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Bioproducts for bioeconomy

An overview of bioeconomy initiatives at subnational level for building competitive and sustainable rural areas

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Bioproducts for bioeconomy

An overview of bioeconomy initiatives at subnational level for building competitive and sustainable rural areas

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Forewords

FAO

The transformation of agrifood systems requires solutions that can simultaneously strengthen food security, support rural livelihoods, address climate change and halt biodiversity loss. The bioeconomy offers a practical pathway to advance these objectives by creating value from biological resources while reducing waste and promoting more efficient and circular use of resources.

Realizing this potential will require action. Countries need enabling policies, investment, innovation, partnerships and stronger capacities to translate bioeconomy opportunities into tangible benefits for farmers, producers and rural communities. Equally important is ensuring that bioeconomy development contributes to the sustainable management of natural resources and delivers positive outcomes for people and the environment.

This publication provides concrete examples from different contexts, demonstrating how bioeconomy approaches can generate employment, diversify rural incomes, reduce losses and strengthen the resilience of agrifood systems. By sharing these experiences, it contributes to building the evidence and practical knowledge needed to scale up sustainable bioeconomy solutions and support countries in achieving their development, climate and biodiversity goals.



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AAFC

Agriculture and Agri-Food Canada (AAFC) provides leadership in the growth and development of a competitive, innovative and sustainable Canadian agriculture and agri-food sector. Agriculture is at the heart of the bioeconomy and AAFC values multilateral cooperation that acknowledges how bioeconomy can generate new farm income streams, encourage market diversification, and increase sustainable agricultural production.

FAO is at the forefront of such networks that share local experiences and implement innovative projects. This publication is a step towards the construction of a global evidence-base framework that allows for greater bio-based innovation of agrifood systems.



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Acronyms

AAFC	Agriculture and Agri-Food Canada
BIC	Bioindustrial Innovation Canada
BioHubCat	Bioeconomy Hub of Catalonia
BPIC	Bio Processing Innovation Centre Alberta
CAP	Canadian Agricultural Partnership
CBE JU	Circular Bio-based Europe Joint Undertaking
DAFM	Irish Department of Agriculture, Food and Marine
EBCA	European Bioeconomy Custers Alliance
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
GFFA	Global Forum for Food and Agriculture
GHG	greenhouse gas
HVO	hydrotreated vegetable oil
ISBWG	International Sustainable Bioeconomy Working Group
MTU	Munster Technological University
NDVI	normalized difference vegetation index
OECD	Organisation for Economic Co-operation and Development
OMAFA	Ontario Ministry of Agriculture, Food and Agribusiness
SDG	Sustainable Development Goal
SMEs	small and medium-sized enterprises
Teagasc	Irish Agriculture and Food Development Authority



Explanatory note of key concepts

Agrifood systems: Systems that "cover the journey of food from farm to table, including when it is grown, fished, harvested, processed, packaged, transported, distributed, traded, bought, prepared, eaten and disposed of. They also encompass non-food products that constitute livelihoods and all of the people, activities, investments and choices that play a part in making available these food and agricultural products. In the FAO Constitution, the term 'agriculture' and its derivatives include fisheries, marine products, forestry and primary forestry products" (FAO *et al.*, 2025). Agrifood systems encompass both food and non-food products.

Bioeconomy: "The production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology, and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy. Bioeconomy is not a static notion, and its meaning is continually evolving" (IACGB, 2024). Bioeconomy is an overarching concept. Definitions vary among sectors, regions, and public and private strategies.[1] In this context, an **agricultural bioeconomy** is a term often understood to encompass the use of agricultural products and residues (feedstocks) to produce food and non-food goods and the sustainable use of biotechnology to drive economic growth (FAO, 2024). Bioeconomy is particularly relevant to the agrifood sectors in value chains that use agricultural biomass for non-food products, including fibres, oils, bioplastics, packaging materials, liquid biofuels, textiles, insulation materials, cosmetic products, bioinputs (e.g. biofertilizers, digestate nutrients, microbial biocontrol agents, microorganisms for bioremediation, and botanical compounds) biochemicals, and biopolymers (von Braun, 2018; Seeger *et al.*, 2026).

Bioproduct: While the sectors included in the definition of bioproducts may vary from source to source, bioproducts generally include products produced with biomass from plants, animals, organic waste or microbes and/or through biomanufacturing through biological processes that sometimes using genetically modified microorganisms (Gao, Song and Guo, 2020; Bobier *et al.*, 2024). Examples of **biological processes** that convert biomass into bioproducts are polymerization, precision fermentation, Fischer-Tropsch synthesis, transesterification with pyrolysis, and enzymatic processes. Bioproducts can be used for both, industrial and commercial purposes in different sectors (e.g. agriculture, biorefineries, textiles, cosmetics).

The most common bioproducts are bioinputs (biopesticides, biofertilizers, biostimulants), bio-based pharmaceuticals, intermediary biochemicals, biopolymers, biofibres, bio-based cosmetics, bio-pharma, bio-based construction materials and paper, briquettes and pellets, and biofuels (e.g. bioethanol). Some sources exclude food but include waste-based feed ingredients or nutraceuticals (WBCSD, 2020; VMR, 2026). Other sources exclude food as well as all forms of feed, medicines, and biomaterials produced in a traditional way (Statistics Canada, 2017).

[1] FAO has published several documents on bioeconomy. For an overview of bioeconomy key terms and concepts, consult *Towards sustainable bioeconomy - Lessons learned from case studies* (Gomez San Juan, Bogdanski, and Dubois, 2019).

A sectoral approach is needed to define the sectors and the units of the bioeconomy, to avoid overlaps when measuring the progress of the bioeconomy (Cingiz *et al.*, 2021).

For FAO[2], "bioproducts" include food, feed, biofuels and bio-based products, while "bio-based products" include non-food materials such as bio-based textiles, paper, etc. This FAO publication uses the term "agri-based bioproduct" (see below) to describe materials made from agricultural biomass, including plant production, agroforestry, animal, or other materials.

Also, there are sources that address mostly bioinnovation as the main driver of the bioeconomy. Bioinnovation often includes biotechnology (e.g. fermentation, food conservation, medicines) and advanced biotechnology for specific applications, which may involve tailored genetic engineering of cells or microorganisms through four types of processes: precision fermentation, biomass fermentation, organism-as-a-product, and tissue-as-a-product (Mayers *et al.*, 2025). While bioproducts can be common materials, such as paper, these sources refer to advanced materials that have undergone modern and extensive processing, such as solvents, polymers and biocomposites (Colmorgen, Khawaja and Rutz, 2020).

Advanced biotechnology is used in the production of biomolecules and biosystems for specific applications, including in agriculture and personal care (Mayers *et al.*, 2025). Biomolecules production covers the mapping of intra-cellular components (e.g. DNA, RNA, and proteins) and measuring their functions within a system through genomics, metabolomics and other large-scale studies of biological molecules (so called omics), as well as the engineering of intra-cellular molecules (e.g. via genome editing). Biosystems cover the complex biological interactions between cells, and the engineering activities at the cell, tissue, or organ level, including stem-cell technologies and transplantation (e.g. cultured meat grown in a lab) (Chui *et al.*, 2020).

As part of bioproducts, the **agri-based bioproducts** considered in this paper are non-food products as defined above that stem from agrifood systems (e.g. bioproducts derived from crop residues, agroindustrial waste, etc.). This study uses the ISO 14044:2006, 330 3.10 definition of co-product to refer to those value-added products arising from applying a bioeconomy lens to crop and livestock production of food as well as to agri-based industries: "Co-product is any of two or more products coming from the same unit process or product system" (ISO, 2006). Product, bioproduct or co-product refer any good or service, while a by-product is the secondary product obtained in the course of a specific process (Merriam-Webster, 2025). Thirty-eight countries have so far developed recommendations for monitoring the sustainability of products for commercial or industrial goods (other than food or feed) composed in whole or in significant part of biological products, forestry materials, or renewable domestic agricultural materials, including plant, animal, or marine materials, which were defined as bio-based products (OECD, 2025a).

Cluster: a cluster in the bioeconomy can be defined as a "geographic region or state where multiple bio-based companies, research institutions, universities and startups are concentrated, creating a hub for innovation, collaboration and investment. These clusters provide access to shared infrastructure, skilled talent, funding and regulatory support, making it easier for biotech businesses to grow" (Bordoloi, 2025).

[2] https://www.fao.org/faoterm/en

Executive summary

This publication highlights the potential of bioeconomy to transform rural areas into more competitive, resilient, and sustainable communities. Focusing on agri-based bioproducts that support food security, it provides case studies and examples where subnational bioeconomy approaches and policies have supported rural areas in adding value to their non-food biomass, diversifying incomes, taking climate action and conserving biodiversity. This publication introduces how bioeconomy approaches and visions can transform agrifood systems, improving food security, managing local natural resources sustainably, and promoting innovative bioproducts.

Competitive and sustainable bioproducts can play a central role in the development of rural bioeconomy, particularly those bioproducts based on crop and livestock systems. If the use of agricultural residues and non-food biomass are maximized, rural areas can contribute to food security beyond production, by providing diversified sources of income, creating interconnected pathways for equitable growth, and building resilience to environmental challenges. While these benefits depend on the context, the publication presents different bioproducts, biomass feedstocks and practices that can be deployed to bring bioeconomy lens to agriculture.

The publication also identifies priority bioeconomy approaches at subnational level to increase competitiveness (e.g. biorefineries, hubs, clusters, and integrated landscape management). Case studies from Canada, Ireland, the European Union and Spain show how these approaches can bring together farmers, industry, innovators, and policy-makers to deliver new markets, diversify rural production, foster innovation, add value to biomass, and generate jobs, all of which strengthen the competitiveness of rural areas based on natural resources. Producer groups are encouraged to collaborate, adopt sustainable practices, and valorize ecosystem services.

Comprehensively assessing biomass availability and monitoring environmental and socio-economic impacts are essential for managing resources efficiently, reducing competition between different biomass uses, and informing policy decisions that are tailored to local contexts. Satellite imagery and other tools can help communities manage resources efficiently and monitor the impacts of bioeconomic activities.

Also, dedicated bioeconomy strategies at sub national level, based on evidence and responding to national priorities, can enhance the enabling environment for developing innovative local bioproducts. Examples of subnational strategies in Brazil, Canada and the European Union are presented and show successful experiences of a range of countries that have dedicated bioeconomy policies at subnational level in different contexts. Coherent policies include enabling mechanisms and dedicated resources to support innovation, technology adoption, market development, and sustainable resource use.

Concrete recommendations from this publication emphasize the need for policies that encourage integrated approaches such as clusters and biorefineries, facilitate cooperation among stakeholders, invest in data for natural resources management, and balance environmental and economic goals while reflecting local realities. Main recommendations are:

- Bioproducts from crop and livestock residues, from innovative feedstock in multi-sector biorefineries to serve as ecosystem services such as soil cover, or as alternatives to burning or waste, should be central to rural development pathways.
- To achieve sustainable bioeconomy, it is important to develop renewable bioproducts, circulate materials, and regenerate soil and biodiversity.
- Collaboration platforms that unite multiple farmers, processors, and entrepreneurs to pool resources, share knowledge, and jointly tackle challenges can encourage landscape-level collaboration and optimize resources and coordinate around shared goals.
- Robust data is key to implement tailored management strategies that optimize nutrient cycling, soil care, biomass valorization, and efficient resource use.
- Both subnational and national policy mechanisms are key to the bio-based industrialization of rural areas, together with the private sector, to facilitate business models that stimulate market pull and push.

There is a need for more global dialogue and knowledge exchange between local governments, rural industrial clusters and other key actors for bioproducts development. Policies and business plans should be designed allowing innovation to come from communities and business groups who understand their specific landscapes and resources. Strengthening the enabling environment will help agrifood systems unlock more value from biomass while addressing pressing social and environmental needs.

The overall message is that bottom-up development strategies, grounded in local experience and supported by smart policies, are an essential part of the solution for unlocking the full potential of bioeconomy. By working together, policy-makers and producer groups can build rural economies that are innovative, competitive, and sustainable, ensuring long-term food security, economic resilience, and stewardship of natural resources.

Chapter 1. Background

The aim of this publication is to raise awareness about the strategic areas of opportunity for bioeconomy policies, practices and partnerships to increase the competitiveness and sustainability of agrifood systems and their bioproducts. Bioeconomy is presented as a pathway to provide opportunities for increasing value-added of agricultural bioproducts, improve resilience, and support climate action and biodiversity conservation.

This publication covers agri-based (crop and livestock) bioproducts that can support sustainable, competitive, innovative and diversified (non-food) bioeconomy. It focuses on the implementation of bioeconomy at rural level through competitive and sustainable agri-based bioproducts, including the role that bioeconomy clusters and other subnational initiatives can play in developing and diversifying local economies, with crop and livestock systems as key players in the production of valuable biomass.

