Circular Bioeconomy 2020

Summary of CIRCULÉIRE's Thematic Working Group Comprehensive Synthesis Report

Elaborated by Irish Bioeconomy Foundation and Irish Manufacturing Research

Authorship

This *Circular Bioeconomy 2020 Summary Report* highlights key findings from the *Circular Bioeconomy 2020 Comprehensive Synthesis Report* – please refer to the comprehensive report for more detailed insights into the Irish circular bioeconomy landscape.

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Acknowledgements

IMR and IBF would like to thank the following actors without which neither the *Circular Bioeconomy 2020 Summary Report* nor the *Circular Bioeconomy 2020 Comprehensive Synthesis Report* would have been possible:

- ***Expert Panel Members***
- ***Anonymous Expert Peer Reviewer***
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About CIRCULÉIRE

CIRCULÉIRE is Ireland's first cross-sectoral industry-led innovation network dedicated to accelerating the net-zero carbon circular economy transition.

CIRCULÉIRE is a public-private partnership co-created by Irish Manufacturing Research (Secretariat), an Enterprise Ireland and IDA Ireland supported Technology Centre, and three Strategic Partners; the Department of the Environment, Climate and Communications (DECC), the Environmental Protection Agency (EPA), and EIT Climate-KIC with a growing network of cross-sectoral Industry Members.

CIRCULÉIRE's overarching objective between 2020-2022 is to source, test, finance, and scale, circular manufacturing systems, supply chains and circular business models to deliver significant reductions in both CO_2 emissions and waste over the lifespan of the program.

CIRCULÉIRE seeks to harness collective insight from the broader Irish innovation ecosystem through annual Thematic Working Groups identifying knowledge gaps and international best practice for replication in Ireland. In 2020 focus areas were:
1) Circular Bioeconomy
2) Industrial Symbiosis
3) Circular Procurement.

Want to learn more about CIRCULÉIRE? Look at www.circuleire.ie or contact circuleire@imr.ie

About Irish Bioeconomy Foundation

Irish Bioeconomy Foundation (IBF) is headquartered on the National Bioeconomy campus in Lisheen, Co. Tipperary. The IBF is Ireland's national bioeconomy association and innovation cluster. IBF was founded in mid-2017 to establish a fora of industry, academia and policy leaders around Ireland's emerging bioeconomy.

IBF mission is to promote the conversion of Ireland's natural land & sea resources to high-value products for the development of a sustainable bioeconomy that is globally competitive and creates local development. To date IBF has 24 members including many of the Irish academic institutes complimented with members from Industry. IBF provides the following pre-competitive services to their members:
1) Support in design and scale-up
2) Access to financing
3) Promotion and Outreach

Want to learn more about IBF? Look at https://bioeconomyfoundation.ie/ or contact info@bioeconomyfoundation.com

Circular Bioeconomy 2020 Thematic Working Group Panel Members

We wish to acknowledge the sixteen external members of CIRCULEIRE's Circular Bioeconomy Thematic Working Group who gave their time between June-October 2020 to contribute insights which shaped the elaboration of the *Circular Bioeconomy 2020 Comprehensive Synthesis Report*, which this Summary Report is based upon.

- Andrea Cawley, Automatic Plastics
- Cera Slevin, Climate Matters Ltd
- Christine O'Connor, TU Dublin
- Declan Devine, Athlone Institute of Technology
- Donald McDonagh, Cillnua Innovation Funding Services
- Gill Higgins, Dawn Meats
- James (JJ) Leahy, University of Limerick
- Joanne Rourke, Eastern-Midlands Regional Waste Management Office (EMRWMO)
- John Colreavy, Meat Technology Ireland (MTI)
- Margaret Brennan, Athlone Institute of Technology (AIT)
- Maeve Henchion, Teagasc
- Nick Holden, UCD / BiOrbic
- Orla Lindsey, Optel Group
- Patrick Barrett, Department of Agriculture, Forestry & Marine (DAFM)
- Patrick Murray, Limerick Institute of Technology (LIT)
- Ramesh Babu, Trinity College Dublin (TCD)
- Robin Curry, Queens University Belfast

Executive Summary

Over the last decade the bioeconomy, circular economy and circular bioeconomy concepts have gained increased attention within the EU Policy arena. According to the 2012 European Bioeconomy Strategy, Bioeconomy is *"the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy"*. This definition cuts across several sectors including agriculture, forestry, fisheries, food, paper & pulp production, as well as parts of chemical, biotechnological and energy industries.

While bioeconomy strategies and scientific publications consider the bioeconomy to be inherently sustainable, others highlight its potential trade-offs and negative impacts namely pressure on water bodies and natural ecosystems, competition for land (i.e. direct and indirect land-use change), agricultural intensification, eutrophication and risks posed by invasive species.

The updated bioeconomy strategy of the European Commission (2018) emphasized that *"European Bioeconomy needs to have sustainability and circularity at its heart"*. Subsequently, all European Bioeconomy related strategies have been linked to the Circular Economy. Merging these two concepts has led to the coining of the term **'circular bioeconomy' (CBE)** which **refers to the intersection of bioeconomy and circular economy**.

Ireland has abundant bioresources that presents immense opportunities for the development of a circular bioeconomy. To explore these opportunities, the CIRCULÉIRE Circular Bioeconomy 2020 Thematic Working Group was established. **A key output of this process was a >200-page Comprehensive Synthesis Report on circular bioeconomy opportunities in Ireland & the EU developed by the Irish Bioeconomy Foundation (IBF)**, based on insights from the Thematic Working Group Panel Members who participated in a number of stakeholder meetings and ideation workshops between June and October 2020.

This summary report is a condensed form of the comprehensive synthesis report. An essential objective of this report is to summarise the state-of-the-art related to the technologies and potential biobased products from relevant sectors of the bioeconomy (bioactives, biomaterials, biobased chemicals and biofuel), as well as key policy items deemed necessary in the transition towards a circular bioeconomy in Ireland.

From a policy perspective, a selection of the most relevant policy elements to narrate the development of the bioeconomy in Europe and Ireland is described. At the Irish level, the two landmark policy documents are the 2018 National Policy Statement on Bioeconomy and the 2019 Bioeconomy Implementation Group Progress Reports. These demonstrate the Government's commitment to monitor and support the development of the Irish Bioeconomy within the context of "rural renaissance" under the Rural Development Action Plan. Policy aside, the Irish Government has implemented several interventions to support the development of the circular bioeconomy in Ireland. These and several regional bioeconomy development projects are highlighted in addition to private investments which are summarised herein.

In addition, key **circular bioeconomy innovation opportunities** were explored during the Circular Bioeconomy 2020 Thematic Working Group process related to the following feedstocks and the findings are presented herein: **1) Spent Mushroom Compost; 2) Dairy Processing Residues; 3) Straw Residues; 4) Forest Wood Biomass Residues; 5) Animal Manure; 6) Brewer's Spent Grain; 7) Organic Fraction of Municipal Solid Waste and 8) Meat Processing Waste.**

The high-level conclusions from this exploration of the Irish circular bioeconomy are; Firstly, the Irish bioeconomy and circular economy has vast unexploited environmental, social and economic potentials but several growth and developmental barriers still exist including 1) Incoherent framework for synergy building towards circular bioeconomy objectives 2) Low competitiveness of bio-based products 3) Weak primary producer value chain, 4) Low commercialisation and market stimulation potential, 5) Less start-up capital and expansion funding opportunities in comparison to other developed economies, 6) Inflexible waste classification systems and handling procedures. Secondly, overcoming the obstacles to the development of the Irish circular bioeconomy will require the promotion of circular thinking, the creation of conducive environments for circular business models to thrive, and ensuring policy coherence across bioeconomy sectors, as well as between bioeconomy sectors, concerned public authorities and consumers.

Contents

1.0 The European Circular Bioeconomy Policy Landscape

Key Messages:

- Bioeconomy, Circular economy and Circular bioeconomy gained attention within European Policy over the last decade.
- More intensive, successive and longer use of biomass residues and wastes via integrated biorefineries and cascading use of biomass is the key strategy for integrating bioeconomy and circular economy development.
- Three major visions of bioeconomy exist namely biotechnology, bioresource and bioecology visions.
- Advances in EU Bioeconomy and Circular Economy Policies has been the key driver of the achieved contextual and operational understandings of bioeconomy/circular economy across EU member states, new research initiatives and technology demonstrations, as well as accompanying research and technology business funding opportunities.

1.1 Evolution of European Circular Bioeconomy Policy

The bioeconomy, circular economy and circular bioeconomy concepts have gained increased attention within the EU Policy space over the last decade.

In 2012, the European Commission presented the first European Bioeconomy Strategy. In this report, the bioeconomy was described as "the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. This definition cuts across several sectors including agriculture, forestry, fisheries, food, paper & pulp production, as well as parts of chemical, biotechnological and energy industries.

The recognition and awareness of the potential role of biomass in meeting the global climate targets set in the Paris agreement (Creutzig et al, 2015) made the concept of "bioeconomy" very prominent within EU policy debates.

More specifically, biomass is one of the few renewable alternatives for the replacement of fossil fuels used within chemical industries, as well as heavy road transport, marine and aviation sectors, hence will considerably reduce the greenhouse gas (GHG) emissions of those sectors (OECD & IEA, 2018).

While bioeconomy strategies and scientific publications consider the bioeconomy to be inherently sustainable (Pfau et al, 2014), others highlight its potential trade-offs (McCormick & Kautto, 2013). Increased pressure on water bodies and natural ecosystems, competition for land (i.e. direct and indirect land-use change), agricultural intensification, eutrophication and risks posed by invasive species are some of the critical issues that put the emission reduction potential and overall sustainability of bioeconomy propositions to question.

In response to these questions, the updated bioeconomy strategy of the European Commission (2018) emphasized that "European Bioeconomy needs to have sustainability and circularity at its heart". Subsequently, practically all European Bioeconomy related strategies have been linked to the Circular Economy. Merging these two concepts has led to the term 'circular bioeconomy' (CBE), which appeared around 2015 and is increasingly being used in scientific publications since 2016. Hence, Circular Bioeconomy is defined from herein as: the intersection of the bioeconomy and circular economy.

1.2 Key strategies for circular bioeconomy

The circular bioeconomy focuses on sustainable, resource-efficient management of biomass in integrated, multi-output production chains to optimise its value.

Key strategies towards a more resource-efficient value optimization within the circular bioeconomy rely on more intensive use of biomass residues and wastes (i.e. either via the biorefinery or the biocascading approach i.e cascading use of biomass).

A biorefining approach may be via stand-alone facilities making a single product (e.g. first generation ethanol mills) or a more complex facility making more products within the same space (i.e. integrated biorefinery concept). The biocascading approach on the other hand involves the organization of biomass use in a manner that the most valuable application option (in terms of possibility for successive use) is prioritized over the next most valuable option and so on, before eventual use for energy recovery. This contributes to the rational use of bioresources and prevents unsustainable biomass use. A graphical description of the essential components and underlying principles of these two key strategies (i.e. biorefining and biocascading approaches) is found in Figure 1.

