployment remains uneven.
- Innovation is strong, particularly in advanced bio-conversion (e.g. enzymatic hydrolysis, pyrolysis, torrefaction).
- However, policy frameworks lag behind technological developments - no clear regulatory path exists for market entry, certification, or inclusion in funding/procurement schemes.

- EU Taxonomy for Sustainable Activities
- Renewable Energy Directive (RED II & RED III)
- Waste Framework Directive
- EU Circular Economy Action Plan
- REACH Regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals)
- Green Public Procurement (GPP) Guidelines

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Present State of the Biorefinery Sector in Europe

Key Dynamics

- Decentralised initiatives: Many small-scale biorefineries with little standardisation
- Research fragmentation: Projects focus on isolated stages (feedstock, conversion, etc.)
- Market barriers: Scale-up is slow due to regulatory uncertainty, lack of investor confidence

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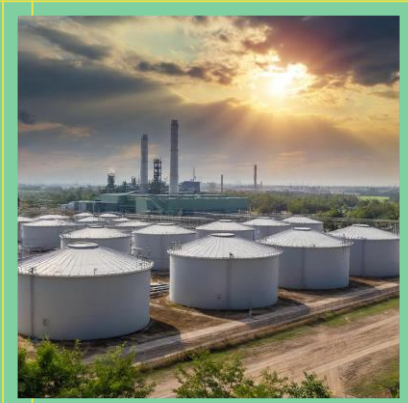
Biorefinery Market Value 2024



162 (USD billion)

~263 by 2030

Source: Precedence Research

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Biorefinery Market Value

2023

150 Bn

- Source: Precedence Research

Now

~178 Bn

- Source: Research Nester

2030

263 Bn

- Source: Precedence Research

2034+

391 Bn

- Source: Precedence Research

The market is growing at a **CAGR of about 8–9%**
Longer-term projections suggest it could exceed **USD 475 billion by 2037**

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Present State of the Biorefinery Sector in Europe

Innovation Drivers

- Demand for bio-based alternatives to fossil inputs (plastics, fuels, chemicals)
- Green Deal & Circular Economy Plans boosting interest
- Emerging digital tools (e.g. LCA automation, biomass flow modelling) aiding design optimisation

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Present State of the Biorefinery Sector in Europe

Research-Policy Gap

- Scientific knowledge exists, but policy frameworks (e.g. sustainability criteria, certification) are outdated or inconsistent
- TRL gaps: Many innovations remain at lab or pilot level with no roadmap to industrial adoption

🧪 *Example: Biogenic CO_2 valorisation and lignin-based polymers are scientifically feasible, but not yet supported by consistent EU-wide market regulations*

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1. Present State of the Biorefinery Sector in Europe

🧪 Example: Lignin-Based Polymers & Biogenic CO_2 Valorisation

- Lignin-derived polymers can replace petrochemical-based plastics in packaging and coatings
- Biogenic CO_2 can be converted into value-added chemicals like methanol or polyols using microbial or catalytic processes

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Example: Lignin-Based Polymers & Biogenic CO_2 Valorisation

Why Aren't These Scaled Yet?

1. Lack of regulatory clarity

- EU legislation still treats all CO_2 emissions similarly — no clear incentives for biogenic CO_2 utilisation
- Certification frameworks (e.g. RED II, taxonomy) don't reward carbon circularity in these cases

Example: Lignin-Based Polymers & Biogenic CO_2 Valorisation

Why Aren't These Scaled Yet?

2. No industry standards

- No harmonised LCA indicators or standardised testing protocols for lignin-based products
- Difficult for SMEs to demonstrate performance or sustainability for market entry

Example: Lignin-Based Polymers & Biogenic CO_2 Valorisation

Why Aren't These Scaled Yet?

3. Fragmented research

- Studies often focus on lab-scale optimisation with little investment in downstream integration
- No common databases or pilot demonstrators linking feedstock availability to application

The Challenge of Fragmentation

Why Integration Across the Biorefinery Value Chain Remains Elusive

Current Reality ¬ *Despite promising R&D outcomes, the biorefinery field remains siloed—leading to slow adoption, duplicated efforts, and underused innovations.*

Where Fragmentation Persists

Discipline-level

- Feedstock, process engineering, and application developers rarely interact

- e.g. biomass experts unaware of downstream conversion limits

The Challenge of Fragmentation

Why Integration Across the Biorefinery Value Chain Remains Elusive

Current Reality ¬ *Despite promising R&D outcomes, the biorefinery field remains siloed—leading to slow adoption, duplicated efforts, and underused innovations.*