Examples are presented to show how agrifood systems can take in bioeconomy approaches to manage the biomass, such as biorefineries, clusters, hubs, land cover planning and others, to create bioproducts for growing markets and for the diversification of primary production, incomes, and landscapes. This publication also provides examples of how to bring agri-based bioproducts to new and established markets and maximize socio-economic benefits, particularly in rural areas, through technology and innovation while addressing context-specific trade-offs.

Biomass is a central element of the bioeconomy, and agrifood sectors that produce biomass have a significant opportunity for transformation. The World Business Council for Sustainable Development estimates that, by 2030, total biomass production is expected to reach 26.6 billion tonnes with an estimated market value of USD 12.8 trillion. Around half of this expected biomass production (13.8 billion tonnes) will be used for purposes other than food and feed, such as textiles, packaging, pharmaceuticals and waste valorization, with a value of USD 7.7 trillion (WBCSD, 2020).

Crop residues and unavoidable food waste can be valuable sources of biomass. Taking only into account food loss and on-farm residues, in 2021, 1.25 billion tonnes of biomass was lost globally after harvest and before reaching retail shelves (FAO, 2025a). Food waste in households, food services and retail amount to more than one billion tonnes (UNEP, 2024a). Agrifood systems also produce non-food products. For instance, 32 million tonnes of natural fibres are produced globally for different uses (FAO, 2021a).

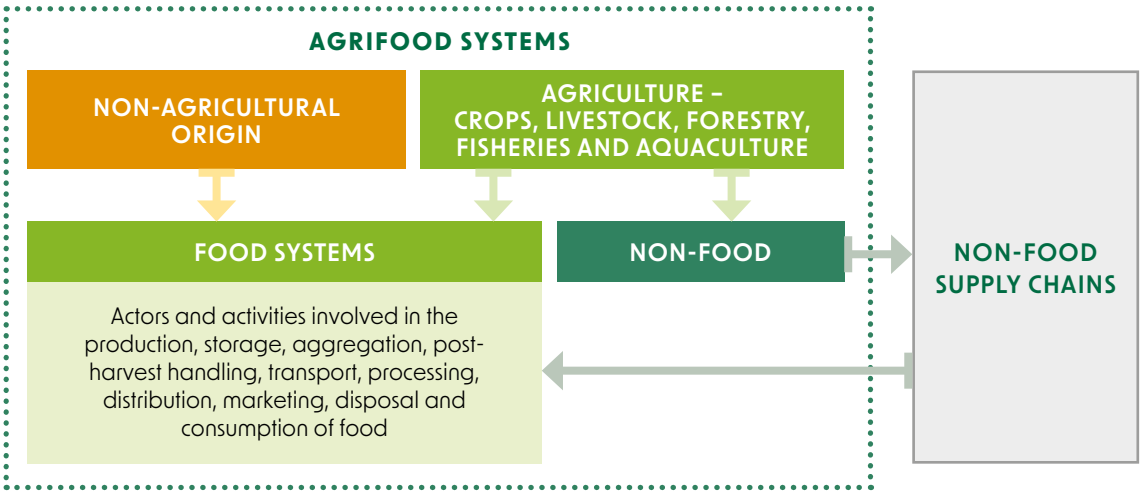
Verified Market Reports, which disaggregates the market potential of bioproducts, estimates a bioproducts market of 20.28 billion in 2026 with the potential to reach 32.9 billion in 2033, with a compound annual growth rate (CAGR) of 7.15 percent (VMR, 2026). With regards to biological processing, the annual market size of advanced biotechnology (including agriculture, food, chemicals, personal care and transport fuels, and excluding pharmaceuticals) is expected to raise from around USD 200–300 billion to USD 0.69–1.11 trillion market by 2040, of which agriculture (including yield improvements in crop and livestock such as advanced breeding and feed additives) would be USD 205–225 billion, and food (including new foods such as via precision fermentation) would correspond to USD 130–395 billion (Mayers *et al.*, 2025). A foresight exercise of approximately 400 pipeline applications of biological processing allowed to estimate that, in 2040 if realized, the direct economic impact could be USD 1.7–3.4 trillion, of which 36 percent (USD 0.8–1.2 trillion) would be associated with biomolecules or biosystems applied in agriculture, aquaculture and food, for example breeding of animals and plants using molecular or genetic markers; the genetic engineering of plants; applications that use the microbiome of plants, soil, animals, and water to improve the quality and productivity of agricultural production; and the development of alternative proteins including lab-grown meat (Chui *et al.*, 2020).

Innovation in all these sectors is needed to respond to the increasing demand for food and agricultural raw materials for industry. Where there is competition in the use of biomass and other biological resources for different bioproducts, agricultural residues offer a strong opportunity for increasing value locally. FAO has identified alternative pathways for the future of agriculture to ensure that rising demand does not undermine sustainable natural management practices, compromise ecosystem conservation, and affect the sustainability of land and water systems (FAO, 2018).

Bioeconomy supports the transformation of agrifood systems by applying biological innovations and technologies that provide a range of opportunities to transform other sectors and provide more sustainable agri-based bioproducts for food and non-food uses in different sectors (crop and livestock production, fisheries and aquaculture, forestry, and agri-based processing industries).

The integral management of agri-based resources throughout the entire spectrum of activities within agrifood systems helps add value to biomass by transforming it into sustainable and competitive agri-based bioproducts. Tailored tools would allow for a better understanding of how to meet the growing demand sustainably and connect primary producers with bioindustries in all sectors producing food and non-food products and with consumers (Figure 1).

FIGURE 1. Conceptual framework for agrifood systems



Note: Food of non-agricultural origin includes meat analogues produced through synthetic biology.

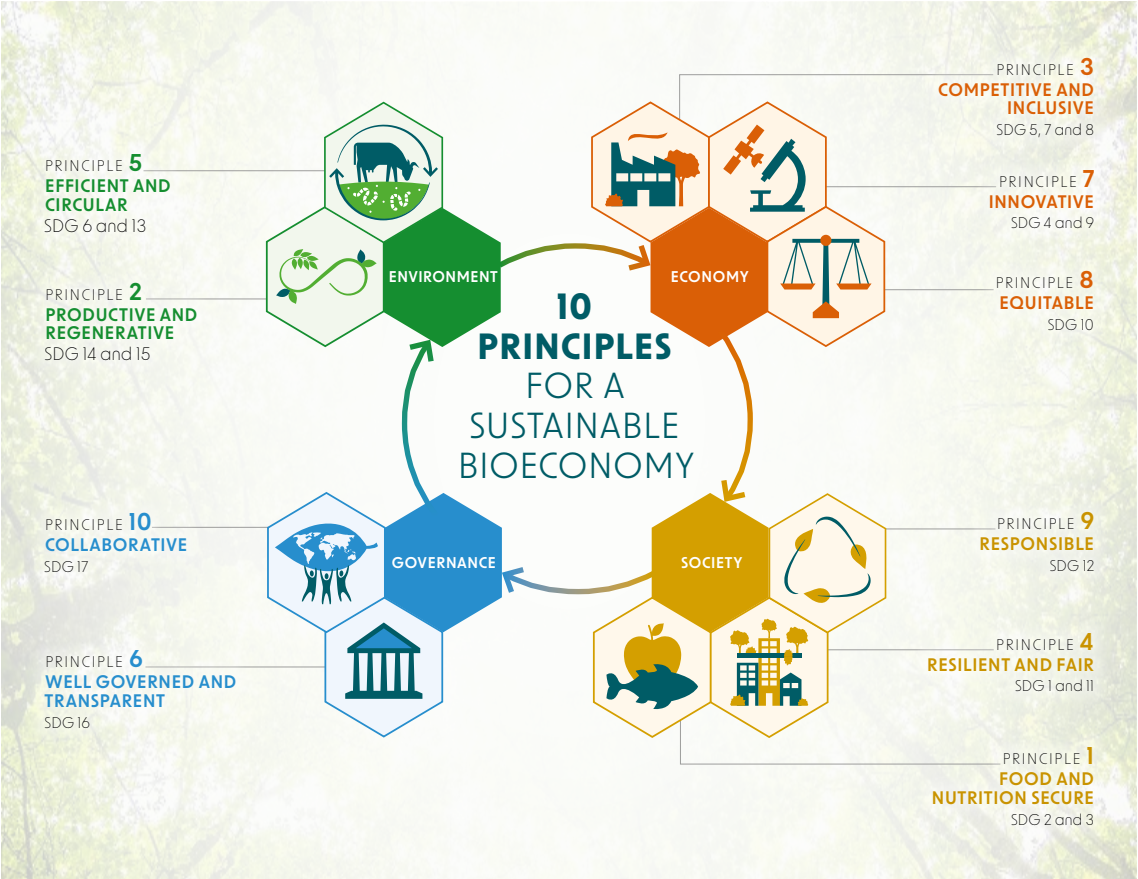
Source: **FAO.** 2021a. *The State of Food and Agriculture 2021. Making agrifood systems more resilient to shocks and stresses.* Rome. https://openknowledge.fao.org/handle/20.500.14283/cb4476en

Bioeconomy is not intrinsically sustainable. It should contribute to create more sustainable agrifood systems that can meet the global demand for biomass and at the same time improve the socio-economic and environmental conditions of local communities. The present study highlights the need for measuring trade-offs in biomass uses and technology deployment which can cover data gaps in measuring bioeconomy at the subnational level. Taking cross-sectoral and informed decisions about the best way to manage local biomass is key to reducing competition between food, feed, fibre and fuel.

Gomez San Juan, Bogdanski and Dubois (2019) identified 15 shared or common sustainability objectives for bioeconomy development. These objectives relate to the environmental, social and economic dimensions of sustainability and the overarching dimension of good governance. For instance, safeguarding food security; substituting fossil-fuel based products with sustainable bioproducts; creating jobs and revitalizing urban and rural economies; establishing fair and equitable value chains; etc. These common objectives indicate that by improving the sustainability of agrifood systems, different countries are working to improve the overall sustainability of bioeconomy and match responsible consumption with production patterns.

FAO and the International Sustainable Bioeconomy Working Group (ISBWG) have developed a set of 10 Aspirational Principles and 24 Criteria (FAO, 2021b) to facilitate the understanding of social, economic and environmental criteria for a sustainable bioeconomy in an integrated way, including governance goals and the management of trade-offs between them (Figure 2). FAO (2025b) is a recent guideline on how to select a monitoring framework for the bioeconomy around these principles and criteria and in close relationship with the Sustainable Development Goals (SDG) and the G20 High Level Principles on Bioeconomy.

FIGURE 2. Overview of the 10 FAO Aspirational Principles for a Sustainable Bioeconomy and the SDGs



Source: **FAO.** 2021b. Aspirat*ional principles and criteria for a sustainable bioeconomy*. Rome. https://openknowledge.fao.org/handle/20.500.14283/cb3706en

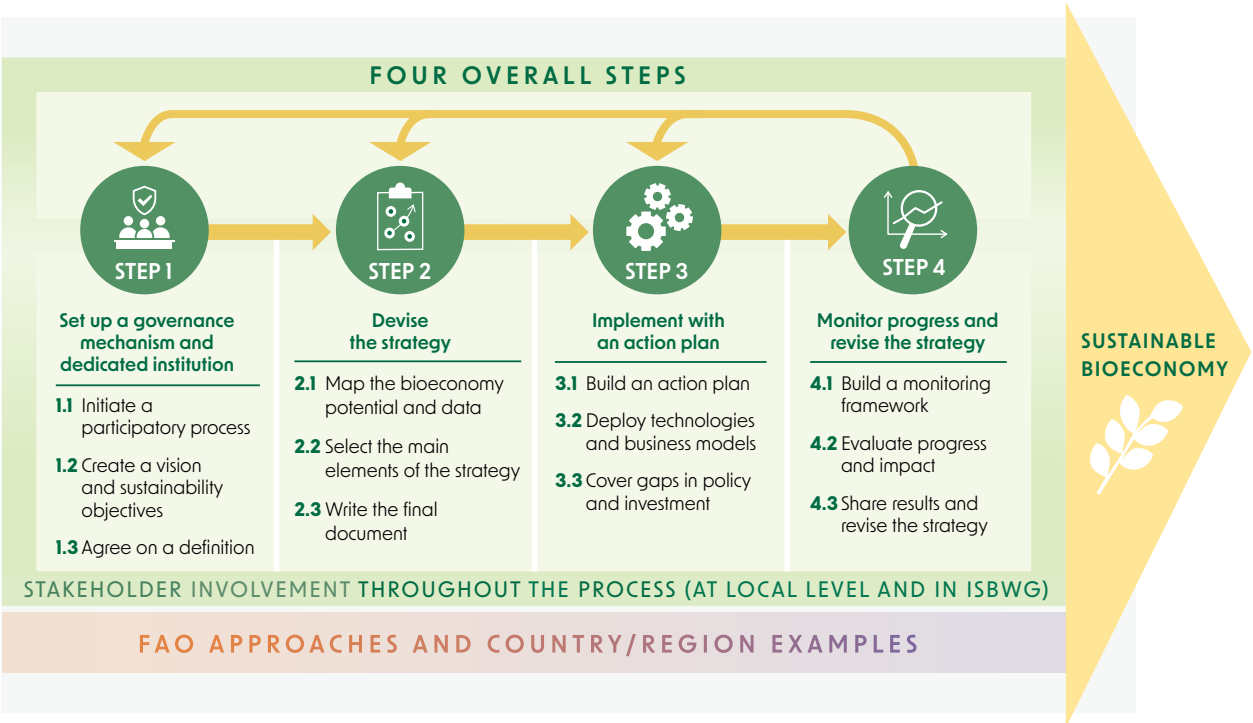
This publication on advancing bioproducts and developing bioeconomy at subnational level, builds on the findings of the *Bioeconomy toolbox – A guide to support the development of sustainable bioeconomy strategies and policies* that provides an overview of existing approaches to determine the availability and different uses of biomass and considers how different approaches can help assess the potential of bioproducts (Gomez San Juan, 2024). Examples presented in this publication to develop bioproducts in rural areas can help to:

- **Better manage local natural resources and incentivize rural industries in agrifood sectors**
  Tools for local businesses and local policy-makers to direct their efforts to develop promising technologies and value chains would support integrated business models to create local value chains and process biomass in rural areas to create rural employment opportunities.