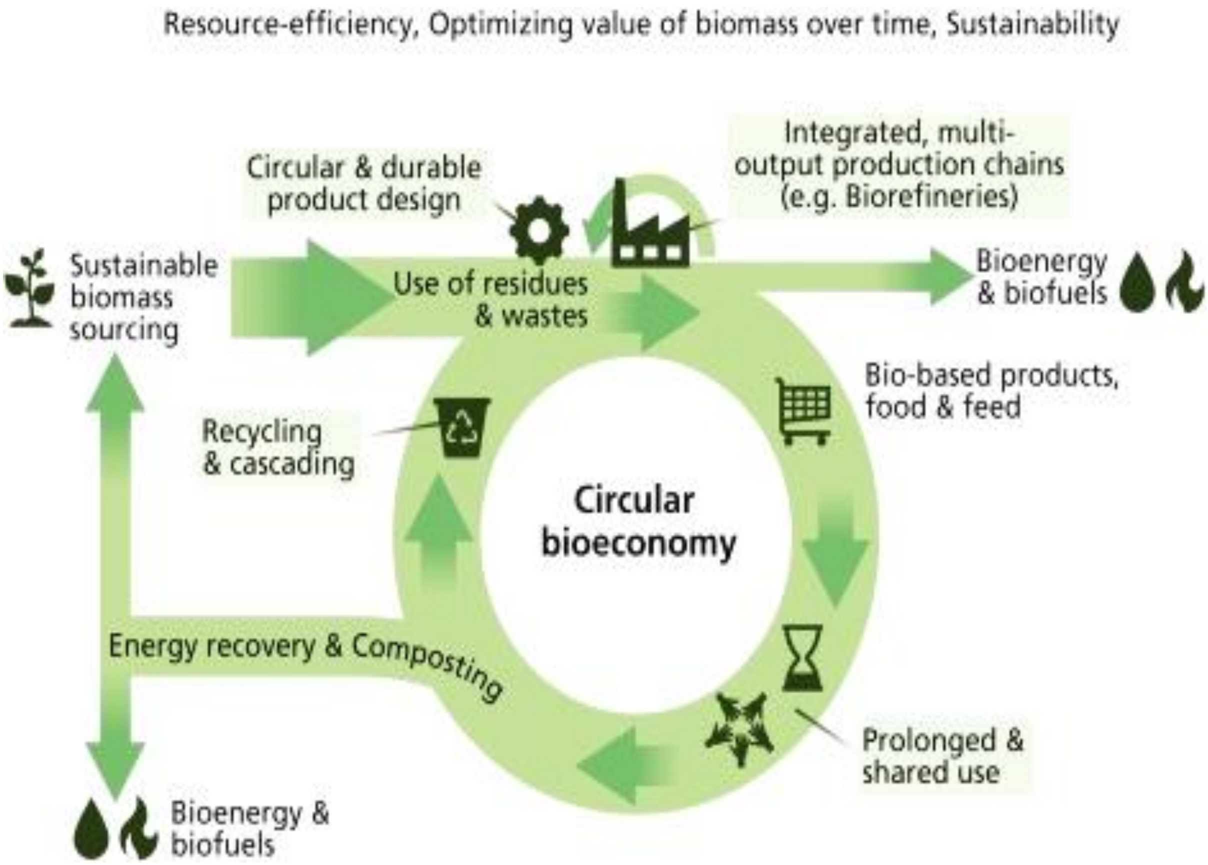

Figure 1: *Essential Components and Overarching Principles of Circular Bioeconomy (Stegmann, Londo & Junginger, 2020)*

Figures 2A and 2B describe the classical waste hierarchy, as well as a potential modification that prevents classification of many by-products/wastes as wastes (via biocascading) hence also enhancing the biorefinery approach (i.e. more prolonged use of biomass in integrated biorefineries).The hierarchy of importance for optimal biocascading is described in Figure 3. Please refer to **Section 1.1.1, 1.1.2 and 1.1.3** of the full synthesis report for further details.

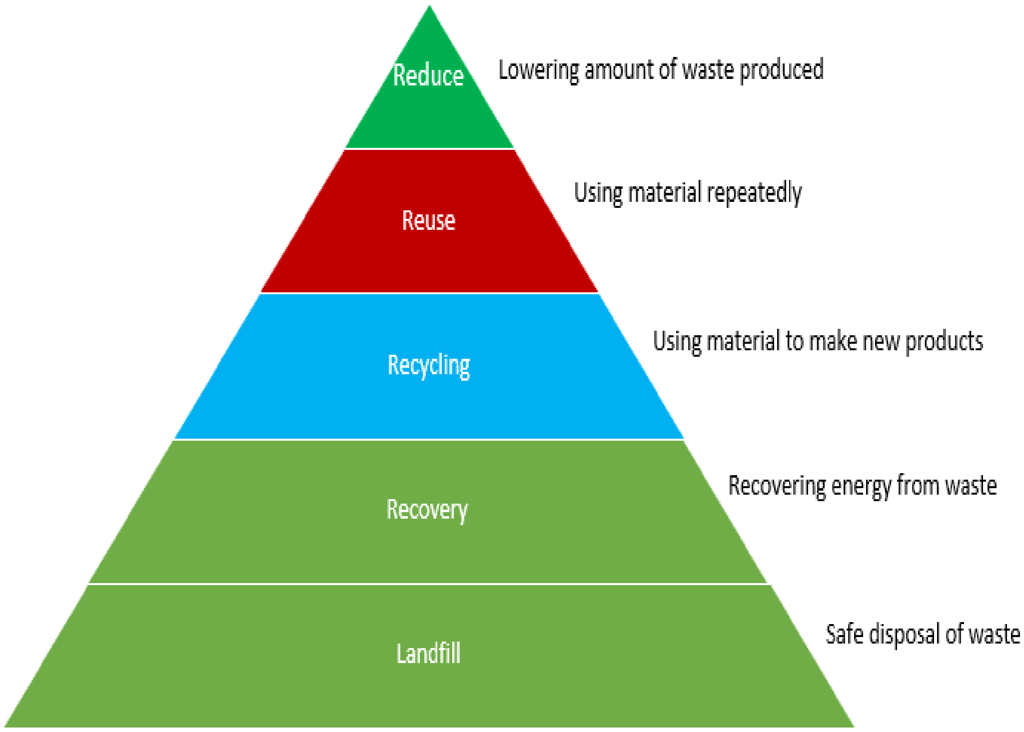

Figure 2A: *The Classical waste hierarchy Waste (OECD, 2020)*

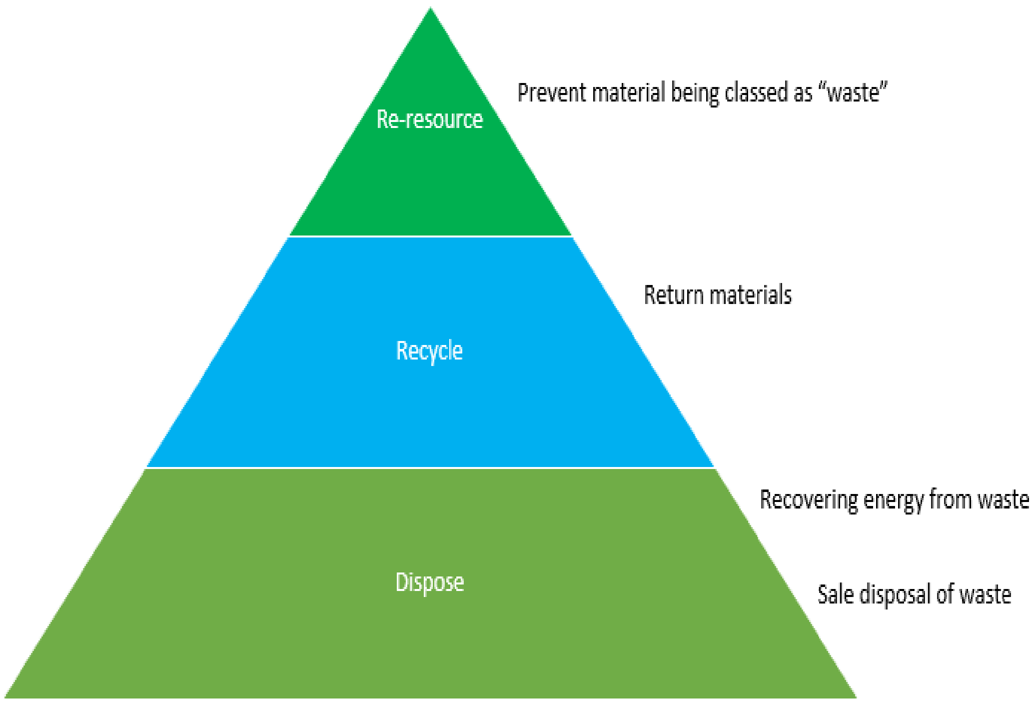

Figure 2B: *A more appropriate hierarchy for reducing barriers to waste biorefining (OECD, 2020)*

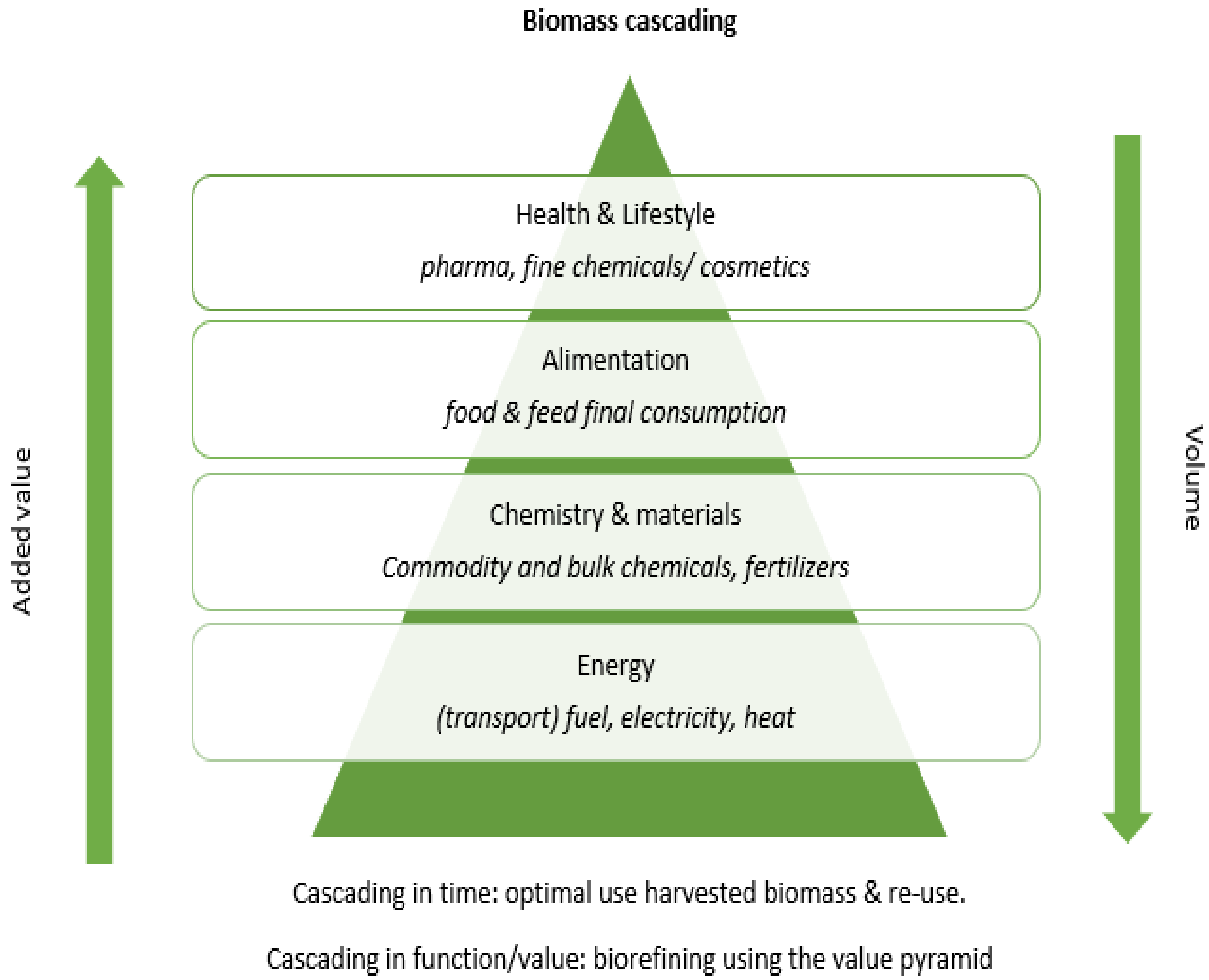

Figure 3: *Optimal sustainable use of biomass CASCADING/REFINING (Beek et al, 2014)*

1.3 Multiple Visions of the bioeconomy

The EU definition of bioeconomy encompasses several sectors, hence multiple visions, or perspectives. According to the Nordic Institute for Studies in Innovation, Research and Education (NIFU), there are three distinct visions of the bioeconomy (Bugge, Hansen & Klitkou, 2016):

1) **Biotechnology vision** emphasises the importance of biotechnology research, application, and commercialisation.