Where Fragmentation Persists

Geographical

- Regional pilot plants operate in isolation (e.g. Central Europe vs. Med initiatives)
- Weak interregional knowledge sharing

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The Challenge of Fragmentation

Why Integration Across the Biorefinery Value Chain Remains Elusive

Current Reality ¬ *Despite promising R&D outcomes, the biorefinery field remains siloed—leading to slow adoption, duplicated efforts, and underused innovations.*

Where Fragmentation Persists

Sectoral

- Industry often not involved until TRL 6+
- Policymakers consult academia, but rarely include SMEs or local cooperatives

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Practical Consequences

- Misaligned metrics for LCA, yield, and circularity
- Incompatible data formats and reporting tools
- Slowed standardisation of bio-based products in procurement schemes

Biogenic CO_2

We saw how biogenic CO_2 and lignin have strong R&D momentum, but stall at scale.

This is a clear symptom of deeper fragmentation — between the science, the regulation, and the market.

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Waste biorefinery technologies for accelerating sustainable energy processes

WIRE's Strategic Vision

Tackling Fragmentation Through Shared Tools, Language, and Outcomes

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WIRE's Strategic Vision

Tackling Fragmentation Through Shared Tools, Language, and Outcomes

What should set WIRE Apart

- Moves beyond coordination → Forges practical interoperability → Aligns experimental protocols, LCA frameworks, and data standards across institutions
- Brings science and industry into dialogue early → Enables uptake-ready results, not just publications
- Promotes systemic thinking → Biomass is approached not just as a resource, but as a flow linked to logistics, conversion capacity, and end-user relevance

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2. Bridging Knowledge and Application

From Research Outputs to Industry-Ready Solutions

The Core Challenge

Europe's biorefinery research is world-class — but much of it remains in TRL 2–4. What's missing? A structured translation layer to move knowledge into usable, replicable systems for market deployment.

Strategic Bridging Priorities

Standardise Experimental Outputs

- Align protocols for torrefaction, pyrolysis, enzymatic hydrolysis across labs

- Share open data and validated models (LCA, material flow, techno-economic)

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Strategic Bridging Priorities

Design for Industrial Uptake

- Engage SMEs and mid-cap industry during R&D, not after

-Create testbeds for co-development (e.g. biomass conversion validation facilities)

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2. Bridging Knowledge and Application

Enablers That Connect Knowledge, Markets, and Governance

Strategic Integration Topics

Standardisation & Regulation for Innovation Uptake

- Harmonised sustainability metrics (e.g. LCA, circularity, carbon intensity)
- Regulatory sandboxes for emerging biorefinery technologies

Case: lack of EU-wide CO_2 valorisation incentives stalls investment

Public Procurement & Bio-Based Market Creation

- Green procurement frameworks can stimulate demand for bio-based materials
- Innovation-oriented procurement allows piloting pre-commercial products

Case: municipal tenders could favour lignin-based coatings or biochar

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2. Bridging Knowledge and Application

Enablers That Connect Knowledge, Markets, and Governance

Strategic Integration Topics

Policy-Embedded Testbeds & Industrial Pilots

- Link R&D outputs to pilot schemes co-funded or recognised by regulators
- Use “regulatory test zones” or “policy labs” to fast-track industry alignment

Case: regional innovation hubs tied to EU Missions (e.g. soil, cities, climate)

Skills & Workforce Transformation

- Reskilling technical operators for new bio-conversion routes
- Policy must support vocational–academic partnerships

Case: training on modular bioreactors for agro-industrial parks

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3. Key Contributions to the Biorefinery Ecosystem

Building Blocks for a Functional and Scalable System

The Core Challenge

1. Interoperable Knowledge Frameworks

- Harmonised methodologies (e.g. LCA, techno-economic analysis, risk mapping)
- Open repositories of validated experimental data and biomass characteristics
- Shared ontologies enabling semantic and computational integration

Knowledge Systems & Data Infrastructure

- Harmonised research protocols and experimental standards
- FAIR and open-access databases for biomass, conversion routes, and outputs
- Shared modelling environments (e.g. LCA, circularity, techno-economics)
- Interdisciplinary training modules to unify terminology and tools

3. Key Contributions to the Biorefinery Ecosystem

Building Blocks for a Functional and Scalable System

The Core Challenge

2. Industry-Ready Research Outputs

- Process results structured for scalability (TRL 4–7 focus)
- Pilots embedded in real industrial and regional contexts
- Technology development aligned with investment criteria and policy needs