- **Assess biomass availability and its potential for different bioproducts**
  Assessing the potential of biomass for different bioproducts include research tools (e.g. satellite imagery) to analyse the entire system, from biomass availability (e.g. where crop and livestock residues are not used or are being burnt and where there is room for potential bioeconomy interventions) to the competition for natural resources.
- **Tackle as many environmental and socio-economic needs as possible**
  There are several sustainability trade-offs in biomass use that must be addressed holistically with tools that take into account context specific trade-offs. When implementing a strategy or a project, this can ensure that the biomass is used in ways that optimize the sustainable use of local natural resources, increase efficiency in nutrient management, reduce pollution, among other objectives.

The *Bioeconomy Toolbox* includes guidance for policy-makers at national and subnational levels on how to design, implement and monitor bioeconomy strategies and programmes using the aspirational principles and criteria developed by FAO and ISBWG in a step-by-step approach (Figure 3) (Gomez San Juan, 2024). The *Bioeconomy Toolbox* is complemented by the FAO Dashboard on Bioeconomy Strategies (FAO, 2025c).

FIGURE 3. Four-step approach for developing, implementing and monitoring a bioeconomy strategy



Source: **Gomez San Juan, M.** 2024. *Bioeconomy toolbox – A guide to support the development of sustainable bioeconomy strategies and policies.* Environment and Natural Resources Management Working Paper, No. 99. Rome, FAO. https://openknowledge.fao.org/handle/20.500.14283/cc8856en

There are different approaches on how to develop and implement a strategy, including countries that have started with a bottom-up approach (e.g. industry-led, or led by territories), complementing other policies and top-down processes. Also, different strategic objectives and visions for bioeconomy will be determined by the local context, as has been noted by various studies (e.g. Bioökonomierat, 2015; Bugge, Hansen and Klitkou, 2016; Meyer, 2017; Vivien *et al.*, 2019; Papadopoulou *et al.*, 2021; Governo do Estado do Pará, 2022; Johnson *et al.*, 2022; Protestou, Schulz and Feindt, 2024; Viaggi, 2025). Four focus areas of bioeconomy, with different visions depending on different contexts, are common to these studies:

- **Biotechnology focus**
  Investing in biomanufacturing can improve value addition of biomass and promote higher revenues while reducing environmental impact of trade of bioproducts.
- **Natural resources focus**
  Regional management of natural resources needs coherent and integrative policies while strong ties among industries that use biomass and regenerate local landscapes.

  In some contexts where goods and services are generated from the resources of traditional communities, the focus of the bioeconomy, including subnational strategies, is both social and environmental and is expressed as *socio-biodiversity focus*, which promotes the improvement livelihoods and the environment, including the resulting rights and traditional knowledge.
- **Ecological focus**
  Bio-based services (e.g. ecosystem services) are the major vehicle for soil conservation and enhancement, as well as biodiversity loss control, and climate action. Biomass uses for these services need to be accounted for and valued at a local level.
- **Socio-economic focus**
  Bioeconomy offers a wide range of possibilities for bioproduct development and commercialization, and local communities should have access to the feedstock as well as the technologies to be part of the new bioeconomy markets and make informed decisions.

This publication seeks to inform policy-makers at the subnational level on how to translate broad bioeconomy objectives to the local context and how to incorporate local needs and progress to wider bioeconomy frameworks, leveraging the importance of agrifood systems to produce renewable resources for economic gain while prioritizing sustainability and ecological well-being.

Chapter 2. Why are competitive and sustainable agri-based bioproducts central for bioeconomy?

2.1. NON-FOOD BIOMASS CAN SUPPORT FOOD SECURITY

Food security goes beyond food production. Safeguarding food security encompasses income diversification, equitable economic growth and increased economic resilience to environmental hazards. That is why rural areas need to upscale actions to support adding value to non-food biomass and building a vibrant bioeconomy. This study highlights that mainstreaming agrifood bioproducts from production to consumption (SDG 12) can help increasing productivity, diversification of incomes, and better nutrient management in agrifood systems, and thus support the four dimensions of food security and wider human livelihoods, as shown in Figure 4 (FAO *et al.*, 2025):

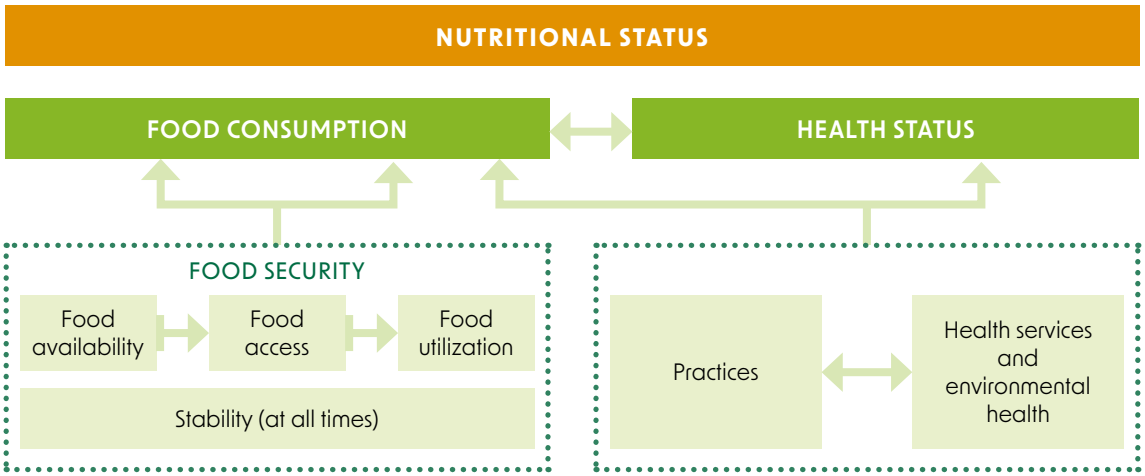
- **Availability of food**
  Food availability is determined mainly by production (domestic), as well as by food imports and existing food stocks. Bioeconomy innovations can improve domestic production and productivity, increase the technologies and knowledge available to farmers, and reduce food loss and waste.
- **Access to food**
  Access to food is about markets, incomes and is affected by households' economic and physical access to food, infrastructure, education, storage, market access and value chains. Reduced access to food can result when primary producers do not have secure land or water tenure. Building bioeconomy value chains can help increasing and diversifying inputs of local communities, through integrated land management for instance, as well as support in the equitable sharing of benefits from the management of natural resources and biomass valorisation.
- **Food utilization**
  Food utilization is about consumption, including nutrition. It is understood as the way the body makes the most of various nutrients. Proper food utilization involves the optimal consumption of a range of nutrients and the efficient use of these nutrients, by humans, animals, plants and microorganisms. Key challenges that need to be overcome to ensure adequate food utilization in rural areas is the increasing pollution of the environment, the low value that is given to local plants and resources and the rapid diffusion of imported highly processed foods. It is important that all consumers are aware of the food and products that support local traditions, add value to local biomass, promote responsible consumption, recognize the value of nutritious food and food security, and build local consumer trust and demand.

- **The stability of the other three dimensions over time**
  Stability of the whole agrifood system to climatic, economic, social and political factors over time addresses the risks that reduce the number of options available for biomass production and its use in industry. Climate change intensifies competition for natural resources, increases uncertainty about whether the amount of biomass produced will be sufficient to support the production of bioproducts, and threatens food security, particularly in rural areas reliant on agriculture. Conflicts, droughts and climate variability drive refugee outflows and increased migration, especially in areas where biological resources are scarce.

These four dimensions of food security need to be addressed to safeguard global and local food security.

Non-food sources of income, stable economies and growth are key elements in the transition towards sustainable agrifood systems that can ensure food security for all. Valorizing all biomass and transforming it into different products is a key element of the agrifood systems.

FIGURE 4. The four dimensions of food security in the wider context of livelihoods



Source: Adapted from **FAO, IFAD, UNICEF, WFP and WHO.** 2025. *The State of Food Security and Nutrition in the World 2025 – Addressing high food price inflation for food security and nutrition.* Rome.
https://openknowledge.fao.org/handle/20.500.14283/cd6008en

The relationship between bioeconomy and agrifood systems revolves around upon four potential benefits, according to the 2025 Communiqué of the Global Forum for Food and Agriculture (GFFA), which recognized that agrifood systems are necessarily at the centre of bioeconomy (GFFA, 2025):

- **Producing biomass sustainably - Solving conflicts of interest**
  Bioeconomy relies on sustainable biomass production mainly from agrifood systems, including agriculture, forestry, aquaculture, organic waste, micro-organisms, and insects. Given the differences in natural resources and socio-economic conditions among different countries, context-specific solutions are necessary to avoid conflicts of interest and ensure the right to adequate food in all contexts. Best practices need to be shared to improve understanding of sustainable production of food and non-food products and reduce trade-offs between different sustainability objectives. Sharing knowledge about best practices like integrated, regenerative and organic farming, or One Health is key to build common parameters. The GFFA 2026 continued the discussion focusing on blue bioeconomy as one of the four pillars of the new edition.

- **Using biomass sustainably - Ensuring global food security**
  The efficient and responsible use of natural resource use is crucial for a sustainable bioeconomy. Focus must be placed on minimizing the demand for land and reducing waste by reusing and recycling, and following the cascading principle. The cascading use of biomass involves the recycling of materials within the value chain to add value to biomass several times and use it for bioproducts and energy, before disposal, thus closing nutrient and material cycles in crop, livestock, fisheries and bioindustries. Also, reducing reliance on synthetic pesticides and fertilizers by adopting biological methods (e.g. biostimulants) leads to more sustainable and efficient production systems. This approach enhances the sustainability and nutritional value of food and promotes functional, recyclable products, (e.g. textiles from wood fibres).

- **Strengthening innovation - Promoting communication**
  Research and innovation are vital for advancing bioeconomy. The development of tailored financing would help improve equitable bioeconomy growth, especially among youth, women, Indigenous Peoples and other stakeholders. Often, innovations are rooted in traditional knowledge, but even though they show significant promise, they remain underutilized. Cooperation on the exchange of technology and knowledge on mutually agreed terms can improve the equitable use of biological resources and support resilience of agrifood systems. Common criteria, methodologies and global data are key elements for transparency and sustainability. Promoting knowledge exchange across different sectors and countries is key to identify strategies for overcoming existing barriers.

- **Creating a fair framework - Harnessing change**
  The increased use of biomass and other biological resources for developing new bioeconomic value chains necessitates rules-based, secure, and transparent trade practices. The social dimension of bioeconomy includes implementing the right to adequate food, empowering women, youth, and vulnerable groups, supporting rural development, improving access to land, and ensuring the fair distribution of benefits within a bioeconomy. Tools and guidelines dedicated for bioeconomy and needed to support mainstreaming sustainability at all levels and in all sectors.



CASE STUDY 1

SUPPORT TO BIOPRODUCTS FOR TRANSFORMING AGRIFOOD SYSTEMS IN CANADA

Canada, which is the second-largest nation by land area, is enhancing food security by maximizing existing resources, harnessing residues and minimizing food loss and waste throughout production, distribution and consumption (Environment and Climate Change Canada, 2022).

In Canada, over 21 million tonnes of raw biomass were processed into bioproducts, including biofuels, bioenergy, organic chemicals, materials and composites, intermediary biochemicals and biomaterials, high-tech fibres, plant tanning agents, enzyme-based additives, and other bioproducts in 2015 (AAFC, 2017). Out of these 21 million tonnes of biomass, around 12.3 million tonnes were sourced from forestry and 8.8 million tonnes from agriculture. The production of these bioproducts employed over 5 600 people and generated approximately USD 3.16 billion in revenue (CAD 4.27 billion)[3] (AAFC, 2017; Statistics Canada, 2017).