2) **Bio-resource vision** focuses on the role of research, development, and demonstration (RD&D) related to biological raw materials in primary production sectors as well as on the establishment of new value chains. The bio-resource vision emphasises the potentials in upgrading and conversion of the biological raw materials compared to the biotechnology vision takes a point of departure in the potential applicability of science.

3) **Bio-ecology vision** highlights the importance of ecological processes that optimise the use of energy and nutrients that promote biodiversity and avoid monocultures and soil degradation.

It is worth noting that these visions are not mutually exclusive and sometimes overlap within policy discussions. For example, while biotechnology is the main element of the biotechnology vision, it can also be regarded as a critical innovation in the other ideas (Lee, Keller & Meyer, 2017).

The biotechnology and bio-resource visions emphasise the technological dimension and the role of research, development and innovation (R&D&I) in a globalised context, while the bio-ecology gives prominence to regional dimensions and the potential of circular and integrated processes and systems. Also, the biotechnology and bio-resource visions give limited attention to changing consumer behaviour and reducing the demand for biobased products as a mechanism to transition to a more sustainable economy.

1.4 EU Bioeconomy Historical Milestones

The first EU policy document on Bioeconomy (the European Bioeconomy Strategy) was published in 2012 with five major objectives and three action plans.

The **EU Bioeconomy Strategy (2012)'s five major objectives** included: 1) reducing dependence on non-renewable resources, 2) mitigating and adapting to climate change, 3) managing natural resources sustainably, 4) ensuring food security, 5) as well as creating jobs and maintaining European competitiveness.

The **EU Bioeconomy Strategy (2012)'s three action plans** set out to achieve these five objectives namely: 1) investments in research, innovation and skills; 2) enhancement of markets and competitiveness; 3) reinforcement of policy coordination and stakeholder engagement activities towards the achievement of the set objectives.

In line with the investment in research, innovation and skills action plan of the 2012 European Bioeconomy strategy, the European Commission funded a three-year project called BIO-TIC project, and one of the key objectives of the project was to draw up a blueprint document of recommendations for overcoming the Industrial Biotechnology (IB) innovation hurdles. This BIO-TIC Project was concluded in 2014 with the release of the FP7 BIOTIC Industrial Biotechnology Roadmap. This was followed by the release of the Standing Committee on Agricultural Research (SCAR) Foresight Report on the Bioeconomy and the EU Circular Economy Package in 2015.
The Dutch Presidency of the EU in 2016 prioritized transition to circular economy as one of the key objectives of its term, hence the publishing of a briefing paper by Lambert van Nistelrooij for the Dutch Presidency entitled "Towards ideal growing conditions for the bio-economy". The briefing paper discussed some of the challenges in implementing and promoting a cascading approach for biomass. The paper also provided recommendations and concrete actions for the promotion of bioeconomy.

Subsequently, Lambert van Nistelrooij, John Bell, Marcel Wubbolts, Catia Bastiolli and Dirk Carrez in particular played an important role in setting up the **Bio-Based Industries-Joint Undertaking Fund (BBI-JU) €3.7bn Fund** (European Parliament, 2017), hence initiating the start of EU Circular Bioeconomy activities.

In 2017, other key milestones followed such as the development of the Bio-Based Industries Consortium-Strategic Innovation and Research Agenda (BIC-SIRA) 2030, the launch of the European Bioeconomy Stakeholders Manifesto, and the formation of the Bio-Based Products Expert Group (BBP EG)These are regarded as strengthening previous activities and kickstarting the bioeconomy and circular economy within the EU.

In 2018, a revision of the 2012 European Bioeconomy Strategy took place. In 2019, the Revised EU Circular Economy Package, the Roadmap for the Chemical Industry in Europe for Transition towards the Bioeconomy and the Circular Bioeconomy 2050 Vision were published.

All of these previous activities culminated into the development of the EU Green Deal, the Farm to Fork Strategy and the Ten Point action Plan to Create a Circular Bioeconomy devoted to a Sustainable Well-Being in the year 2020. See Figure 4 for an overview of EU bioeconomy milestones (2012-2020) described in this section.

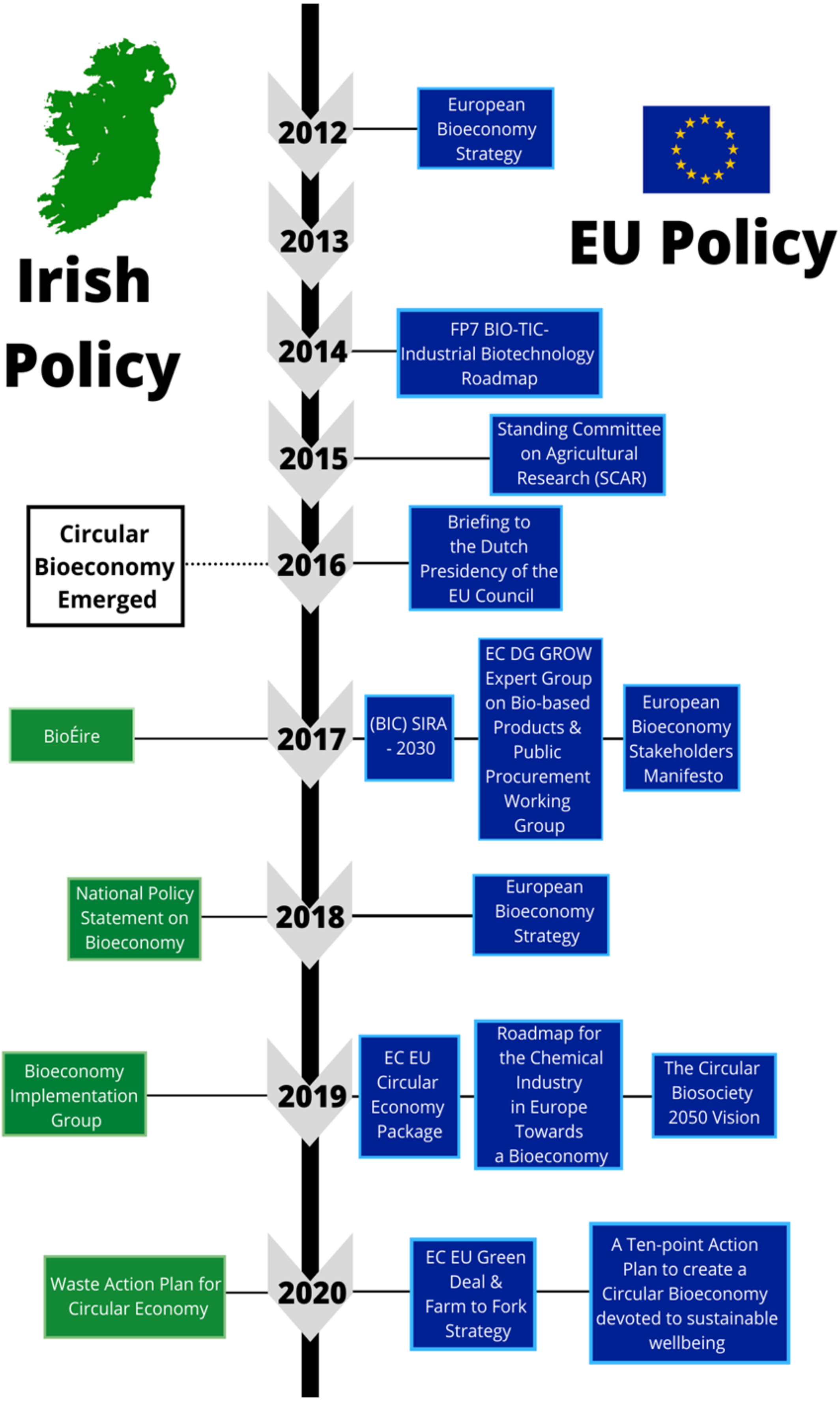

Figure 4: *EU and Irish Bioeconomy Policy Timeline*

Ireland Bioeconomy Policy Overview - Key Messages:

- The two landmark policy activities at Irish level are the 2018 National Policy Statement on Bioeconomy and the 2019 Bioeconomy Implementation Group Progress Report.
- The focus of the Irish Bioeconomy Policy is "Rural Renaissance".
- Pre-2018 Irish Bioeconomy activities that culminated into the development of the two policy documents included several collaborative academic-led bioeconomy related research projects funded by the Department of Agriculture, Food and the Marine (DAFM) of Ireland, as well as a National Workshop on Bioeconomy organized by the National Department of the Taoiseach and the Interdepartmental Group on the Bioeconomy.
- Several regional bioeconomy development projects and ventures in Ireland received funding from the Regional Enterprise Development Fund (REDF) of Enterprise Ireland, EU's Horizon 2020 Programme, the Bio-Based Industries-Joint Undertaking Fund (BBI-JU), the Agricultural European Innovation Partnership of the EU (EIP-AGRI), as well as from private investments (Glanbia).
- Ireland is still the fourth worst performing EU country on GHG emissions according to Social Justice Ireland, but has numerous natural and locational comparative advantages for bioeconomy development namely a well-established agri-food sector that uses two-thirds of its land and employs over 170,000 people (7.75% of its working population), a healthy and productive soils together with suitable climate for producing good grass, hence its thriving beef and dairy production sectors, mostly commercial forest sector based on fibrous exotic conifers for pulp and board (approximately 11 % of Ireland's land), a significant seabed territories which is about ten times its landmass and is an enormous reservoir of genetic material with a vast natural product potential, as well as a booming and rapidly growing biopharmaceutical sector, with 24 out of the 25 largest pharmaceutical companies in the world having a presence in Ireland (worth €39bn in exports).
- Aside natural and locational advantages, Ireland has other key enablers of the bioeconomy namely high capacity to contribute to multiple Sustainable Development Goals, Supportive National Policies, as well as Coordinated Research and Innovation Funding.
- The major gaps and barriers for the development of the bioeconomy in Ireland include; 1) Incoherent framework for synergy building towards circular bioeconomy objectives, 2) Low competitiveness of bio-based products 3) Weak primary producer value chain, 4) Low commercialisation and market stimulation potential, 5) Less start-up capital and expansion funding opportunities in comparison to other developed economies, 6) Inflexible waste classification systems and handling procedures
- Overcoming the barriers to the development of a bioeconomy include 1) greater stakeholder engagement, 2) facilitating more access to EU and private funding, 3) establishing the necessary legislative and technological framework required for making biobased products commercially viable.