Industrial Integration & Technology Readiness

- Pilot-scale demonstrations embedded in value chains
- Industry co-development of conversion pathways (e.g. biochar, lignin derivatives)
- Use-case alignment with market trends (e.g. sustainable packaging, green construction)
- Robust TRL 4–7 mechanisms for cross-border tech transfer

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3. Key Contributions to the Biorefinery Ecosystem

Building Blocks for a Functional and Scalable System

The Core Challenge

3. Continuous Policy–Market Feedback Loops

- Living regulatory intelligence: feedback from pilots to adjust frameworks
- Evidence-based standards development
- Coordinated dialogue platforms for legal certainty, incentives, and uptake

Policy & Regulatory Foundations

- Adaptive policy design for emerging bio-based value chains
- LCA-based procurement and certification systems
- Early-stage regulatory guidance to reduce innovation bottlenecks
- Clear sustainability criteria tied to EU Green Deal and taxonomy

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3. Key Contributions to the Biorefinery Ecosystem

Building Blocks for a Functional and Scalable System

The Core Challenge

4. Institutionalised Collaboration Mechanisms

- Long-term infrastructures for public–private–research partnerships
- Multi-actor governance of shared resources (e.g. biorefinery data spaces, testbeds)
- Policy and funding instruments designed to support collaboration, not competition

Systemic Coordination & Long-Term Structures

- Stable funding pathways for infrastructure and multi-actor governance
- Federated research environments across regions
- Digital twins and scenario tools for forward planning
- Neutral spaces (observatories, hubs) for aligning science, policy, and industry

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4. Impact & Future Opportunities

Toward a Coherent and Competitive Biorefinery Future for Europe

Emerging Opportunities

- Scaling decentralised biorefinery models in rural and industrial regions
- Creating real-time knowledge systems (digital twins, open dashboards)
- Embedding biorefinery innovation in EU Missions (Soil, Circular Cities, Climate)
- Expanding high-value product markets (bio-based chemicals, advanced materials)

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4. Impact & Future Opportunities

Toward a Coherent and Competitive Biorefinery Future for Europe

Strategic Priorities

- Institutionalise collaboration platforms between science, policy, and industry
- Build testbeds and pilot clusters linked to procurement and regulation
- Shape policy frameworks for adaptability, not just compliance
- Secure long-term investment mechanisms beyond project-based funding

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4. Impact & Future Opportunities

Toward a Coherent and Competitive Biorefinery Future for Europe

Vision for the Next Phase

A sustainable biorefinery system in Europe will depend on:

✓ Trusted, standardised knowledge

✓ Validated, scalable technologies

✓ Responsive and enabling policies

✓ A governance model that connects all three

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4. Impact & Future Opportunities

Toward a Coherent and Competitive Biorefinery Future for Europe

Vision for the Next Phase

A sustainable biorefinery system in Europe may have:

✓ Multi-purpose biorefineries integrated into industrial symbiosis networks (e.g. Kalundborg-style models that optimise resources, emissions, and value exchange) producing fuels, materials, and chemicals while exchanging energy, by-products, and data across sectors

✓ Integration with Carbon Capture pathways to enable negative emissions and expand the value chain through biogenic CO_2 utilisation.

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Call to Action
What Comes Next?

A Strategic post-Action Sustainability project (PASP) to Sustain and Scale the WIRE Vision

Why a PASP is Needed?

- WIRE has built tools, protocols, and trust this should not dissolve post-Action
- Key stakeholders (industry, policymakers, researchers) now share a common language
- The biorefinery transition requires structures, not just projects

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Strategic PASP Directions for WIRE

❖ European Biorefinery Intelligence Hub

→ A platform combining data, policy briefings, LCA standards, and industrial contacts
→ Circular Bio-based EU Partnership, Digital Product Passport, or taxonomy instruments

❖ Distributed Testbed & Demo Platform

→ Networked pilot nodes across Europe to test feedstock-conversion-market chains
→ Open to SMEs, research labs, and regional authorities

❖ Innovation Centre of Excellence for Translational Biorefinery Solutions

→ Open, challenge-driven opportunities for SMEs and researchers to co-develop and validate scalable bio-based technologies
→ Supports real-time collaboration, mentoring, and regulatory alignment to accelerate industrial and policy uptake

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THANK YOU

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