By 2030, the global food and non-food bioeconomy is projected to reach USD 7.7 trillion annually (CAD 10.5 trillion) (WBCSD, 2020). Canada's share is estimated to be around USD 167 billion (CAD 240 billion), if the country's potential for industrial value addition to agricultural biomass for different bioproducts is realized (AAFC, 2025a).

From the perspective of Canadian industry, companies and organizations within the country's bioeconomy have yet to reach their full potential (BIC, 2019). In Canada, the definition of bioeconomy is quite broad and touches on the mandates of several federal departments and agencies as well as provincial and municipal governments. There are several initiatives in the country that support the development of bioproducts to strengthen rural communities and improve sustainability and innovation of agrifood systems.

Initiatives related to agricultural bioeconomy aim to support the development of new value chains for bioproducts that can contribute to making the agriculture sector stronger and more competitive. Multistakeholder groups provide platforms to define how bioeconomy can be implemented in different sectors and levels. For example, the Federal-Provincial-Territorial Bioproducts Working Group, created in 2015, is a working-level initiative that facilitates information sharing and working-level collaboration between federal, provincial, and territorial agriculture departmental representatives (AAFC, 2015; Symth, 2025).

[3] Using a currency exchange throughout the text of 1.36, as of 1 July 2025.

CASE STUDY 1



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A significant initiative that promotes bioproducts and other innovation in agrifood systems is the Sustainable Canadian Agricultural Partnership (Sustainable CAP), a USD 2.6 billion (CAD 3.5 billion) 5-year agreement between the federal, provincial and territorial governments that runs from 2023 to 2028 (AAFC, 2025b). Sustainable CAP works to strengthen the competitiveness, innovation, and resiliency of the agriculture, food and agri-based products sectors. It focuses on the five key priority areas:

- building capacities, growth and competitiveness;
- support for greenhouse gas (GHG) emission reductions and the long-term vitality of the sector;
- science, research and innovation;
- market development and the trade of food and bioproducts; and
- resiliency and public trust.

Sustainable CAP includes around USD 0.73 billion (CAD 1 billion) in federal programmes and activities and USD 1.84 billion (CAD 2.5 billion) in cost-shared programmes and activities, which is shared between the federal and provincial and territorial governments. The federal government contributes 60 percent of the costs of the programme and the provincial and territorial governments contribute 40 percent.

Funding under Sustainable CAP also supported the creation of two innovation clusters, the Bioproducts Cluster (discussed in more detail in Case Study 5) and the Biomass Cluster. The Bioproducts Cluster is managed by Bioindustrial Innovation Canada (BIC), and provides new opportunities for Canadian farmers to profit from biomass, such as crop residues, making the agricultural sector more competitive in the growing Canadian bioeconomy. The Biomass Cluster is managed by BioFuelNet and helps to expand and invigorate Canada's bioeconomy through technologies to boost the production of biomass and value-added agricultural materials, develop biomass supply chains and reduce production costs and expanding export markets for biomass.

This support for innovation into agrifood systems through bioproducts at the national level is then translated to the subnational level (provinces and territories). For example, the Ontario Ministry of Agriculture, Food and Agribusiness (OMAFA) supports innovation and trade to safeguard the food supply chain and ensure the safe and sustainable production of food. The end goal is to develop a sustainable, resilient, trusted and thriving agrifood system and strong rural communities.

Ontario is the top agrifood exporting Canadian province. In 2025, agrifood exports totalled USD 21.49 billion (CAD 29.34 billion), a 3.7 percent increase from USD 20.66 billion (CAD 28.18 billion) in 2024. The 2025 agrifood exports totalled a 10.9 percent increase with respect to 2023 and 21.1 percent increase if compared to 2022. (OMAFA, 2026a). Ontario exports are mainly value-added or consumer-oriented goods (74 percent in 2023) rather than bulk goods (14 percent) or minimally processed goods (12 percent). In 2025, Ontario's agrifood gross domestic product (GDP), including primary production and food and other related manufacturing industries, was USD 38.86 billion (CAD 52.85 billion), a 5.9 percent of the total GDP of the region (OMAFA, 2026b). The agrifood sector also provided over 854 142 jobs (10.4 percent of the total labour force in the region) in 2025 (OMAFA, 2026c). OMAFA aims to have a robust agrifood industry that strengthens Ontario's economy, generates quality employment opportunities, and provides local food for better nutrition.

One of the OMAFA programmes is 'Strong agriculture, food and bioproduct sectors and strong rural communities', which has had a dedicated budget since 2021. For the fiscal year 2025–2026, the programme has a budget of USD 445.8 million (CAD 606.33 million), to cover operational expenses that support to the agrifood sector management. The programme also has a capital expense budget, which provides support to long-term investments and projects. For the 2025-26 fiscal year, this capital expense budget of OMAFA is estimate at USD 9.3 million (CAD 12.6 million), an increase of 33.3 percent from the 2024–2025 estimates (OMAFA, 2025a).

Circular bioeconomy approaches promote the use of local organic waste for manufacturing bioproducts that can be used to improve nutrient use efficiency, such as bioinputs used as fertilizer. Through the Ontario Fertilizer Challenge, OMAFA has promoted alternatives to traditional fertilizers to solidify this industry. For example, OMAFA provided USD 1.47 million (CAD 2 million) to the Fertilizer Accelerating Solutions and Technology Challenge in 2022–2023 (OMAFA, 2025b). OMAFA also invests in open research programmes and projects to enhance bioproduct development. The most prominent example is the Ontario Agrifood Innovation Alliance,[4] a collaboration between OMAFA and the University of Guelph that increases the competitiveness, profitability, and growth of the agrifood sector through innovative products and product improvement, from concept to prototype (e.g. alternative proteins, foods of the future, bioproducts) (BDDC, 2025) such as the 'Sustainable Packaging Solutions to Advance Ontario Towards a Circular Economy' project about converting industrial packaging and food waste into new sustainable products.[5]

The Bioproducts Discover and Development Centre (BDDC) at the University of Guelph has developed the Ontario BioProducts website, which serves as a web-based directory of the entire value-chain of the bioproducts sector in Ontario, including for agri-based feedstocks (Ontario Bioproducts, 2025). The directory includes details on bioproduct certifications, biomass sustainability certifications, and listings of all critical groups operating in Ontario's bioproducts sector (e.g. grower associations, industrial manufacturers of consumer products and biochemicals, services organizations, research institutions and government agencies). Bioproducts listed in the directory include bioplastics, bio-based pharmaceuticals, pulp fibres, biofoam, cellulose fibrils, plant-based oils, biorubber, construction materials, oleochemicals, bio-based packaging, spider silk, biocomposites, biolubricants, biotextiles, biocleaning agents, biocarbon, bioenergy and biofuel.

[4] https://www.uoguelph.ca/alliance/

[5] https://www.bioproductscentre.com/research/Projects/Sustainable_Packaging

CASE STUDY 2

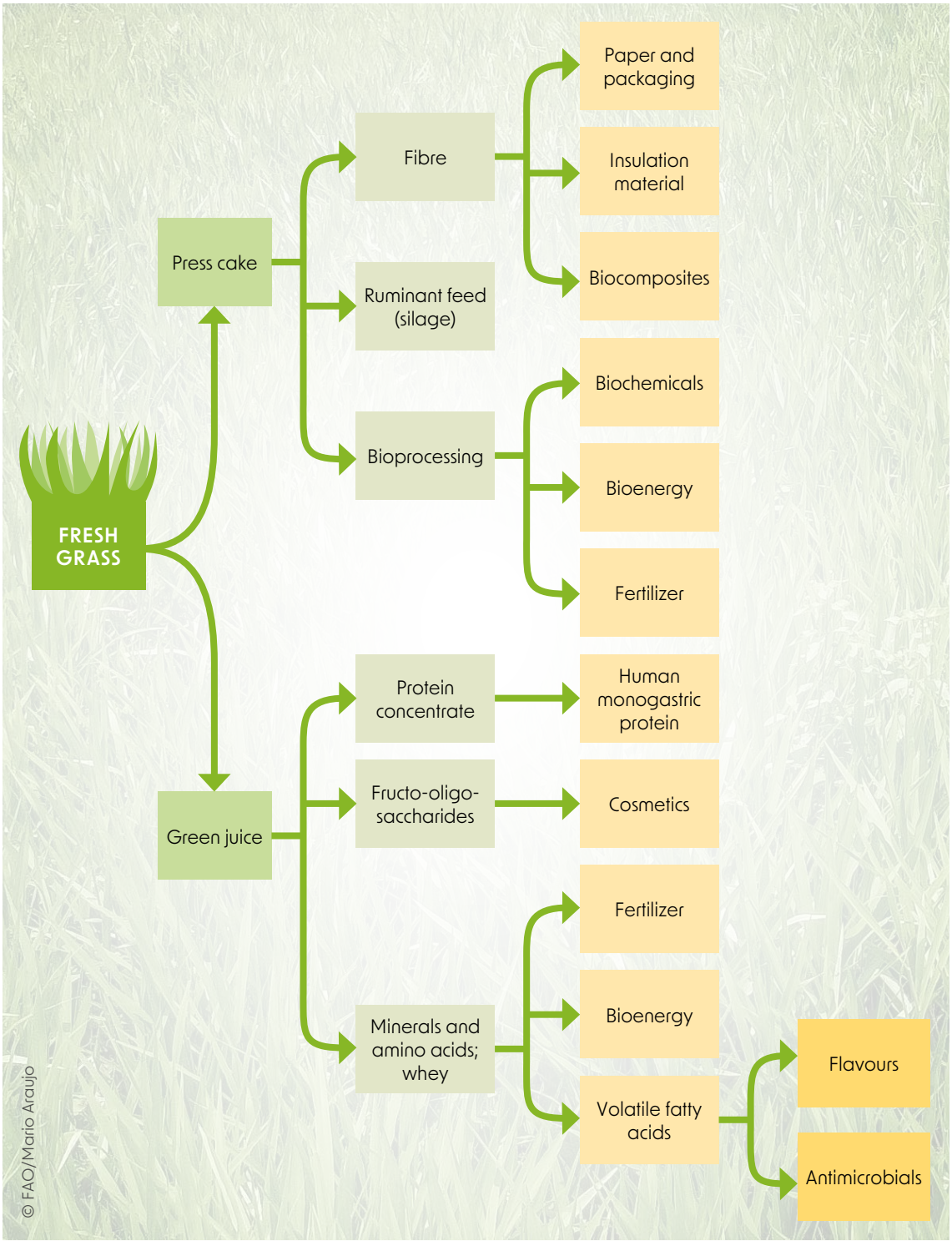
GRASS BIOREFINERIES BEING DEMONSTRATED IN IRELAND

Ireland is developing a grass-based bioeconomy demonstration pathway that builds on the country's comparative advantage in productive grassland systems. Grass and other green biomass can be fractionated into press cake/fibre, protein concentrates, sugars, minerals and residual streams that can be used for animal feed, food ingredients, bioenergy, bio-based fertilizers and other bio-based products. The Irish case is most useful not only as a grass biorefinery example that integrates the manufacturing of multiple products in one setting, but also as a country-wide bioeconomy demonstration pathway involving farmer-led trials, on-farm demonstration, university pilot equipment, integrated anaerobic digestion and national pilot-scale biorefinery infrastructure. Such plan to manage an abundant biomass resource is developed in a multistakeholder manner to comprehensively reduce competition between food and other uses, extracting the maximum social, economic and environmental value (BioRefineryIreland, 2025).

The technical rationale for the pathway is that green biorefining can separate grass into complementary fractions. Press cake can be used as forage or fibre, and some research demonstrated increase nitrogen use efficiency and lower nitrogen and phosphorus losses in excrement of cows that ingest grass biorefinery pulp. The pulp could be used also for paper, fibre boards, straws, plastic alternatives, and other materials. The biorefinery could also separate the cytoplasmic 'white proteins' from the chloroplastic 'green proteins', and use the white proteins rich in the rubisco enzyme in a range of pig and poultry feed and, with further processing and regulatory validation, human food applications. Some of these products have foaming, gelation, and emulsifying properties that have the potential to add value to biomass. Sugars and other compounds extracted from grass have the potential to be used in prebiotics, flavours, cosmetics or other ingredients. And residual streams can support fertilizer or bioenergy uses. Most of these products are not yet commercially available, and their impacts such as replacing imported feeds, replacing silage, reducing nutrient losses, or producing food-grade ingredients depend on the specific context and should be tailored to different situations.