2.0 The Irish Circular Bioeconomy Policy Landscape

2.1 Post 2015 EU Circular Economy Package

Activities in the Irish Circular Bioeconomy Landscape was kickstarted after the presentation of the EU Circular Economy Package in December 2015 and during the Dutch Presidency of the EU Council (January-June 2016). The two landmark policy documents at Irish level, are the 2018 National Policy Statement on Bioeconomy and the 2019 Bioeconomy Implementation Group Progress Report.

These two policy documents demonstrate a clear commitment from the Government to monitor and support the development of the Irish Bioeconomy within the context of "rural renaissance" under the Rural Development Action Plan.

The narratives of both policy documents seem to echo the bioresource focus of the European Commission. They are in harmony with national economic growth objectives, which expects jobs to come from economic growth in traditional sectors of the bioeconomy. It is essential to note that the number of jobs in the EU bioeconomy is shrinking due to automation and the application of other more sophisticated technologies (a decline of 10.5% or 2.2mn between 2008 and 2014) (Ronzon et al, 2017). Ireland therefore needs a focus on more labour-intensive, traditional sectors in furtherance of its bioeconomy. The projected contributions of traditional sectors such as agriculture and food increase the economic relevance of the bioeconomy for Ireland.

The two policy documents on bioeconomy are consistent with Ireland's national agri-food (FoodWise 2025), marine (Our Ocean Wealth), and forestry strategies (Forests, Product and People), as well as the National Mitigation Plan and other significant national programmes such as Origin Green.

Before the 2018 National Policy Statement on Bioeconomy, the Department of Agriculture, Food and the Marine (DAFM) of Ireland funded several collaborative academic-led bioeconomy related research projects. Notable among such projects was the BioÉire research project led by TEAGASC. BioÉire focused on identifying and prioritising interlinking cross-sectoral value chains in the bioeconomy. The results from BioÉire projects and the papers from BiOrbic, UCD and the Marine Institute gained traction with the national department of the Taoiseach and the Interdepartmental Group on the Bioeconomy culminating in a collaborative design thinking workshop in February 2017. These research and workshop activity helped to shape the 2018 National Bioeconomy Policy Statement, which was now followed by the first progress report by the Bioeconomy Implementation Group in 2019.

Aside the policy documents, the Irish Government also introduced several interventions to support the development of the bioeconomy and the circular economy circular bioeconomy in Ireland. Particularly important is the provision of around €17.8mn through Science Foundation Ireland for the BiOrbic Research Centre which will explore how to convert biomass resources and the residues produced during food production into higher-value products. Science Foundation Ireland also supported the MaREI (Marine and Renewable Energy Research Development and Innovation Centre) for similar functions. The innovation projects (TRL>5) that evolve from BiOrbic and MaREI will be further scaled up and disseminated via Irish Bioeconomy Foundation (IBF), which is supported and funded by Enterprise Ireland. Most recently, DAFM supported the development of next-generation wood-based products through a collaborative project between the SFI funded centres, AMBER and BiOrbic.

2.2 Ireland's Progress on the Circular Bioeconomy

Agriculture is responsible for 10.3% of the EU's GHG emissions and 33% of Ireland's GHG emissions, with nearly 70% of those coming from the animal sector (European Environmental Agency, 2019).

Globally harmful Greenhouse Gas (GHG) emissions are projected to fall by 8% by the International Energy Agency (IEA) in its Global Energy Review 2020, due to renewable energy growth, the biggest fall in absolute terms than any other year on record. While this reduction rate is welcome, it is only temporary because of the challenge to ensure that investment in recovery from COVID 19 Pandemic also supports progress for climate commitments.

The IEA notes from the experience of previous crises, including the 2008 Great Recession that temporary drop in emissions have been more than compensated for by stronger growth of emissions in the following years. A sharp rebound on carbon emissions is therefore likely as economies begin emerging from lockdowns (EPA, 2019). We therefore need policies to support and build on the environmental gains of 2020. **This will be particularly challenging for Ireland** because Ireland was the fourth-worst performing European Union (EU) country on greenhouse gas emissions, as seen in Figure 5 below.

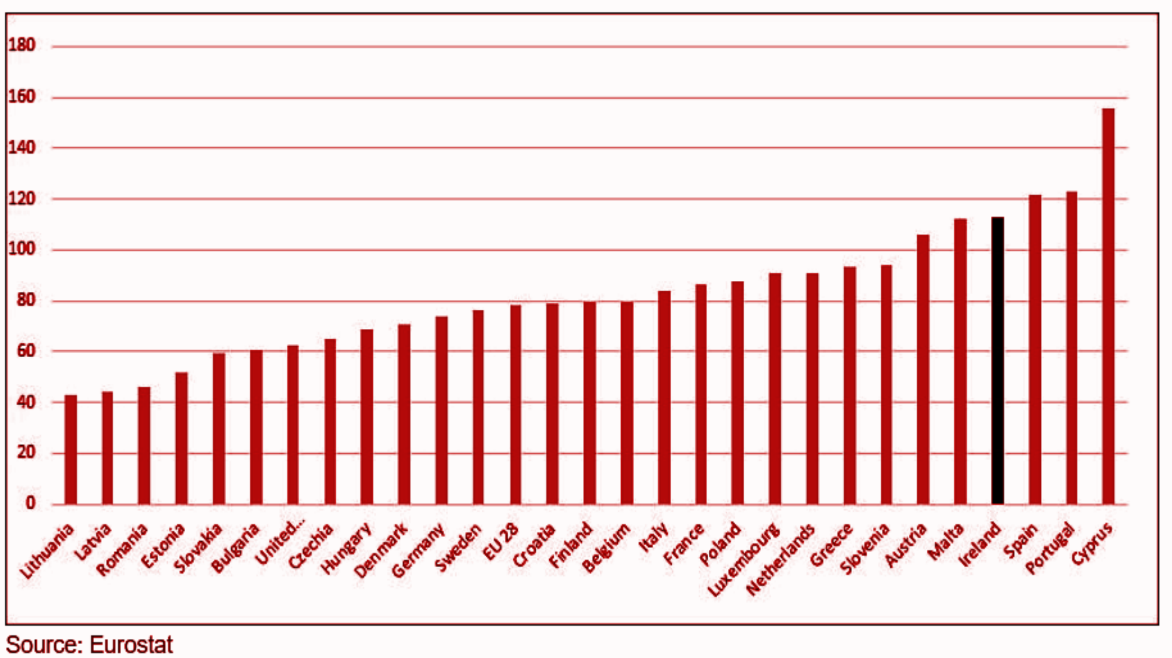

Figure 5: *Greenhouse Gas Emissions EU 2017 (Social Justice Ireland, 2020)*

2.3 The key gaps/barriers (in practice and policy) and how to overcome them

The government's €116bn development plan for the next decade, Project Ireland 2040, highlights the potential of the bioeconomy in terms of Ireland's future economic and environmental wellbeing. The major gaps and barriers identified for the development of Bioeconomy in Europe and Ireland include:

- Lack of coherent framework (among sectors, stakeholders/actors, networks, technologies, policies, practices etc.) for synergy building towards circular bioeconomy-required framework for synergy building is still at an early stage
- Lack of competitiveness of bio-based chemicals/materials with (a) bioenergy and (b) fossil fuel-based chemicals and materials

a) **Competition with bioenergy**: Biobased chemical and material production and use is in competition with bioenergy for biomass not used for food or feed. Demand for bioenergy has also increased the prices of biomass and land, making access to biomass for chemical and material production and use more expensive.

b) **Competition with fossil fuel-based chemicals/materials**: The fossil fuel based chemical and material industry outcompetes the biobased chemical and material industry because the petrochemistry for fossil-based energy applications are heavily taxed but those for fossil based chemical and material applications are neither subjected to heavy taxes or import duties. Please refer to **Section 3.1.4** of the comprehensive report.

- Weak primary producer value chain (low rural income and stagnant rural economy)
- Low commercialisation and market stimulation potential
- Less start-up capital and expansion funding opportunities in comparison to other developed economies
- Subsisting waste classification systems and handling procedures

The 2018 National Policy Statement for the Bioeconomy and the 2019 Bioeconomy Implementation Group Progress Report outlined the critical actions required to overcome the gaps and barriers identified to the development of bioeconomy in Ireland.

The five critical actions recommended by the National Policy Statement 2018 are as follows:

1. Promoting greater coherence between the many sectors of the bioeconomy.
2. Strengthening the development of promising bio-based products.
3. Accessing funding available at EU level as well as leveraging private investment.
4. Progressing the principal value chain propositions identified in the Bio-Eire project by establishing the conditions required for their commercial viability and how these might be fulfilled.
5. Establishing a network of people who work in the bioeconomy industry and those in public bodies and institutions.

The seven critical actions outlined by the 2019 Bioeconomy Implementation Group are as follows:

1. Ensure that there is **coherence between all sectoral strategies** which impact on the bioeconomy in Ireland.
2. **Establish a network of representatives** of commercial entities operating within the bioeconomy and relevant public bodies to inform the future development of the bioeconomy.
3. **Encourage the translation of research into real-world applications** through promoting collaboration between research institutions (academia) and industry using pilots/demonstrations at the model demonstrator facilities.
4. Assess the **current legislative definition of waste** and recommend whether a re-designation is necessary for residual waste flows to be successfully managed for use in the bioeconomy.
5. Ensure greater sectoral coherence within the bioeconomy through the development of risk

assessment and management protocols regarding the use of by-products which encourages the piloting of opportunities.

6. Progress the leading value chain propositions identified in the **BioÉire project** by establishing the conditions required for their commercial viability and how these might be fulfilled.
7. Examine how greater primary producer, public and consumer awareness of the bioeconomy and its products could be built up – through knowledge transfer, advisory, sustainable business models, public procurement, consumer awareness campaigns and product labelling initiatives, etc.

2.4 The key enablers of circular bioeconomy in Ireland

Irelands' Comparative Advantages (Natural and Locational)

Ireland enjoys some critical comparative advantages for the bioeconomy which the Government is determined to capitalise onr. Bioeconomy encompasses living organisms (i.e. crops, forests, fish, farm animals and micro-organisms) or their parts and by-products that have potential use or value. It extends across sectors including farming and the agri-business, marine, forestry, water and waste management (Government of Ireland, 2018). It has a well-established agri-food sector that uses two-thirds of its land and employs over 170,000 people (7.75% of its working population). Agriculture is arguably Ireland's most important business sector. According to the Department of Agriculture, Food, and the Marine (DAFM), the total land area in Ireland equates to 6.9mn hectares of which 4.5mn, or approximately 65% is used for agricultural purposes (Walsh et al, 2017). Ireland has healthy and productive soils, as well as suitable climate for producing good grass, hence its thriving beef and dairy production sectors.

Approximately 11 % of Ireland's landmass is covered by forests. Irish forest produces 3.2mn m^3 of material each year. This is forecasted to increase to 8mn by 2035. Irish forestry sector already employs more than 12,000 people and there is potential for creation of more rural jobs. Forests provide a range of ecosystem services, including the direct benefits of forest products, the indirect benefits of carbon sequestration, as well as the retention and filtering of water. In countries with large areas of forest, these benefits have been argued to far exceed those from timber or conversion to agriculture. Almost all Irish forest is commercially ran and a significant proportion of it comprise of exotic conifers. As trees proliferate in Ireland's climate, the wood is fibrous and so is used mostly for pulp and board (Bullock, 2008).

Ireland has one of the most significant seabed territories in Europe which is about ten times its landmass and is an enormous reservoir of genetic material with a vast natural product potential. Oceans provide the primary sources of protein for over 3.5bn people globally. Seafood delivers more dietary protein than cattle, sheep or poultry and a wide variety of vitamins and minerals. The Irish Marine industry is worth €39bn in exports. The fish catching sector provides over 6,000 direct jobs while an additional 10,000 jobs onshore are dependent on catches from Irish vessels. Ireland also has a growing seaweed industry due to the health benefits of seaweed and the potential for their use in the discovery of naturally occurring bioactive compounds. Marine organisms are potential sources of bio-based products such as enzymes, biomaterials, chemicals, cosmetics and bioactive compounds (DAFM, 2017). In 2016, Ireland's ocean economy had a turnover of €5.7bn. The direct economic value was worth €1.8bn or approximately 0.9% of the GDP. Aside the traditional sectors of the bioeconomy, Ireland also has a booming and rapidly growing biopharmaceutical sector, with 24 out of the 25 largest pharmaceutical companies in the world having a presence in Ireland. The Irish pharmaceutical industry is worth €39bn in exports.

Capacity for Contribution to Multiple Sustainable Development Goals

In a circular economy, waste and inefficient utilization of resources are minimised; the value of products and materials is maintained for as long as possible through good design, durability and repair. When a product has reached the end of its life, its parts are reused as much as possible and then recycled to create further useful products. Hence, the circular economy can contribute to some of the United Nations Sustainable Development Goals (SDGs) such as SDG7 (Affordable and Clean Energy), SDG8 (Decent Work and Economic Growth), SDG9 (Industry, Innovation and Infrastructure), SDG11 (Sustainable Cities and Communities), SDG12 (Responsible Consumption and Production), SDG13 (Climate Action), SDG14 (Life Below Water), and SDG15 (Life on Land).

Supportive National Policies

Ireland's waste management policy has long prioritised waste prevention and this has been the starting point for the growth of circular economy thinking. Since 2004, our National Waste Prevention Programme managed by the Environmental Protection Agency (EPA) has led the way in developing measures and initiatives that have fostered the evolution of policy and practice towards circularity. The current programme captures the place we are now at on that journey. Our national experience has shown that we have opportunity and capacity for adopting circularity. Early movers such as the Rediscovery Centre, Recreate Ireland and Dublin Bikes and CIRCULÉIRE itself have shown what is possible and have energised and inspired others. To this end, the European Commission's Circular Economy Action Plans 2015 and 2020 have proven valuable guides towards meaningful change. As the legislative revisions agreed in 2018 now enter into force domestically, we need to step up again to engage in new proposals announced in March 2020. The EU has the ambition of achieving climate neutrality by 2050, decoupling economic growth from resource use while maintaining long term competitiveness and leaving no one behind. For a summary of the recent Waste Action Plan, please see Appendix 1.17 of the full synthesis report.

Coordinated Research and Innovation Funding

Currently, there are a number of sizable, well-coordinated research and innovation funds available to support the development of the circular economy and bioeconomy in Ireland through the EU, as well as via different Government Ministries and agencies including Department of Agriculture, Food, and the Marine, Department of Communication, Climate Action & Environment, Department of Business, Enterprise and Innovation, Enterprise Ireland, Environmental Protection Agency, Science Foundation Ireland, Irish Research Council etc. Some of such funds are available for start-up, technology demonstration and innovation research. Also in favour of the development of the circular economy and bioeconomy in Ireland is the growing number of researchers from Europe and other parts of the world working in the innovation sector.

2.5 Recent regional bioeconomy development initiatives in Ireland

In Tipperary county, two promising bioeconomy projects are being developed. The €32mn AgriChemWhey project is a first-of-a-kind, industrial-scale bio-refinery which will take by-products from the dairy processing industry and convert them into cost-competitive, sustainable lactic acid which in turn will be used to make value-added bio-based products for growing global markets for biodegradable plastics and bio-based fertilizer. AgriChemWhey project is led by Glanbia Ingredients, co-partnered by 10 other partners across the EU and co-funded by Bio-Based Industries-Joint Undertaking Fund (BBI-JU)-€22mn, and other private investments-€10 mn. In 2017, Irish Bioeconomy Foundation (IBF) secured a €4.5mn Regional Development Enterprise fund from Enterprise Ireland for a pilot-scale bioprocessing demonstration plant in Lisheen. The facility will enable scaling bioeconomy technologies in alliance with industry and research producing organisations. The key objective of IBF is to establish a fora of industry, academia and policy leaders around Ireland's emerging bioeconomy. IBF also promotes the conversion of Ireland's natural land and marine resources to value added products for the development of a sustainable circular bioeconomy that is globally competitive and creates local development.

Monaghan Mushrooms was awarded a €5mn REDF grant for the Development of the Bioconnect Innovation Centre in Monaghan, which will work with agri-food producers within the region to grow and develop new biobased products. The Centre will create a space for a consortium of the agri-food sector to use biotechnology services, networking and brainstorming to solve problems facing the companies in a non-competitive environment.

Noteworthy is the Institute of Technology, Tralee's (Now Munster Technological University MTU) participation in Europe's first Digital Innovation Hub for a circular bioeconomy, together with IBF. The ICT-BIOCHAIN initiative received funding to the value of close to €1mn under Bio-Based Industries Joint Undertaking, a public-private partnership focused on the development of Europe's bioeconomy. The ICT-BIOCHAIN initiative kicked-off in Brussels on the 28th of June 2018 and ran until May 2020. The project focused on the development of efficient biomass supply chains for sustainable chemical production in bioeconomy regions across Europe. The Bio-based Industries Consortium established a target of 30% of European chemicals coming from biobased sources by 2030, and an increase in available biomass supply chains of 20% by 2030 to help achieve this objective. Since 2016, the European Commission has designated six regions across Europe as Model Demonstrator Regions for Sustainable Chemical production i.e. chemicals produced from locally available biomass, waste or CO_2. Three of these regions are represented in the ICT-BIOCHAIN initiative. Ireland's South East and West, including the Lisheen Bioeconomy Campus are test bed regions to evaluate bioresource potential and feedstock-specific ICT solutions.

In June 2020, ITT (now MTU) secured funding from BBI-JU for the BIOSWITCH project. The project aims to encourage and support brand owners to switch to a bio-based approach. It will do this by creating a framework through a series of events and outreach activities. The project will lead to the development of a toolbox/aid that will encourage brand owners to switch to bio-based products. In addition, the project will unlock untapped biomass resources by raising awareness of its potential profitability with owners. So far there are 400 Stakeholders and organizations involved in the project. Thus, this project is anticipated to make the EU a leader in the bio-based economy, strengthening its economic growth and industrial competitiveness.

BioICEP is a €12mn EU Horizon 2020 funded project led by Athlone IT with LIT and TCD as Irish partners (BioICEP, n.d.). The project's overall objective is to demonstrate a route to a circular economy for plastics by developing advanced waste plastic biotransformation into high market demand bioproducts and bioplastics. The project brings together experts from industry and academia, contributing a set of technologies to achieve the following specific objectives:

1. Develop high-efficiency biodegradation plastic by incorporating microorganism communities that are capable of expressing novel enzymes that enable the degradation of mixtures of plastics.
2. The sustainable degradation of at least 20% of mixed plastics.
3. Bioprocess high-value products, including equivalent bioplastics valorising mixed plastic waste.
4. Sustainable prototype system plan, paving the way to bring the developed solution to the market, fulfilling current needs, futures expectations, and delivering a seamless bio-innovative route for a circular economy for plastics.

Biorefinery Glas facility located in West Cork aims to increase the usable protein from grass by 40% (Cadogan, 2019). It is led by the Institute of Technology, Tralee and has five partners including the **Barryroe Co-operative, the Carbery Group, GRASSA B.V. and University College Dublin**. Funded by the **Agricultural European Innovation Partnership of the EU (EIP-AGRI) and the Department of Agriculture, Food and the Marine** under the Rural Development

Programme. Biorefinery Glas is a first demonstration of small-scale biorefinery in Ireland, supporting development of new business models and farmer diversification into the circular bioeconomy. Biorefinery Glas is a first step towards changing the role of farmers in the bioeconomy, from suppliers of biomass to producers of finished and semi-finished products. Grass goes into the biorefinery, and one of the products produced is an ideal feed for dairy or beef cattle, because it contains grass proteins that are easily digestible by cattle. As a result, the cattle eating this will generate less greenhouse gas emissions compared to eating untreated grass. The remainder of the grass proteins can be siphoned off to make a concentrate feed for pigs or chickens, which again has only the proteins they can digest efficiently. This feed can replace imported feeds, another small step towards carbon neutrality, by reducing emissions. Another co-product from the biorefinery is fructo- oligosaccharide (prebiotic sugar), which is potentially valuable for the human and animal nutrition markets. The EU wants to reduce its dependence on these imported protein ingredients, and the biorefinery can play a role by better utilising the proteins from our homegrown grasses. This project is particularly suitable for Ireland, as it is the only country in Europe that is more than 50% grassland.

Between 2013 and 2016, researchers at **National University of Ireland Galway (NUIG)** demonstrated the viability of using Irish Sitka spruce for the manufacture of **Cross Laminated Timber (CLT)** as part of the project 'Innovation In Irish Timber Usage' funded by the Department of Agriculture, Food and the Marine (DAFM) . This project led to two joint research projects investigating the links between forestry management practices and the properties of Irish timber (Sitka spruce, Norway spruce and Douglas fir). Later, NUIG developed collaborations with the main European producers of CLT panels **with Balcas sawmill located in Fermanagh**, which was established for the supply of Irish timber. The potential to use native timber in a high-performance building product will have significant environmental benefits if brought to full production and utilised widely in the construction sector (Harte, 2016).

Ecocem and other Irish companies are producing a material called **GGBS (Ground Granulated Blast Furnace Slag)** from by-products of the iron industry. This is relevant to a circular bioeconomy because normally this waste is buried in soil. The GGBS production process comprises the rapid cooling of blast furnace slag by adding water which granulates the material and then refining the granular material in a milling plant, producing a fine cement powder. GGBS has high performing technical properties comparable to traditional cement. These properties include higher strength gains and increased service due to enhanced durability, which leads to longer times before first repair and replacement. In addition to the enhanced technical qualities, there are benefits of higher environmental performance. GGBS is commonly specified in construction projects procured in both the private and public sectors (Irish Green Building Council, 2018).

In 2020, the Irish Manufacturing Research facilitated an Industrial Symbiosis innovation demonstration pilot between St Mel's Brewery and Panelto Food of Longford County. This collaboration (i.e. Symbiobeer project) was funded through EPA's 2019 Green Enterprise Fund. The project utilized waste bread as a substitute for virgin malted grain to create a new beer and subsequently used the fermented brewer spent grain from the beer production process as yeast for a new bread, hence creating a closed loop (i.e. bread to beer to bread). In addition, the Symbiobeer project is also exploring broader industrial symbiosis opportunities within the wider Longford area.