Figure 5 summarizes potential bioproducts that could be obtained from the grass value chain. This figure summarises the main grass biorefinery product streams. Those streams have been tested and demonstrated through a range of sequenced project, including six main initiatives presented in the narrative below: Biorefinery Glas, Rural BioReFarmeries, Farm Zero C anaerobic digestion and green biorefinery demonstration infrastructure at Shinagh Farm, pilot green biorefinery at Munster Technological University (MTU) Kerry Campus, Grass4Value and the BioScaleUp/ National Bioeconomy Pilot Plant at Lisheen, Co. Tipperary.

FIGURE 5. Bioproducts potential from grass biorefineries



Source: Adapted from:

Biorefineryglas. 2020. Deliverable 1.3 *Operational Guide for Grass Biorefinery*. https://biorefineryglas.eu/documents/

Gaffey, J., Rajauria, G., McMahon, H., Ravindran, R., Dominguez, C., Ambye-Jensen., Souza, M.F. 2023. Green biorefinery systems for the production of climate-mart sustainable products from grasses, legumes and green crop residues. *Biotechnology Advances*, Volume 66, 108168. https://doi.org/10.1016/j.biotechadv.2023.108168

Rural BioReFarmeries. 2025. *From grasslands to green bio-based products – forging a robust farm – centred bioeocomy in Europe*. [online]. Dublin. [Cited 22 September 2025]. https://ruralbiorefarmeries.eu/the-project/

The development pathway has been chronological and cumulative and has involved a sequence of linked investments and projects. It began with farmer-led proof-of-concept work, moved into European and national demonstration projects, and is now being connected through pilot plants and scale-up facilities. This pathway is relevant to countries seeking to move from research evidence to investable rural bioeconomy value chains.

The first stage was a farmer-led proof of concept multi-actor project. Biorefinery Glas[6], a European Innovation Partnership Operational Group funded by Ireland's Department of Agriculture, Food and the Marine (DAFM) under the Rural Development Programme 2014-2020, demonstrated small-scale mobile grass biorefining with farmers in south-west Ireland. It tested the production of improved fodder press-cake fibre for cattle, protein concentrate feed for monogastrics, high-value prebiotic sugars, and nutrient-rich residual streams for fertilizer or bioenergy, including whey. This activity was the foundation for the later Irish demonstration pathway, because it showed both the technical product streams and the farm-centred business model challenge.

The second stage is on-farm and decentralised demonstration. Rural BioReFarmeries (2024-2028), funded by the Circular Bio-based Europe Joint Undertaking (CBE JU) and coordinated by MTU's Circular Bioeconomy Research Group, is scaling the grass biorefinery concept through a European consortium. The project aims to operationalize a demo grass biorefinery that balances farm input products and high-value ingredients (e.g. white protein and volatile fatty acids) for food, flavour and health applications (Rural BioReFarmeries, 2025). This Irish demonstration is hosted at Farm Zero C on Shinagh Farm in West Cork. This is important because Shinagh also hosts Ireland's integrated anaerobic digestion and green biorefining demonstration investment as part of the wider Farm Zero C project.[7] In 2023, Ireland announced USD 3.47 million (EUR 3 million) for Farm Zero C project[8] implemented by University College Dublin and MTU Carbery Group to develop this integrated anaerobic digestion and green biorefining facility, demonstrating how local grass protein, bio-based fertilizer, renewable energy and other co-products can support farm diversification and reduced some imported feed and fertilizer emissions.

The third stage is pilot equipment and linked demonstration capacity. In January 2026, MTU launched a pilot green biorefinery at its Kerry Campus.[9] The facility, funded by Enterprise Ireland in collaboration with the Centre for Applied BioSciences Research Technology Gateway, and is designed to develop technologies that convert grassland biomass (pressed juice and the pulp or press cake) into silage for ruminants, high-quality feed for monogastric and ruminant livestock such as protein-concentrate, proteins for human consumption, prebiotics, flavours, fertilizers, bioenergy, and chemicals.

6 EU CAP Network. Biorefinery Glas - Small-scale Farmer-led Green Biorefineries website: https://eu-cap-network.ec.europa.eu/projects/biorefinery-glas-small-scale-farmer-led-green-biorefineries_en

7 Project announcement: https://www.gov.ie/en/department-of-agriculture-food-and-the-marine/press-releases/ministers-mcconalogue-and-heydon-announce-3-million-for-integrated-anaerobic-digestion-and-green-biorefining-demonstration-initiative/

8 BiOrbic website: https://biorbic.com/e3-million-in-funding-awarded-for-grass-bio-refinery-activation-across-ireland/

9 Green Biorefinery at MTU website: https://www.mtu.ie/news/2026/mtu-launches-green-biorefinery/

CASE STUDY 2



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The fourth stage is national connection and scale-up. Grass4Value is a DAFM-funded research and demonstration project led by MTU that links the pilot green biorefinery at MTU Kerry Campus (which in turn builds on Biorefinery Glas and Rural BioReFarmeries) and the Farm Zero C anaerobic digestion and green biorefinery demonstration infrastructure at Shinagh Farm, since the opening in 2026 of both facilities, as well as the National Bioeconomy Pilot Plant at Lisheen, Co. Tipperary that is presented next. This interlinkage is central to the Irish case study: it shows how grass biorefinery capacity is being organised as a connected demonstration system rather than as isolated projects.

In parallel, the EU Just Transition Fund Bioeconomy Demonstration Initiative[10] is supporting wider piloting and demonstration in the Midlands in Ireland, to develop innovation hubs to create new products (DAFM, 2025; Rural BioReFarmeries, 2025). Two calls for initiatives

[10] For more information on the initiative: www.gov.ie/en/department-of-agriculture-food-and-the-marine/publications/2025-eu-just-transition-fund-bioeconomy-demonstration-initiative-call-2/

(in October 2024 and April 2025) have been launched.[11] One winner included the Lisheen Bioeconomy Scaleup Initiative (BioScaleUp) at the National Bioeconomy Campus at Lisheen Thurles in Tipperary. The project is led by the Tipperary County Council and aims to demonstrate six innovative technologies at the biorefinery, including the conversion of dairy side streams and wood processing wastewater into bio-based chemicals for food ingredients or for bio-based ingredients in the cosmetic and pharmaceutical sectors.

Finally, the Agriculture and Food Development Authority, Teagasc, which is the national body providing integrated research, advisory and training services to the agriculture and food industry and rural communities, has undertaken research on bioresource mapping (in projects such as InformBio[12]) and geographic information systems (GIS) to strengthen this demonstration pathway by identifying where biomass supply, farm participation and logistics, cooperative structures, proximity to pilot and demonstration assets, processing infrastructure and market demand can be clustered to enhance the country's bioeconomy potential (Teagasc, 2025).

The case study shows how Ireland is moving from grass biorefinery research to piloting to a country-wide bioeconomy demonstration pathway involving farmer-led trials, on-farm demonstration, university pilot equipment, integrated anaerobic digestion and national pilot-scale biorefinery infrastructure. Green biorefinery development requires more than a promising feedstock: it needs farmer participation, cooperative and industry partners, pilot equipment, on-farm demonstration, links with farm-based technologies such as anaerobic digestion and nutrient cycling, and scale-up infrastructure that can de-risk investment. Ireland's pathway remains at demonstration stage, but it provides a useful example of how a grassland-based country can test local protein, renewable energy, bio-based fertilizer and high-value ingredient opportunities while seeking additional income streams for farmers.

2.2. CROP AND LIVESTOCK SYSTEMS HOLD GREAT POTENTIAL FOR BIOECONOMY

There is an urgent need to rethink how we use biomass to reduce the pressures and negative impacts on natural resources. Between 1970 and 2020, the total amount of biomass extracted (e.g. crops, crop residues, timber, grazed biomass, and wild-caught fish) nearly doubled. Agriculture is responsible for 75 percent of global biodiversity loss (UNEP, 2024b), while it is also affected by disasters, with an average of USD 123 billion per year of crop and livestock production losses (FAO, 2023).

Around 916 million people, or 26 percent of the global workforce, are employed in agriculture (data of 2023) and 375 million people work in off-farm operations within agrifood systems such as bio-based industries (data of 2019), while almost half the world's population (3.83 billion people) live in households linked to agrifood systems and are reliant on them (data of 2019) (Davis *et al.*, 2023; FAO, 2025d).

[11] For more information on the EU Just Transition Fund award for Midlands Bioeconomy Demonstration Initiatives: https://www.gov.ie/en/department-of-agriculture-food-and-the-marine/press-releases/ministers-announce-10-million-eu-just-transition-fund-award-for-two-midlands-bioeconomy-demonstration-initiatives/

[12] InformBio project webpage: https://informbioproject.ie/

Transitioning to a growing bioeconomy would entail economic growth in primary production sectors. A 50-percent increase in food, feed, and biofuels will be required to meet global demand in 2050 compared to 2012 levels (FAO, 2017; 2022). Similarly, under a business-as-usual scenario, the global gross agricultural output (in terms of monetary value) is expected to double between 2012 and 2050 (FAO, 2018). These figures indicate the potential to add value to agricultural products and to create additional employment.

The contribution of agriculture to global GDP has been stable at around 4 percent in the last 20 years. The monetary value of agricultural production increased by 96 percent between 2000 to 2023, when it reached USD 4 trillion (FAO, 2025d). There is potential to add more value to primary production by diversifying into bioproducts that do not compete with food through integrated systems or multipurpose crops. This can help farmers in accessing new non-food markets (e.g. cosmetics and pharmaceuticals) and increase rural employment.

Crop and livestock systems play a crucial role within the bioeconomy framework for transforming agrifood systems. More innovation is needed in the crop and livestock sectors to improve efficiency, increase value addition and promote inclusivity. In the European Union, agricultural production (crop and livestock) accounted for around 49 percent (8.4 million) of jobs in bioeconomy in 2023, and improvements in these value chains would support bioeconomy development (Lasarte-López and M'barek, 2025).

Applying bioeconomy innovations generated from biotechnologies or biological sciences in crop and livestock systems can lower costs in some contexts. It can also enhance the resilience and diversity of production systems by improving the efficiency of energy and water use. This can be achieved by both, using the newest technologies and adopting traditional small-scale farming practices, such as agroecological farming, which, in certain circumstances, can increase agricultural production that produce a range of co-products and deliver other benefits. Improved manure management can help to restore soil fertility and increase soil organic content. On small farms, animals have historically grazed on uncultivated land and converted crop waste into food and manure.

Capacity development is needed, for farmers and other stakeholders in the agrifood system about recycling nutrients including crop residues and unavoidable organic waste. It is essential to minimize the use of finite resources (e.g. land and nutrients) and maximize regenerative practices. Using bioinputs (e.g. biostimulants and biopesticides) instead of harmful chemical inputs can lower the environmental footprint of agricultural activities. Understanding the strategic role of microorganisms in enhancing the resilience and productivity of plants, animals and ecosystems as well as in new bioindustries and production methods is a priority. For example, residues from cereal crops can be used to grow mycoproteins which are then processed into construction materials or textiles, and whey from dairy side streams (whey permeate and delactosed whey permeate) can be used to produce minerals for food supplements, bio-based fertilizers, lactic acid as well as biodegradable plastics.

The efficient use of biomass, including valorization of unavoidable waste, residues, and by-products can help minimize the trade-offs in the used of biomass, especially trade-offs associated with food–feed competition, and improve competitiveness. Increasing efficiency can be done by establishing agro-innovation hubs, improving agro-processing to increase nutrient recycling and reduce post-harvest losses, and investing in high-value skills and capacities for agricultural innovation. Rural infrastructure is key for the upscaling of innovations because it increases the links between transport routes, agricultural production areas, and markets. As rural areas industrialize, producers often gain better access to agricultural inputs and services, which leads to higher productivity and increased income levels.

2.2.1. CROP-BASED BIOPRODUCTS VALUE CHAINS

Between 2000 and 2023, global primary crop production increased by 61 percent, reaching 9.9 billion tonnes. Sugarcane, maize, wheat, and rice made up half of this production. Cereals, which are grown on also around half of the world's harvested land, accounted for nearly one-third of primary crop production. This was followed by sugar crops (23 percent) and vegetables and oil crops (12 percent each). Cereals were the most traded commodity in 2023. The Americas and Europe were the top exporters, and Asia was the largest importer. In terms of monetary value in 2023. Cereals accounted for around one-third of the total the value of primary crops produced, followed by vegetables (19 percent) and fruits (17 percent) (FAO, 2025d).

Data is critical for determining the co-products that have been obtained from a single crop, or a single farm, and monitoring the increases in the overall value of agriculture as a result of bioeconomy development. Often cover crops, crop residues, losses, waste and other biomass sources can be valorized and be used in alternative value chains, which increases overall agricultural productivity and resilience.

At the global level, food residues and animal feed together are estimated to worth USD 105 billion in exports in 2023. This amount does not account for industrial co-products and by-products (e.g. animal offal or vegetable extracts). The major exporters of food residues and animal feed are: China (6.9 percent), Germany (5.4 percent), United States of America (the) (4.6 percent), and Vietnam (4.2 percent), followed by France, Indonesia, Poland and United Kingdom of Great Britain and Northern Ireland (the) that range between 3.1 and 3.9 percent), and Canada, Italy, Japan, Mexico, Republic of Korea, Spain and Thailand range between 2.4 and 2.8 percent (Growth Lab, 2025).