Circular Bioeconomy Innovation & Opportunities- Key Messages:

- There are four major biobased product sectors namely Bioactives and Functional Ingredients, Bioplastics and Non-Plastic Biomaterials, Biobased Chemicals, and Biofuels
- Bioactives are compounds that typically occur in small quantities in plants, animals and other organisms, and are usually beneficial for crop, animal and human health.
- Bioactives and functional ingredients have proven effective in treating ailments, preventing chronic diseases, and supplying nutritional needs for improved cell, organ and overall body function, as well as regulated muscle growth, weight management and heart health in humans.
- Bioactives also reduce cattle GHG emissions (a major global greenhouse gas emission source), protect plants from herbivory and microbial pathogens, attract plant pollinators, solubilise P nutrients thereby reducing leaching and eutrophication rates (as biofertilizers), and are part of integrated pest management strategies aimed at reducing the use of chemical pesticides (as biopesticides).
- Active areas of study for plant bioactive and ruminant health include wool growth, carcass composition, milk yield, reproductive efficiency, methane production and nematode control.
- Bioplastics are biodegradable or compostable replacements for fossil-based plastic and elimination of plastic pollution which is a global threat to marine biodiversity. Non-plastic biomaterials is key for meeting EU Zero Energy Building targets. Important biomaterials that can play a role in meeting the EU Zero Energy Building targets include Cross Laminated Timber (CLT), Ground Granulated Blast Furnace Slag (GGBS), and the Microfibrillated Cellulose (MFC).
- Biobased chemicals that could be potential building blocks or platform chemicals from which many value-added substances may be derived include Levoglucosenone (LGO), 2,5-Furan dicarboxylic acid (FDCA), 5 Hydroxymethyl furfural (HMF), Muconic acid, Itaconic acid, 1,3-Butanediol, Glucaric acid, Levulinic acid, n-Butanol, 1,4-diacids (succinic, fumaric and malic), 3-hydroxy propionic acid, aspartic acid, glutamic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol.
- The four most promising biofuels for replacing or substituting fossil fuels include biomethane, bioethanol, biodiesel and sustainable aviation fuel (SAF).
- Identified available bioresources for meeting circular bioeconomy needs in Ireland include spent mushroom compost, dairy processing residues, straw residues, forest wood biomass residues, animal manure, brewer's spent grain, organic fraction of municipal solid waste and meat processing waste.

3.0 Key circular bioeconomy innovations & opportunities

3.1 Biobased products sectors for the European Circular Bioeconomy

There are four major biobased product sectors. They include **Bioactives and Functional Ingredients, Bioplastics and Non-Plastic Biomaterials, Biobased Chemicals, and Biofuels.** The EU market for bio-based products is expected to reach €50bn in 2030 representing a Compound Annual Growth Rate (CAGR) of 7% per annum. This growth will be primarily due to projected increases in the use of biofuel and bioplastics. The growth of the bio-based industry in Europe is driven by a number of factors including population growth, environmental concerns, limited fossil fuels, product differentiation and opportunities for cost reductions. The demand drivers often vary according to the sector. The biofuels sector is more policy and regulation-driven, while the biobased chemicals sector is driven more by environmental legislation, brand identity and feedstock availability issues. The next sections examine the individual demands and needs of the four major biobased product sectors in Europe and Ireland within the context of the development of a circular bioeconomy. For further detail on each biobased product please refer to **Section 4** of the full synthesis report.

1. Bioactives and Functional Ingredients Industry

This category encompasses active ingredients derived from plants, animals and other organisms used in the nutrition (food and pharmaceuticals), as well as the agriculture industries (biofertilizers and biopesticides). The Bioeconomy is a broad sector, and its boundaries are naturally fading in non-obvious ways at the respective edges of bioenergy/biofuel & bioactive/Pharma-or-Food. Typically, biofuels are considered as the base of the bioeconomy value pyramid, similarly to how bioactive is found at its top. Bioactives are compounds that typically occur in small quantities in food and can be beneficial for health. They are derived from plants or other organisms, even though botanicals has the larger segment of the market. Unlike essential macro- and micronutrients, they are not essential for life, and the body can function without them.

Many bioactive compounds discovered vary widely in chemical structure and function. While the focus of many studies is on demonstrating the effectiveness of specific bioactive in preventing chronic diseases and other human health benefits, there is a growing focus on using bioactive for environmental concerns such as supplementing cattle with bioactive ingredients in an attempt at reducing GHG emissions. Since bioactive compounds occur in food in small amounts, it could be less than is needed to have a specific health effect. Therefore, the food and drink industry are developing new products containing higher concentrations of selected bioactive compounds. These bioactive enriched foods (BEF) are also known as functional food products. Functional foods deliver health benefits above the basic nutritional needs of a person by improving human health and reducing the risk of disease (Marine Institute, 2017). For example, Glanbia produces a range of bioactive enriched foods formulated to improve cell, organ and overall body function from muscle growth, weight management and heart health.

Bioactives derived from plant

Some bioactives from plants (secondary metabolites) have no direct function in growth and development of the plant but perform important ecological roles such as protection from herbivory and microbial pathogens as well as attracting pollinators. Their biological effects on human health have been known for many years. Many drugs in use today are derived from secondary plant metabolites. An example of this is Artemisinin, which is a highly effective anti-malarial drug (Arrow et al., 2004).

Bioactives derived from other organisms

Even though more bioactives have been discovered in plants, those from other sources are also receiving attention. Recent studies have focussed on valorising the extraction of bioactive proteins from fish processing residues. By-products of the fishing industry can be used for processing fish blood, protein fractions, marine lipids, omega-3 fatty acids and other bioactive compounds with nutraceutical potential. Exoskeletons of shellfish are a source of a number of bioactive compounds. The extraction of chitin from shellfish has gained interest due to its nitrogen-containing properties and resulting wide range of uses across different industries. The EraNET BlueShell project has been exploring the extraction of chitin and chitosan from crab, prawn and mussel shells. Through new extraction methods and product development, these molecules may be used to benefit human and animal health as well as bring profit to an industry that would have otherwise discarded these materials as waste (Devaney & Henchion, 2017).

Bioactive compounds have also been extracted from fungi in a project with Monaghan Mushrooms which is looking at its applications in the area of drug delivery. Microalgae also synthesise different bioactive compounds and therefore have varied applications in the nutraceuticals, pharmaceuticals, and food industries (Walsh et al, 2017). Some bioactives can be extracted from algae. These include carotenoids and fucoxanthin. There is huge possibility for extracting bioactive compounds from seafood and seaweed as Ireland's natural 7,500 km coastline is rich with marine biodiversity. **This is also a massive opportunity for the Irish bioeconomy.**

Emerging role of bioactives in agriculture

There has been a shift away from the use of synthetic chemicals in animal agriculture as it is now known that these chemicals can harm animal and human health, as well as the environment. For example, antibiotics have been fed to healthy livestock to increase growth for meat production and still are in some countries. These antibiotics are excreted into the environment where they can cause microorganisms in the soil to become antibiotic-resistant. Due to this shift away from synthetic chemicals, there has been a drive to find alternatives by using plant-derived bioactive compounds to boost immune health of the animals. There are certain areas of animal health research where the focus has been on ruminant-specific production issues. Active areas of study for plant bioactive and ruminant health include wool growth, carcass composition, milk yield, reproductive efficiency, methane production and nematode control. Perhaps the most important of these, in terms of environmental health, is in ruminant's methane production. Legumes containing condensed tannins help decrease the methane gas formation and promote microbial deamination via plant–protein interactions. This can in turn help reduce methane emissions and ruminal protein degradation, and by extension lead to decreased metabolic energy losses and reduced gaseous nitrogen emissions (Danielsson et al, 2017). Please refer to **Section 4.1** of the full synthesis report for more details.

The intensive use of synthetic chemicals as fertilizers and pesticides for crop yield improvement on an industrial scale in the last century led to soil nutrient over-enrichment, and an increase in soil, groundwater, freshwater and marine pollution and toxicity. In order to reduce these multiple environmental impacts, a substitution of synthetic chemicals with biobased alternatives is proposed under a circular bioeconomy, hence the potential of biofertilizer and biopesticides are discussed below.

Biofertilizer

Most inorganic fertilisers are mineral salts which contain varying amounts of Nitrogen (N), Phosphorus (P) and Potassium (K). They are chemical nutrients added to soil to increase crop yield and quality. The use of chemical fertilisers is an inefficient process of adding nutrients to deficient soil for several reasons. The production of chemical fertiliser consumes $4bn worth of energy every year due to the substantial amount of fossil fuels used in the production and mining of P fertiliser, these costs influence the price of fertiliser (Childers et al, 2011). Estimates show that in less than 100 years, chemical fertilisers will have reached their maximum potential for crops after which there will be no increase in yields. Approximately 70% of fertiliser applied is unavailable to plants due to binding by aluminium, iron, calcium and magnesium present in the soil. Hence, this may encourage farmers to add fertiliser in excess, which can cause ecological problems such as loss of microbial diversity (which has an influence on the availability of fertilizer nutrient for plant assimilation), reduction in crop production and leaching of nutrients into freshwater (causing eutrophication). Due to these reasons, there is a need to develop more sustainable agricultural practices.

Biofertilizers on the other hand contain microorganisms and are added to soil as microbial inoculants to improve the nutrient status of the land. They contain microorganisms that solubilise P, hence reduce leaching and eutrophication rates. Several laboratory-controlled studies indicate that plants inoculated with phosphorus solubilising microorganisms (PSM) show an increase in the accumulation of P in the soil. For example, a study found that there was significant growth and P accumulation in plants that were inoculated with biofertilizers as compared to an uninoculated control (Richardson et al, 2001). Experiments at field level have however been less successful due to difficulties in understanding how the inoculant will behave when added to a natural environment. Hence, If biofertilizers are to be used on a broader scale and more successfully, the relationship ratio of particle fractions, porosity and moisture content of the soil as well as the competition from other microorganisms i.e. the community dynamics of soil microorganisms in response to Phosphorus need to be better understood (Khan, Zaidi & Wani, 2011). An additional success factor that may aid the effectiveness of biofertilizers might be the addition of lime. Lime addition to agricultural land has been known to increase crop productivity for centuries. Liming increases the activity of soil microorganisms and the availability of nutrients including phosphorus.

Biopesticides

Biopesticides are pesticides derived from organisms such as animals, plants and bacteria. These pesticides are environmentally friendly alternatives to insecticides, herbicides and fungicides. They are used as part of integrated pest management strategies on farms to reduce chemical use in crop production. They are most commonly used in glasshouses but are increasingly being used in field settings. Biopesticides fall into three classes: Biochemical Pesticides, Microbial Pesticides and Plant Incorporated Protectants (PIP). Biochemical pesticides are naturally occurring substances that control pests by non-toxic methods such as interfering with mating. Microbial pesticides contain microorganisms which have a different effect on the pest depending on microorganisms used with the most common being from Bacillus thuringiensis (Bt). Plant Incorporated Protectants (PIP) are plants that are genetically modified to incorporate a gene from a microorganism such as a Bt gene from Bacillus thuringiensis. This gene enables the plant to express a protein that has insecticidal action. (EPA, n.d.).

2. Bioplastics and Non-Plastic Biomaterials Industry

This category comprises of both plastic and non-plastic materials. The annual production of plastics increased globally from only 1.5mn tonnes in 1950 to 400mn tonnes of plastics in 2018. A report estimates that global plastic production will reach 1.8bn tonnes per year by 2050 (Qualman, 2017). Only 18% of overall plastic wastes have been recycled, and about 70mn tonnes of plastic are accumulated in the environment, which eventually break down into microplastics causing marine ecosystem and human health concerns (Smith et al, 2018). There are around 8mn tonnes of plastic waste entering the oceans annually, and the accumulated amount of **plastic in the oceans** is estimated to be approximately **100 to 200mn tonnes**, which has caused catastrophic damage and deaths of marine ecosystems. At this rate, the mass of plastics in the ocean will exceed the weight of fish by 2050. The potential annual energy savings that could be achieved from recycling all global plastic waste is equivalent to 3.5bn barrels of oil per year. Besides, the carbon footprint effect of recycling 1mn tonnes of plastics is the equivalent of taking 1mn cars off the road (European Commission, 2018).

Plastics are mostly by-product of the distillation of oil production. Petrol refining transforms crude oil into gas producing ethane as a by-product which is turned into ethylene. Ethane is a building block for cheap, hard to recycle, single use plastics used in packaging such as water bottles (Khan, 2019). Therefore, it will keep being produced as long as oil is extracted for fuel and lubricants etc. What needs to be done is to design plastic products that are long lasting, easy and safe to reuse and that are easily recyclable through standardisation of materials, for example. There are many benefits of these types of plastic products such as long-lasting durability, lightweight and the reduction of weight of vehicles, meaning less carbon footprint from travelling. However, there has been a growing trend of production, use and disposal of single use plastic packaging such as water bottles i.e. the single largest source of plastic pollution (OECD & IEA, 2018). According to the Pew Charitable Trusts "Breaking the Plastic Wave" report, there are a number of measures to reduce plastic pollution (Pew Charitable Trust, 2020) namely **Reduce consumption, Design for recycling (**with mechanical recycling prioritized over chemical conversion)**, Disposal as last resort** (reuse as many times as possible)**, Substitute for alternatives** (e.g. recyclable paper, compostables and bioplastics).

Bioplastics

The term **'bioplastics'** is often loosely used to refer to plastics that are biobased, compostable, biodegradable, or mix of any two or three properties. For bioplastics to be better understood, the material's origin and its waste options need to be distinguished. The term **'biobased'** describes a material's origin i.e. derived from biomass resources. The term **'compostable'** describes a material's waste option i.e. is the material suitable for the disposal of home composting or industrial composting and fulfils the defined criteria for the respective environment. The term **'biodegradable'** describes a material that can biodegrade with the help of microorganisms. Bio-based plastics are not necessarily compostable, some are designed for recycling (bio-PET) and some for composting (PLA). Some bio-based plastics, such as PLA and PHA, are technically both recyclable and industrially compostable if the right infrastructure is in place. Similarly, not only bio-based materials are compostable, certain fossil-based plastics such as PBAT and BASF EcoFlex are also industrially compostable (World Economic Forum, 2016) See Figure 6 below.

Non-plastic Biomaterials

Building Materials- The European Energy Performance of Buildings Directive Recast 2010 (EPBD) requires all new buildings to be nearly Zero Energy Buildings (nZEB) by the end of 2020. This means that any buildings completed after these dates should achieve the standard irrespective of when they were started. The achievement of these standards are dependent on the building materials used for construction. 'Nearly Zero – Energy Buildings' is a building that has a high energy performance and in which "the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources produced on-site or nearby" (SEAI, 2017). In July 2016**,** the European Commission published additional guidance on the nZEB standard. The guidance proposes the following recommendation:

Offices: 40-55 kWh/ (m2.y) of net primary energy with, typically, 85-100 kWh/ (m2.y) of primary energy use covered by 45 kWh/(m2.y) of on-site renewable energy sources.

New single-family house: 15-30 kWh/ (m2.y of net primary energy with, typically, 50-65 kWh/ (m2.y) of on-site renewable energy source.

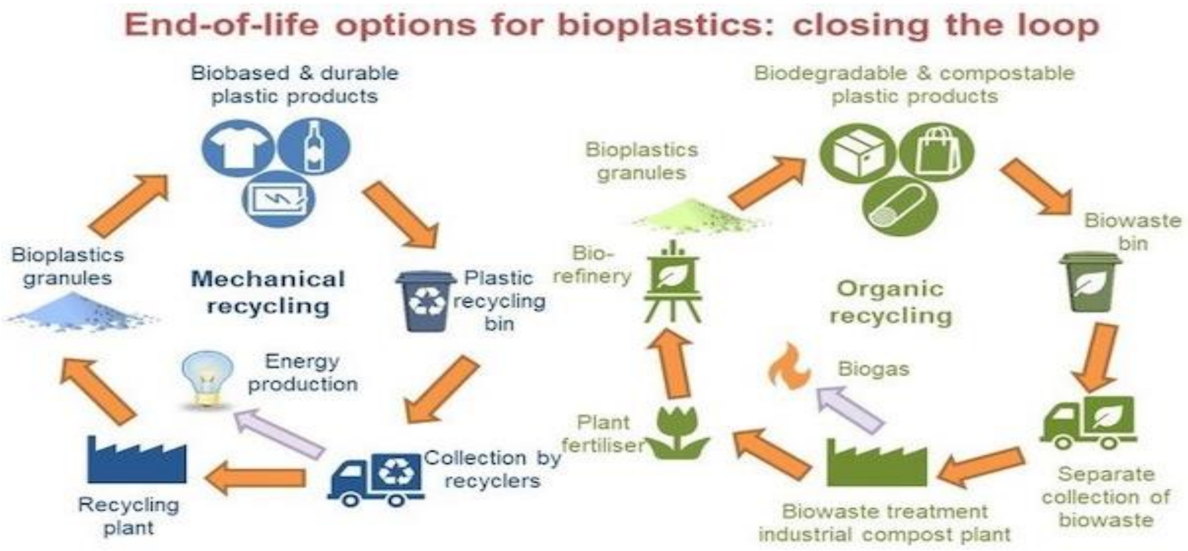

Figure 6: *Recycling options for bioplastics (European Bioplastics, n.d.)*

Biomaterials expected to play an important role in meeting the nZEB standards in an Irish context include the Cross Laminated Timber (CLT), Ground Granulated Blast Furnace Slag (GGBS), and the Microfibrillated Cellulose (MFC). CLT is the most popular engineered construction wood. It provides innovative building solutions for residential houses, multi-storey residential and commercial buildings. GGBS has high performing technical properties comparable to traditional cement. MFC is a biobased substitute that is stronger than steel, safe for food contact and has the potential to transform the paperboard and packaging industry. Please refer to **Section 4.2** of the full synthesis report for more details.

3. Biobased Chemicals Industry

Biobased chemicals are chemicals that can be produced using biomass feedstock through a bioprocessing route. The European chemical industry plays a significant role in economic development, providing products and materials, and enabling solutions in numerous sectors, with 1.14mn employees and sales of €507bn in 2016. By replacing fossil-based products with bio-based chemicals (that have a smaller carbon footprint), the chemical industry can make a critical contribution to the EU's climate goals, while also generating new job opportunities in the region (RoadToBio, 2018). However, the majority of chemicals are still derived from fossil-based feedstocks. Most industrial materials made from fossil resources can be substituted with bio-based counterparts, however, the current cost of biobased production in most cases is more than that of petrochemical production. An increase in the price of fossil fuels, as well as consumer demand for environmentally friendly products and a limited supply of non-renewable resources, have opened new opportunities in the bio-based chemicals sector (IEA Bioenergy, 2020). An example of the shift towards biobased chemicals can be seen in succinic acid. Biobased succinic acid accounted for 5% of total succinic acid in 2009 and now accounts for 50% of succinic acid produced. Several biobased chemicals have been highlighted as potential building blocks or platform chemicals from which many value-added substances may be derived. They include Levoglucosenone (LGO), 2,5-Furan dicarboxylic acid (FDCA), 5 Hydroxymethyl furfural (HMF), Muconic acid, Itaconic acid, 1,3-Butanediol, Glucaric acid, Levulinic acid, n-Butanol, 1,4-diacids (succinic, fumaric and malic), 3-hydroxy propionic acid, aspartic acid, glutamic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol. Please refer to **Section 4.3** of the full synthesis report for more details.

4. Biofuels Industry

The Biofuel encompasses of liquid, aqueous and gaseous fuels made from biomass. It is now widely accepted that global warming and climate change is attributed to the burning of fossil fuels and the resulting release of CO_2 and other greenhouse gas emissions. Global sources of fossil fuels, particularly oil, are rapidly being depleted due to overconsumption. For these reasons, there is a growing need for a more economical and environmentally friendly alternative to meet the increasing energy demands of a growing global population. In certain areas, wind or solar energy are viable, but these are not enough to fill the global energy demands. Biofuels are therefore the attractive renewable alternatives to fossil fuels. The UN IPPC report on climate action points to using 15% biofuels in transport if global warming is to be controlled. Despite surge in demand and use in the US, Brazil and the EU, biofuels currently represent around 3% of road transport fuels used around the world. These fuels are often mixed with existing fossil fuels, for example, E10 fuel is 10% bioethanol and 90% regular petrol. Domestic blending mandates in the majority of the EU member states is expected rise in line with the Renewable Energy Directive (RED) target of a 10% share of the road transport fuel pool (Spekreijse et al, 2019). Under a circular bioeconomy in the EU and Ireland a surge in demand for biofuels is expected. Some of the most promising biofuels for replacing or substituting fossil transport fuels include biomethane, bioethanol, biodiesel and sustainable aviation fuel (SAF). Please refer to **Section 4.4** of the full synthesis report for more details.

3.2 Bioresource Availability in Ireland

The major feedstocks for the bio-based products sectors in Ireland can be sourced from the three traditional bioeconomy sectors: agriculture, forestry and marine. Other significant sources of feedstock for the bio-based industry are household waste (organic waste) and by-products of food processing. According to Bord Bia, the estimated value of food, drink and horticulture exports from Ireland for 2019 was €13bn – capping a decade of extraordinary growth where the value of Irish food and drink exports increased by 67%. Therefore, it is no surprise that there are abundant quantities of agro-based biomass/spent biomass available in the country. The following feedstocks have been identified as key feedstocks that are available in Ireland for meeting the needs of the biobased product sectors under a bioeconomy:

- Spent Mushroom Compost.
- Dairy Processing Residues.
- Straw Residues.
- Forest Wood Biomass Residues.
- Animal Manure.
- Brewer's Spent Grain.
- Organic Fraction of Municipal Solid Waste.
- Meat Processing Waste

3.3 Circular Bioeconomy Innovation Opportunities

As part of CIRCULEIRE's Circular Bioeconomy 2020 Thematic Working Group a series of ideation sessions (from July 27-31) were hosted with Panel Members to develop new project ideas that will promote the conversion of available agro-based feedstocks to bio-based products, thus promoting circular thinking that will benefit and complement the Irish economy. The ideation session was set up so that 16 panel members who are experts in the field of bioeconomy could apply their knowledge on how to utilise eight different feedstocks (spent biomass) that are available in Ireland. The session was held over three days using Microsoft Teams and Miro. Miro is an online whiteboard platform that allow users to post ideas on 'sticky notes' as seen in Figure 7 below.