Crops and crop residues are essential feedstocks for various bio-based industries and applications. They are feedstock to produce bio-based materials (e.g. bioplastics, textiles, and construction materials) and provide sustainable alternatives to fossil-based products and energy. Crop residues and by-products are taken to biorefineries to produce biochemicals, biomaterials, and other value-added items. However, crop production is facing challenges related to trade-offs related to land use, and competition is increasing for biomass in different sectors. A comprehensive approach is necessary to explore synergies in biomass production, apply innovative technologies for processing, and build connections within and between value chains.

One way to tackle competition for biomass is to improve efficiency in the use of biomass. Key elements for improving efficiency are circularity and the cascading use of biomass, which focus on recycling and optimizing the use of biological resources throughout their lifecycle. This approach boosts sustainability by adding value to agricultural residues and creating new market opportunities and value networks that foster cross-sectoral collaboration. For example, while a certain percentage of crop residues must be left on the soil to improve its structure and nutrient content, surplus residues can also be used for feed, materials, energy, textiles, and other products.

There are several ways to apply circular and cascading approaches for biomass. For example, integrated production systems (e.g. crop-livestock, crop-aquaculture, livestock-sylviculture) enhance the local availability of resources; conservation agriculture diversifies crop species through rotations, sequences, and associations of both annual and perennial crops; and organic production systems that use of bioinputs (e.g. biostimulants, bio-based fertilizers and biochar soil amendments) can increase crop productivity. Restoration is another long-term strategy that bioeconomy can support by promoting reduction soil and water pollution significantly with bioinputs that include microbial and phyto-remediation that utilize living organisms to clean contaminated environments, as well as integrated agro-silvo-fisheries systems that focus on restoring peatlands. These approaches not only enhance environmental health but also create economic opportunities through the sustainable use of natural resources and contribute to ecological and economic resilience.

Improvements are also being made to improve efficiency in agrifood systems through digitization and regional data management. These activities can promote sustainable farming by promoting precision agriculture by other advanced farming techniques. They are boosting productivity and quality by integrating innovative technologies like genome selection, synthetic biology, and artificial intelligence into breeding programmes. Biotechnological advancements in genetics and breeding have resulted in significant increases in productivity, resilience to biotic and abiotic stresses, such as climate change, and improved nutritional quality. Biotechnology can help reduce reliance on agrochemicals, enhance soil health, and support small-scale farmers.

Finally, promoting traditional products from Indigenous Peoples can create niche markets and raise awareness about these unique products. Collaborating with trusted representatives from the private sector, governments, and researchers is vital for developing sustainable marketing strategies for indigenous products. Advanced technological tools such as whole genome sequencing can be used to discover new uses for indigenous crops and livestock. Tapping into existing knowledge and creating inventories of indigenous products for bioeconomy is also critical. The use and availability of traceability data is key to increase transparency in sourcing and benefit and value sharing.

2.2.2. LIVESTOCK-BASED BIOPRODUCTS VALUE CHAINS

Livestock primary production encompasses goods and services derived from animals, including milk, eggs, animal-derived fibre, meat, offal, raw fats, and fresh hides, skins, as well as a range of ecosystem services. In 2023, 34.2 percent of the total meat produced globally (in tonnes) came from chicken production; 33.7 percent from pig production, and 19 percent from cattle. Between 2000 to 2023, meat production has grown 60 percent (an increase of 138 million tonnes), half of this increase comes from chicken production (an increase of 68 million tonnes) (FAO, 2025d).

Animal-sourced foods and co-products play a crucial role in circular production systems. By utilizing non-edible biomass, such as grasslands, crop residues, crops unsuitable for food and by-products from other industries, livestock can convert low-value resources into high-quality nutrient sources for human consumption. Practices such as grazing livestock on non-arable land or incorporating fish and innovative protein sources (e.g. insects) can also strengthen the development of circular systems and support the efficient use of resources. Responsible animal husbandry and circularity practices play a crucial role in the livelihoods of many rural households, and in some countries, women in particular benefit from these practices.

In contrast to the linear nature of some current livestock systems, where not all inputs are converted into products consumable by humans and residues contribute to environmental pollution, circular bioeconomy approaches focus on nutrient recycling and the reduction of food–feed competition. Using food residuals as feed and valorizing by-products and waste streams can reduce dependency on commercial inputs and improve resource use efficiency. Circularity practices can be found across different production contexts. There is already a lot of experience in many countries on animal farming that uses circular practices, such as using food waste as feed and valorizing the residues to utilize scarce resources efficiently. FAO data shows that raw hide and skin production from cattle and goats in low- and middle-income countries grew by nearly 70 percent between 2000 and 2024 reaching over 11 million tonnes (FAO, 2026).

Making feed production more sustainable through the restoration and management of pastoral and agro-silvo-pastoral systems also has great potential for bioeconomy. Around 86 percent of livestock feed is not suitable for human consumption, allowing such crops to be converted into a range of co-products in an integrated manner (Mottet *et al.*, 2022). For instance, grass is used to produce a range of products, such as biochemicals, biogas, grass fibres (e.g. silica and cellulose) and grass juices (e.g. sugar proteins, colourants, alkaloids and insulin). Worldwide, grassland accounts for 26 percent of the total land and 70 percent of the agricultural land (FAO, 2025e). Bioeconomy potential for grass value chain is based on the natural advantage in the rapid growth of grass (DBEI, 2019).

Permanent meadows and pastures, which account for 67 percent of world agricultural use (FAO, 2025d), are defined as land that is used growing herbaceous forage crops for five years or more. Research suggests that adopting a bioeconomy model at scale could transform primary production by feeding livestock primarily with residues, by-products, and marginal lands, leaving croplands for direct human consumption (FAO, 2025f). Additionally, alternative feed sources (e.g. algae and insect protein) can reduce dependence on traditional crops. Should feed ingredients such as cereals, fish, pulses and vegetable oil be replaced with agrifood system co-products, global food availability would increase by 13 percent and by 15 percent in terms of kilocalories and protein, respectively (Sandström *et al.*, 2022). Biotechnology can also be applied to improve the nutritional value of feed. The supply of livestock products decreases when feed prices rise and some processed goods, like vegetable oils and by-products can increase the availability of feed resources.

Developing bioeconomy offers significant opportunities for the livestock waste management and the circularity of biomass through the transformation of unwanted biomass into feed. Livestock manure can be transformed into bioenergy and fertilizers through processes like anaerobic digestion that can lead to reduced GHG emissions. Additionally, animal by-products can be used to produce bio-based materials, such as collagen for biomedical uses and biopolymers from animal processing by-products (FAO, 2025g). It is also necessary to lower emissions coming from livestock value chains.

Rendered animal fat is one of the main sources of hydrotreated vegetable oil (HVO) biofuel. There are commercial plants in Italy, United Kingdom of Great Britain and Northern Ireland (the) and United States of America (the) that produce HVO as well as other grease by-products from soybean, palm tree, sunflower and rapeseed (Biofuture Platform, 2018).

It is estimated that emissions from the livestock sector could decrease by 30 if producers implemented practices that create animal products with low emission intensities by adopting good practices in animal feeding, animal husbandry and health, and improved manure management (Ruane and Lucio Restrepo, 2024).

Genetics for yield improvement or advances in microbiome science offer crucial insights into the complex connections between humans, animals, and ecosystems, aligning with the One Health approach. For example, GHG emissions intensity can be reduced with genetic improvement or through the use of prebiotics, probiotics, symbiotic, and postbiotics that have shown benefits in improving the health of plants, animals, and humans.

CASE STUDY 3

BIOECONOMY POTENTIAL OF CROP AND LIVESTOCK BIOPRODUCTS IN CANADA

Around half of Canadian farms (37.9 million ha of 62.2 million ha) are crop land, while pastures cover 18.6 million ha (data of 2021) (Statistics Canada, 2022). Crop and livestock systems are mostly located in the prairie provinces (Alberta, Manitoba, Saskatchewan), Quebec and Southern Ontario. Biomass residues and accumulation are therefore higher in these provinces. Generally, crop residues are used for bioenergy in Alberta, Manitoba and Saskatchewan, while livestock manure is a significant feedstock for agricultural biogas production in Alberta, Quebec and Ontario (CER, 2025).

Crop residues

Canada has approximately 82.4 million dry tonnes of agricultural residues available annually (Li *et al.*, 2012; Jacobson *et al.*, 2025). Straw and other residues have existing uses and even markets. A portion of the residue needs to remain on the field to maintain soil health and avoid erosion. Some of the grain crop residues have competing uses as they are used for livestock feeding, bedding, insulation, and mulching if left on the field. Collection of crop residues requires trained labour with specific equipment. Also, the stover can often be contaminated with dirt or ash, which can require more processing and cleaning. The actual proportion of crop residues accessible for use in bioproducts, including bioenergy, is therefore significantly lower.

Depending on the context and soil zone, and after deducting soil conservation and livestock uses, about half of the produced crop residues are estimated to be available for other use on average (Shanmugam *et al.*, 2024). The amount of biomass available depends on the crop:

- Wheat straw is estimated to be the largest biomass crop residue removed from the field in terms of weight. Wheat production is estimated at 34.9 million dry tonnes a year (Statistics Canada, 2025a). It is estimated that, on average, for every 1.3 kg of wheat grain, approximately 1 kg of dry wheat straw is produced as residue, and half of this residue is already used on the field (Shanmugam *et al.*, 2024). Thus, around 27 million dry tonnes of wheat straw are produced annually, and about 14 million dry tonnes available for bioproducts.
- Corn stover is mainly available in Ontario and Quebec. For each kg of harvested corn for grain, an additional kg of corn stover is produced (Li *et al.*, 2012). Annual corn production is around 15.3 million tonnes (Statistics Canada, 2025a), which produces an equal amount of corn stover. Thus, if half of the corn stove is required for use on the farm, on average around 7.5 million dry tonnes per year of corn stover could be removed from the fields.

CASE STUDY 3



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- Canola straw is also an important source of biomass. Canada, one of the largest producers of canola, produces around 17.8 million tonnes annually, with production concentrated in the Prairie provinces (Statistics Canada, 2025a). Canola seed is processed into oil and meal. It is used in cooking oil, processed foods (e.g. margarine), biofuel, animal feed, protein for human consumption and industrial products (e.g. inks, plastics, cosmetics, paints, adhesives and sealants) (Canola Council of Canada, 2025). For each kg of grain harvested, an additional kg of straw is produced. Around 8.9 million dry tonnes of canola straw could be used if half of the residues are left on soil (Li *et al.*, 2012). The cake and other by-products from processing the seed are estimated to be 4.5 million tonnes, which are exported mostly to United States of America (the) and China, and is estimated to be worth USD 1.9 billion (40 percent of the total global trade value of this product) (Chatham House, 2025).

Straw and other residues have existing markets for livestock, bioproducts, and bioenergy. A portion of the residue needs to remain on the field to maintain soil health and avoid erosion. Recognizing the fluctuations in feedstock availability is crucial for the financial viability and operational strategies of biorefineries. Factors such as the amount of residue produced per hectare and the specific soil types will affect the establishment of facilities that utilize biomass from crop residues.

Livestock by-products

Manure management, treatment and use can provide opportunities for farmers to reduce costs and reduce environmental impacts. In 2021, around 51 percent of Canadian beef producers, and 29 percent of Canadian dairy farmers and poultry farmers, used good practices to manage or treat solid manure (Statistics Canada, 2023). Liquid manure management is more commonly applied to land (e.g. pig production systems), often using global positioning system (GPS) tracking or guidance systems. The amount of available livestock residues would vary depending on the system and activity:

Cattle production

Canada has a large livestock sector, with around 11.9 million cattle in 2024 (Statistics Canada, 2025b). Beef is mostly produced in the province of Alberta. A single dairy cow can produce up to 62 kg of manure per day, whereas beef cattle generate around 37 kg per day, depending on the breed and the context. Manure could be used for anaerobic digestion to produce biogas and digestate fertilizer. Besides biogas, there are other processes that can be used, for instance acid hydrolysis can convert the hemicellulose component in the manure fibre into sugar platform in a biorefinery.

Swine and poultry production

The swine production sector in Canada accounts for 14 million animals, and poultry producers raise over 152 million, between broilers and layers (Statistics Canada, 2022). Swine manure yields roughly 6.5 kg per day, depending on the context, and can be used for a range of bioproducts (e.g. fertilizer, compost, biochar, bio-oil or biogas). Poultry waste is also a resource. For example, it can be used as fertilizers or for biogas production combined with other residues.

Processing by-products

Animal carcasses and other meat industry by-products can be used for biogas. They are also sources of other products such as collagen and hormones. There are other very valuable residues from which high-value bioproducts can be extracted, such whey and other cheese by-products from the dairy industry (Awasthi *et al.*, 2019).