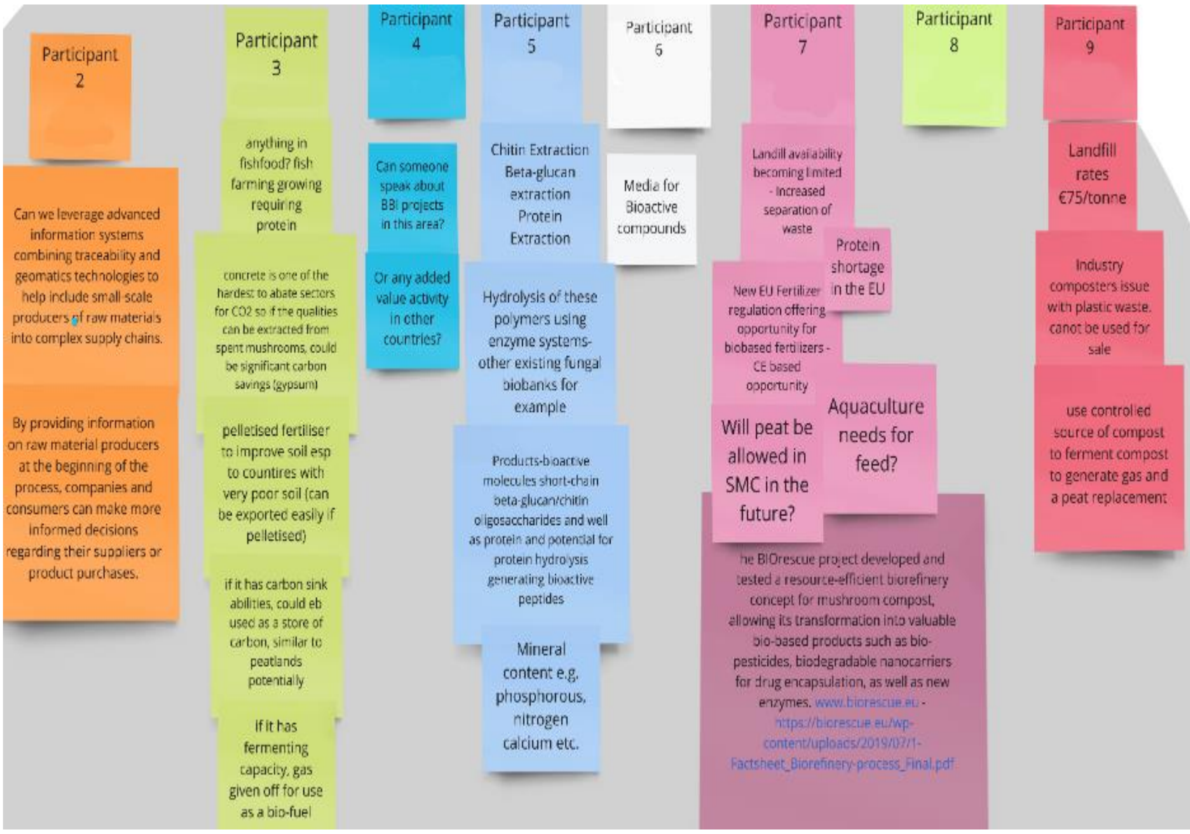

Figure 7: *Screenshot of Miro Board for Spent Mushroom Compost (SMC)*

The first ideation session took place on 27 July 2020 which involved giving panel members an overview of the ideation sessions and how to use Miro collaborative software. Only two feedstocks were discussed in the first session: Spent Mushroom Compost (SMC) and Dairy processing residues. The second session took place 29 July 2020; during this session, the feedstocks discussed were Straw Residue, Forest Biomass Residue and Animal Manure.

The third ideation session took place 31st July 2020; the feedstocks discussed during this session were Brewers Spent Grain (BSG), and Organic Fraction of Municipal Solid Waste (MSW). The most relevant suggestions proposed on Miro by panel members and during the discussion on Microsoft Teams were noted and expanded on by members of IBF. The findings of the three ideation sessions are summarized in Table 1 below.

Figure 8. *Straw Residue Feedstock*

Figure 9. *Spent Mushroom Compost (SMC)*

Figure 10. *Brewer's Spent Grain Feedstock*

Figure 11. *Municipal Solid Waste (MSW) feedstock*

Table 1: Ideation Feedstock Register of Opportunities Summary

Feedstock	**Ideas Generated**
Spent Mushroom Compost (SMC)	1. Lignin for blending with bioplastic. 2. Application for soil conditioner. 3. Fertiliser for fruit production. 4. Biofuel production. 5. Bioactive compounds. 6. Animal feed. 7. Use in composites and materials
Dairy Processing Residues	1. Bioactive compounds.
Straw Residues	1. Agricultural production. 2. Natural fibre composites
Forest Biomass Residues	1. Lignocellulose fibres. 2. Wood flour composites. 3. 3D printing. 4. Construction materials.
Animal Manure	1. Production of biogas via AD. 2. Power generation. 3. Sterilisation. 4. Fertiliser. 5. AD in Ireland compared to Germany
Brewer's Spent Grain	1. Construction. 2. Ingredients for baking. 3. Growth medium for microorganisms. 4. Biogas production. 5. Engagement with small companies.
Municipal Solid Waste (MSW)	1. Soil Conditioner. 2. Value Added Products.
Meat Processing Waste	1. Bioactive compounds.

Recommendations & Concluding Remarks

Key Messages:

- The Irish bioeconomy and circular economy has vast unexploited environmental, social and economic potentials but several growth and developmental barriers still exist.
- Overcoming the obstacles to the growth and development of the Irish circular bioeconomy will require the promotion of circular thinking, the creation of conducive environments for circular business models to thrive, and ensuring policy coherence across bioeconomy sectors, as well as between bioeconomy sectors, concerned public authorities and consumers.

Even though the EU has made some progress with regards to circular economy and bioeconomy, Ireland is yet to significantly exploit vast opportunities and potentials available in most biobased product sectors. Circular bioeconomy have vast potential for reduce the dependence on fossil fuels with added social (in terms of job creation), economic (in terms of income/revenue generation, GDP expansion and improved competitiveness) and environmental (in terms of carbon emission reduction and waste elimination) benefits.

Within the Irish context, circular bioeconomy is specifically expected to contribute to integrated rural and regional development. Despite this however, several developmental and growth barriers still exist. Since the adoption of the EU Action Plan for the Circular Economy in 2015, changes in favour of circularity have been numerous and impressive. Yet, barriers both at the company level and along the value chain, as well as from a policy perspective persist in Ireland.
Overcoming these obstacles and seizing these opportunities will require **promoting circular thinking**, **creating conducive environments for circular business models to thrive,** and **ensuring policy coherence across bioeconomy sectors, as well as between bioeconomy sectors, concerned public authorities and consumers**. Europe needs to transition towards more sustainable and competitive economic model to attain its ambition of becoming the global leader in the circular economy.

4.1 Promoting circular thinking and circular business models

Inefficient linear production models still thrive in Ireland and other parts of the EU. There is therefore need for committed leadership and engagement of senior management, stakeholders of concerned businesses and industries to achieve this. Clear-sighted legislation and a strong set of local governmental policies will also be key.

Currently, linear business models seem cheaper and more financially rewarding than adopting circular solutions in the shorter term. Virgin raw materials often cost less than secondary ones when transportation and logistics are considered. Current taxation patterns are not always supportive of a just transition, particularly the over taxation of labour and under taxing of raw materials and waste. This makes circular business models less attractive for businesses, hence the need for legislation and policy tools that will address this imbalance.

To promote circular thinking as a preferred approach in Ireland, we must address the barriers and utilise the enablers and comparative advantages.

The instruments at our disposal to support this transition are numerous namely natural capital (forests, farms, oceans etc.), locational advantages, supportive policies, coordinated research and innovation funds, growing innovation research community etc. Linking circularity to company's sustainability policy and objectives (such as corporate social responsibility strategies) and creating more favourable taxation systems to improve company margins, by for instance reducing VAT on repaired and reused goods, or by subsidising them in favour of the conservation of natural resources, are just some of the examples of what can promote the transition of the private sector towards the adoption of circular approaches. Therefore, work is still required to ensure circular business approaches become the best option for companies willing to gain competitive advantage and maintain their market share, while aligning their objectives with other societal goals.

4.2 Policy Coherence is essential to grow the circular bio-based economy in Ireland

The 2018 EC review of the 2012 EC Bioeconomy Strategy found that significant achievements had been completed particularly in terms of research and innovation. However, it indicated that a greater level of policy coordination and stakeholder engagement is still required (European Commission, 2017).

The requirement of greater policy coherence among relevant sectors was highlighted in the updated EC Bioeconomy Strategy of October 2018. Advancing circular bioeconomy requires that policymakers understand how the design and coherence of public policy can contribute, or create barriers, to the development of a bio-based market in the wider economy. The bioeconomy is complex from a policy perspective. Therefore, the growth and development of circular bioeconomy will be influenced by a number of policy arenas including specific sectoral policies across agriculture, food, marine, forestry and energy sectors, cross-sectoral waste and multi-level economic, social and environmental policies, among others.

To ensure policy coherence between all sectoral strategies that impact on the bioeconomy in Ireland, Ireland has already established a Bioeconomy Implementation Group (BIG) which presented its first progress report in 2019. The Department of Environment, Climate Action and Communication of the Government of Ireland has also published the policy document "Waste Action Plan for a Circular Economy" (DECC, 2020), which identifies opportunities for the application of circular economy principles across a range of areas such as food, where we generate 1.3 million tonnes of waste per year, or end-of-waste and by-products. An end-of-waste decision has significant value because it allows for the creation of new products from the material and takes it out of the waste regulatory system. It therefore has a significant role to play as we move to a more circular economy by moving material up the waste hierarchy and extracting value from what would have been discarded previously. This helps us meet recycling targets, facilitates use as a product and reduces pressure on waste infrastructure.

In March 2020, the European Commission adopted a revised Circular Economy Action Plan which is one of the main building blocks of the European Green Deal (Futur Enviro, 2020). With measures along the entire life cycle of products, the new Action Plan aims to make our economy fit for a green future, strengthen our competitiveness while protecting the environment and giving new rights to consumers. Building on the work done since 2015, the new plan focuses on the design and production for a circular economy, with the aim to ensure that the resources used are kept in the EU economy for as long as possible. In order to transition to a circular bioeconomy, Ireland needs to closely align its bioeconomy and circular economy strategies with the objectives of the revised Circular Economy Action Plan and the European Green Deal.

4.3 Concluding Remarks

Bioeconomy and circular economy are not silver bullets for eliminating climate change and environmental degradation. However, they represent incredibly significant, important, and necessary steps towards a more sustainable future. To enhance the development of the circular economy and bioeconomy in Ireland, there is need to promote circular thinking, create a conducive environment for circular business models to thrive, and ensure policy coherence among sectors, as well as between sectors, concerned public authorities and consumers. Lastly, there is also a need to closely align new bioeconomy and circular bioeconomy strategies and policies with the revised EU Circular Economy Action Plan (CEAP 2.0) and the European Green Deal.

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Climate-KIC is supported by the EIT, a body of the European Union