In 2022, Canada exported 1.5 million tonnes of agricultural waste related to the livestock sector with a value of USD 1.6 billion. This waste includes fodder crops (696 000 tonnes), animal fat (364 000 tonnes), skins, hides and leather (122 000 tonnes), meat and fish meat for animal feed (119 000 tonnes), other inedible products of animal origin (66 200 tonnes). Animal fat is the by-product with highest value-added, USD 628 million (Chatham House, 2025). On average one tonne of animal fat yields 1 043 litres of methyl ester. There are new biodiesel industries that use rendered animal fats, tallow and yellow grease as feedstocks, such as the Innoltek[13] plant in Saint-Jean-sur-Richelieu, Quebec (USDA, 2023).

[13] Innoltek website: https://innoltek.com/index.php/en-us/

Support for bioeconomy in the province of Alberta

In the province of Alberta, the provincial government is promoting bio-industrial opportunities to foster bioeconomy and innovation in agrifood sectors. The Bio-Industrial Opportunities Section (BIOS)[14] within the provincial government provides technical and industry development support the commercialization of non-food value-added products and applications (Government of Alberta, 2025). In Canada, Alberta and Saskatchewan have the greatest land area covered by crops. The Bio Processing Innovation Centre (BPIC), run by the Bio-Industrial Opportunities Section (BIOS), is a 929 square meter pilot facility that supports the expansion of bioeconomy by supporting product development and scaling-up successful initiatives. BPIC helps to maximize value by fractioning biomass to isolate high-value ingredients, identifying new opportunities for agricultural processing and producing value-added products from crop residues and agro-industry by-products. The value-added fractionation programme helps companies to develop natural ingredients from oilseed, specialty plants and other biomass. Biomaterial development and characterization is another service of the BPIC facility. To manufacture their products for the market while their own facilities are being built or renovated, clients can rent the BPIC the facility.

The economy of Alberta is significantly shaped by the agriculture and food processing sectors. The agriculture and food manufacturing industries have grown, but little is known about the residues and by-products that are left behind. In 2015, almost 3.4 million tonnes of dry organic waste were identified in the Province (282 thousand tonnes per month), with most of it coming from manure, 0.5 million tonnes coming from food processing waste, and 0.2 million tonnes from residential yard waste (Bell, 2015). There is a concentration of organic waste from manure changes throughout the year in relation to the size of the herds. Animals produce more manure as they get older, and in the fall when calves born the previous spring are taken to feedlots.

Another public initiative in the Province was Alberta Innovates Bio Solutions, which provided research and innovation support for bioeconomy, including biorefining and biomass use diversification. The Alberta Bio Future programme was a related accelerator that provided grants directed at bio-industrial product development, conversion technologies, market readiness, and feedstock development and primary processing (Alberta Innovates Bio Solutions, 2015).

In Alberta, there are also private sector bioeconomy initiatives. For example, Silvacom, an employee-owned Canadian natural resource management consultancy company provides business development services and encourages entrepreneurship and investment in bio-resource valorization. They produce high-resolution local biomass inventories for defining the economic characteristics of feedstock. Their publications include theoretical biomass supply estimations and the potential in different buffer areas (Silvacom, 2025). Another example is Natural Products Canada, which works with bioeconomy startups across Canada, and in 2024 has supported two Alberta companies to create sustainable and innovative bioproducts (e.g. bio-based industrial dyes, asphalt, bioplastics, and poultry feed) from crop and livestock residues (NPC, 2025).

[14] BIOS website: https://www.alberta.ca/bio-industrial-opportunities-section

CASE STUDY 4

A BIOECONOMY HUB STRENGTHENS FARM-LEVEL BIOECONOMY IN SPAIN

In northeast Spain, Catalonia's agrifood sectors generate substantial flows of biomass, co-products and by-products. Converting these streams into high-value products and bioenergy can improve farm resilience, reduce environmental pressures, and create new rural economic activity. However, in practice, many initiatives stall between a promising technical idea and an investable project because of fragmented information on the feedstock availability and needed quality, as well as technology options, permits and other requirements. Also, weak coordination across actors, limited access to pilot infrastructure and specialised expertise, or administrative barriers are common barriers nowadays.

In this context, the Catalonia's Bioeconomy Hub, BioHubCat, helps bridge those gaps through a "one-stop shop" model that links primary producers, industry, and the innovation ecosystem. Based in Lleida's AgroBioTech Park, it mobilises capabilities from a network of public and private organisations to generate economic value from renewable local organic resources such as bioenergy, biofertilisers, biomaterials and bio-based ingredients. For instance, bioactive compounds such as polyphenols can be used to produce high value molecules for human and animal nutrition, cosmetics and pharmaceuticals (BioHubCat, 2026a).

Overall, the Hub aims to reduce risk and accelerate implementation by identifying bottlenecks across the pipeline and mobilising the right technical, business and administrative support, from a systemic perspective. Technical support is provided on the following five areas: feedstock availability and logistics; technical validation under real conditions and scale-up facilities; compliance and permits; market development and off-taker engagement; and evidence generation to secure finance. This support is complemented by institutional mediation, helping projects navigate public compliance in transparent way.

A bioeconomy hub is not, in itself, an industrial plant or a single 'shared factory'. It operates as a coordination platform embedded in a wider innovation ecosystem of technology providers, consulting firms, research organisations, clusters, public agencies and local administrations. The Hub delivers its mandate through three main lines of action (BioHubCat, 2026b):

- One-stop shop: connecting companies and entrepreneurs with service providers across the ecosystem based on project needs and maturity; mediating between companies and public administrations at all levels; supporting partner search and consortium building for innovation projects; and supporting initiatives with territorial impact that strengthen rural resilience, create local economic activity and foster fair value-chain participation for primary producers.
- Creation of enabling conditions for bioindustries: supporting the local government in facilitating bioeconomy industrial activity, providing technical assistance to local administrations for bio-based industry proposals that often involve multiple sectoral authorities; developing practical guidelines; and translating lessons from projects into policy and regulatory recommendations.

CASE STUDY 4



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- Ecosystem building through connection, positioning and communication: participating in national and international networks to exchange methods, anticipate trends and improve practice; identifying collaborations and strategic initiatives where regional capacities can be harnessed; positioning the ecosystem and its organisations to attract partners, and investment interest; and communicating tangible outcomes to build trust and replication.

This hub is also part of the implementation of the subnational Catalonia Bioeconomy Strategy 2030 (GenCat, 2021), led by the local Department of Agriculture, Livestock, Fisheries and Food. This bioeconomy strategy promotes a transition towards an economic model based on the sustainable and efficient use of renewable, local biological resources. It places particular focus on the primary sector and recognizes knowledge and innovation as key drivers of transformation. According to the local government data, the bioeconomy in the Catalonia currently represents 9.8 percent of the production and 5.2 percent of employment (BioBOOST, 2023). The strategy is deployed through triannual action plans. The current one (2025–2027) prioritizes four value chains (GenCat, 2025):

- enhancing forest management and the sustainable use of forest resources;
- recovering value from livestock and organic waste;
- reusing co-products and by-products from the agrifood chain; and

- creating resilient agricultural and forest landscapes that ensure the sustainable provision of ecosystem services.

Catalonia Bioeconomy Observatory supports monitoring the development of the strategy (GenCat, 2026). The Catalonia Bioeconomy Strategy 2030 has set targets of achieving 30 percent of businesses in the innovative agrifood system to be based on circularity and bioeconomy, and to increase by 20 percent the number of companies in agriculture and fisheries sectors that adopt these technologies. The overall vision is to achieve a dynamic agrifood system that generates value based on bioeconomy and guarantees sustainability and circularity along the value chains. This is aligned with the Catalan Biogas Strategy (2024–2030) and Digestate Strategy (2024–2030), as well as Catalonia's industrial and food strategies.

Moreover, the BioHubCat operates under the framework of the Catalan 'Research and Innovation Strategy for Smart Specialisation' (RIS3CAT 2030) (GenCat, 2023). The RIS3CAT 2030 steers transformative research and innovation towards seven systemic transformations, one of them being agricultural bioeconomy, and applies a systems-thinking, place-based and multi-actor approach called Shared Agendas. This model has been documented by the Organisation for Economic Co-operation and Development (OECD) as a good practice through its Mission-Oriented Innovation Policy case-study work.[15] In October 2025, the BioHubCat presented the region's Shared Agendas approach at the Economic and Financial Committee (Second Committee) of the General Assembly of the United Nations General Assembly.

Within this policy framework, BioHubCat collaborates with other initiatives such as the Virtual Bioeconomy Office in Ruralcat, Catalonia's digital knowledge and advisory platform for the rural and agrifood sectors.[16] The regional government seeks to replicate successes and learn from bottlenecks that were overcome to integrate bioeconomy and circularity into the economy of Catalonia in different projects. For instance, the EU-funded project BioBoost, which provides project development assistance to farmers and small and medium-sized enterprises (SMEs), including technical design support, piloting, and guidance on standards and certifications, with a focus on circular solutions in livestock and wastewater management (GenCat, 2024).

At the municipal level, both BioHubCat and BioBoost supported an initiative in the municipality of Alcarràs, that led to the first specialised bioindustrial area in Catalonia. 'Alcarràs Bioproductors' is a cooperative of 150 livestock families committed to circularity and the joint management of waste from the cattle and pig sectors. They are converting organic waste into high-quality biofertilizer and biomethane, contributing to research on the production of other biomaterials. Both 'Alcarràs Bioproductors' cooperative and the BioHubCat are part of the European project PRIMED (2024–2026), which is developing circular bio-based business models by integrating primary producers into novel bio-economy value chains and leveraging advanced bio-refineries in five living labs in Spain, Portugal, Italy, Ireland, and Finland (BioHubCat, 2026c). Results are expected to be presented at the Global Bioeconomy Summit to be held in Ireland on 20 and 21 October 2026.

[15] For more information on the OECD initiative: https://stip.oecd.org/moip/case-studies/41

[16] Ruralcat website: https://ruralcat.gencat.cat

Finally, at the international level, BioHubCat contributes to the global bioeconomy development through sharing experience and participating in networks. As an example, the BioHubCat participates in the Circular Bio-based Europe Joint Undertaking Working Group on Primary Producers[17], an initiative developing recommendations on fair value distribution in bio-based value chains. Another example is the EU-funded project STRONGBIONET that aims to develop a "network of networks" in the European Union and beyond, with the BioHubCat acting as a link between the European core and the Latin American Bioeconomy Network. Also, the Bioregions Facility, led by the European Forest Institute, is an example of a knowledge-led platform that accelerates regional bioeconomy development through transregional cooperation, networking and exchange of practices, particularly in forest-based circular bioeconomy value chains.

BioHubCat's ecosystem-building approach thus aligns with broader European and global initiatives that promote rural resilience and interregional cooperation. Together, these efforts reinforce BioHubCat's role as a practical bridge between local project implementation and wider policy learning and cooperation frameworks.

[17] For more information on the primary producers working group: https://www.cbe.europa.eu/working-group-primary-producers

Chapter 3. How to increase competitiveness and markets for sustainable agri-based bioproducts?

There is a growing demand for non-food biomass and biological resources as a whole. The availability of these biological resources to meet the demand and their potential to be transformed in bioproducts can be assessed and improved at different levels:

- at the farm, industry or business level by assessing capacities for value addition and for collaboration with other businesses (e.g. integrated business models);
- at the landscape or territorial level by optimizing resource use efficiency, for example through supportive infrastructure for transportation and logistics, and satellite imagery that can detect the burning of crop residues and propose options for adding value to these residues; and
- at the policy level by formulating subnational strategies that provide the enabling conditions for improving sustainable consumption and production of local resources and shape national bioeconomy monitoring (e.g. statistics and trade flows).

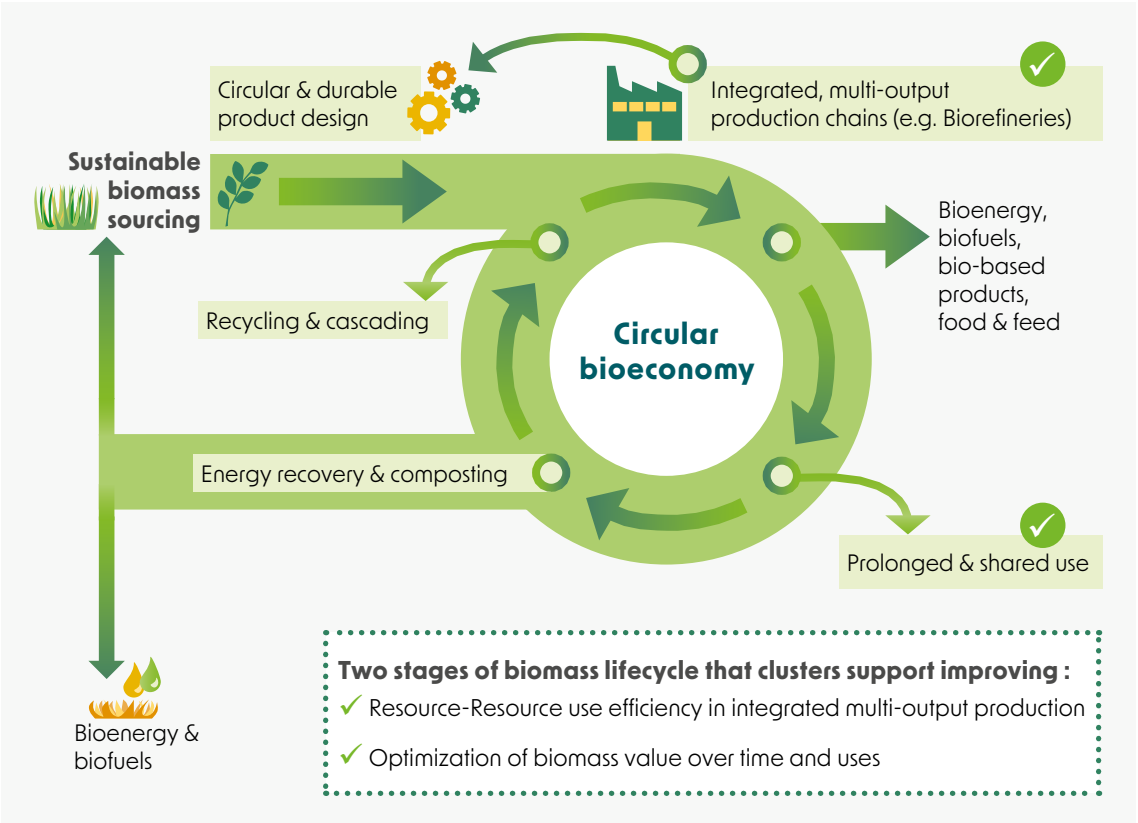
The potential for increasing competitiveness and markets for bioproducts requires creating industrial networks, assessing how much biomass is needed for different sectors and markets, regulating this competition through subnational bioeconomy strategies, and incentivizing innovation on business models. This chapter presents three ways in which taking a bioeconomy approach to the management of natural resources supports better decision-making in agrifood systems, through bioindustrial clusters, through data and assessments, and through policy.

3.1. BIOINDUSTRIAL CLUSTERS IN RURAL AREAS CAN HELP TRANSFORM AGRICULTURAL FEEDSTOCKS INTO NOVEL PRODUCTS AND APPLICATIONS

Clusters in bioeconomy are ecosystems of bioindustries that collaborate in an integrated way. Clusters often use circular business models, in which the waste from one industry becomes the feedstock of the other (Salvador *et al.*, 2023). These clusters are growing in many rural areas around the world. They are hubs that concentrate different types of biomasses for a network of bioindustries. For this reason, these hubs are often located in rural areas, close to the agricultural production systems. Also, through biorefineries, more than one bioproduct can be obtained and is a common technology in clusters.

Several agrifood or bio-based industries or biorefineries are normally included in one cluster. These industries seek to reduce logistics costs, optimize biomass value over time, and improve social sustainability by connecting farmers to food, bioproducts and energy markets (Figure 6).

FIGURE 6. The role of bioeconomy clusters in the lifecycle of biomass



Source: **Stegmann, P., Londo, M. & Junginger, M.** 2020. The circular bioeconomy: Its elements and role in European bioeconomy clusters. *Resources, Conservation & Recycling: X*, Volume 6, 100029. https://doi.org/10.1016/j.rcrx.2019.100029

Clusters adopt business models that advance bio-based solutions in the primary sector. They encourage farmers to collaborate with different industrial sectors, research and academic institutions, policy-makers, civil society and consumers, in designing efficient systems that match sustainable levels of consumption with the sustainable production and trade of biomass. Subnational jurisdictions should assess how to improve the efficiency of their primary production sector in rural areas so that they are tailored to local conditions and natural resources, human capital, infrastructure and other assets. Three circularity criteria underpin new business models in this area (EMF, 2025):

- eliminate waste and pollution, by changing the take-make-waste system from design;
- circulate products and materials at their highest value, by keeping materials in use and retaining their value; and
- regenerate nature, by supporting natural processes and leaving room for nature to thrive.

Also, integrated biorefineries in which a single crop or type of biomass can yield a range of bioproducts have become a growing industrial phenomenon. Integrated biorefineries (multi-output production chains) are often the first step towards the development of multi-sector industrial clusters. Small-scale biorefineries that are simple to duplicate and modify for local circumstances can be a pathway for promoting the greater adoption of bioproducts and building the economies of scale for underutilized or undervalued resources.

For example, similar biomass from different crops like the stems in the leaves of a range crops (e.g. banana, pineapple) can be used for bio-based textiles using similar technologies. In Eastern Africa for instance sweet potato, cassava, sorghum, etc. could benefit from innovation and entrepreneurial activities that bioeconomy clusters include to foster collaboration within the region and with other tropical zones such as in Latin America and the Caribbean (Cingiz *et al.*, 2025).

In India, there are seven main bioeconomy clusters that support both startups and large enterprises that host biotechnology parks, such as Biotech Park Lucknow, as well as incubators and research centres. Main clusters are in Bangalore, Hyderabad, Pune, Delhi-NCR and Mumbai and three emerging hubs in Chennai, Ahmedabad and Kolkata that aim at attracting domestic and foreign investment (Bordoloi, 2025). India has also supported High-Performance Biomanufacturing Platforms of biofoundries hubs, a recent initiative of the Department of Biotechnology and the Biotechnology Industry Research Assistance Council, under the BioE3 (Biotechnology for Economy, Environment and Employment) Policy (DBT and BIRAC, 2025), and falling under the overall support to biofoundries by the flagship Make in India 2.0 Plan launched in February 2021 (WEF, 2024). Biofoundries are research and development factories of microorganisms that can be used in biomanufacturing (e.g. fermentation processes or enzymatic pretreatment of biomass).



CASE STUDY 5

BIOECONOMY CLUSTERS TO DEPLOY AGRI-BASED BIOPRODUCTS MARKETS IN CANADA

In 2015, approximately one-third of 190 Canadian businesses engaged in the non-conventional industrial bioproducts had integrative models or collaborative arrangements with other businesses or academic institutions (Statistics Canada, 2017). In this way, Canada has been able to unlock new market opportunities in the bioproducts activity that comes from agrifood systems.

Incorporating agricultural feedstocks and bioproducts into diverse industry value chains has helped to expand opportunities in Canada's agricultural sector and support the decarbonization of industries. Mobilizing stakeholders and creating a partnership between industry, government and academic institutions simultaneously addresses national priority goals and industry interests.

Clusters are normally strategically located to reduce the costs of obtaining bio-based raw materials and maximize the economic benefits (e.g. near cross-country borders or ports). This approach has spurred the development of advanced technologies for the sustainable use of biomass in Canada.

There are many bioeconomy industrial clusters developing in the country. These clusters also have the advantage of partnering with research institutions and all sectors and stakeholders for better product development.

Examples of cross-sectoral clusters at the provincial level in Canada:

- **Greater Regina Area biomass cluster, Saskatchewan**
  An agricultural biomass cluster has been established for low-carbon bioenergy, biofuels, and biomaterials to create added value to agricultural production, support development in rural communities such as Moosomin and others, and foster collaboration between, the government, the private sector, civil society and community builders, and research institutions at the University of Regina (EDR, 2025).
- **Ag-West Bio cluster, in Saskatoon, Saskatchewan**
  Ag-West Bio is the Province's bioscience research cluster and an industry association. It is a hub for agriculture research and proves facilities to encourage investments in the small-scale industry and support commercialization. Activities include to develop organic agriculture, protein, oilseeds, and biotechnology for canola (Ag-West Bio, 2025). In 2023, the region's biotech sector benefited from a funding agreement under the Sustainable Canadian Agricultural Partnership, a federal-provincial initiative that supports the growth of innovations in agriculture, food and bioscience businesses.
- **Prince Edward Island cluster**
  The cluster in the eastern maritime province of Prince Edward Island focuses on specialty crops and food processing waste streams, marine algae, and animal health. Also, the provincial government has public procurement programme for bio-based building and infrastructure (Prince Edward Island BioAlliance, 2025).

CASE STUDY 5



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- **Sarnia-Lambton cluster, Ontario**
  Located in southeastern Ontario, near the border with United States of America (the), the Sarnia-Lambton Hybrid Chemistry Cluster has a strong focus on agriculture. It includes a biorefinery for biochemical and bioenergy development and has a centre for research and development of bio-based processes. It is a hybrid chemical cluster, simultaneously producing soybeans, wheat and corn and making biofuels and bio-based chemicals. Also, Lambton College, in partnership with the Western Sarnia-Lambton Research Park, supports the development of the chemical clusters locally and bio-based businesses in the province of Ontario to facilitate growth from renewable and biofuels, chemicals, and materials linking agriculture to the traditional hydrocarbon value chain (Sarnia-Lambton Economic Partnership, 2025).

This latter cluster belongs to BIC, a not-for-profit business accelerator based in Sarnia, Ontario, which provides strategic investment advice and services at the national level particularly for SMEs. BIC supports clusters, including business developers of clean, green, and sustainable technologies, and projects, to help improving biomass production, developing new bioproducts from Canadian crops, and turning by-products into value-added bioproducts.

BIC collaborates with the government under a public private partnership with Agriculture and Agri-Food Canada (AAFC). This partnership promotes rural development through several mechanisms. For instance, the Bioproducts AgSci Research Cluster initiative is a project, managed by BIC, which helps to create new and growing economic opportunities for Canadian farmers, supporting pre-commercial science and research activities in the agrifood sector.

BIC bioproducts clusters focus on specialized technologies to turn renewable resources (e.g. agricultural residues) into biochemicals, biomaterials and bioenergy, such as bioethanol and biodegradable and compostable plastics. The main objective is to support emerging technologies and tap into the significant opportunities for the development and commercialization of bioproducts through green chemistry. Apart from the cluster in Sarnia-Lambton, Ontario, other clusters are Alberta Heartland, Thunder Bay, Niagara Sustainable Chemistry Cluster, St Larence Corridor Sustainable Chemistry Cluster, Nova Scotia Innovation Hub, and Trois-Rivieres Bécancour Sustainable Chemistry Cluster.

These clusters, hubs and projects managed by BIC contribute to the transition to a bioeconomy, strengthens Canada's bioindustrial sector through research and innovation, increases competitiveness, supports rural development and reduces GHG emissions through three pathways:

- improving biomass production;
- developing new bioproducts from Canadian crops; and
- turning by-products into value-added bioproducts.

BIC also participates in international networks of clusters and collaborates bilaterally with clusters in other countries (e.g. the Belgian cluster GreenWin and the Italian circular bioeconomy cluster, 'Sustainable processes and resources for innovation and national growth' - SPRING) to unlock the potential of bioeconomy globally (BIC, 2025).

Clusters can be drivers of bioeconomy. They can follow bottom-up approaches in the development of nation-wide priorities. BIC is an example of this. In May 2019, BIC and BioDesign, a consortium led by industry and comprising companies, associations, and academic institutions, prepared a policy paper that resulted in a Bioeconomy Strategy for the sector. This document reflected the input of over 400 industry stakeholders nationwide and urged both the government and the private sector to capitalize on the opportunities within the industrial bioeconomy (BIC, 2019; Bioökonomie, 2023).



CASE STUDY 6

A MACRO-ALLIANCE OF BIOECONOMY CLUSTERS TO ENABLE GLOBAL ACTION IN THE EUROPEAN UNION

The European Bioeconomy Custers Alliance (EBCA) currently unites 19 Full Members and 2 Associate Members. They are national and subnational bioeconomy clusters from 13 EU Member States to accelerate the growth of the bioeconomy sector, drive policy advocacy, and enhance cross-sector collaboration. Through a Memorandum of Understanding, the alliance represents a major step forward in achieving the transition towards a sustainable and resilient bioeconomy, based on innovation and sustainability collaboration across borders (EBCA, 2026).

European clusters that are part of the alliance:

- Austria: Bioeconomy Austria;[18]
- Belgium (2): Flanders' FOOD;[19] and the Agri-Food Innovation Cluster of Wallonia (Wagralim);[20]
- Denmark: Food & Bio Cluster;[21]
- Finland: World Bioeconomy Association;[22]
- France: Bioeconomy For Change (B4C);[23]
- Germany: Cluster Industrielle Biotechnologie e.V. (CLIB);[24]
- Greece (2): Cluster of Bioeconomy and Environment of Western Macedonia (CluBE);[25] and Greek Bioeconomy Council (GBC);[26]
- Ireland (2): Irish Bioeconomy Foundation;[27] CLIC Innovation;[28]
- Italy: Italian Circular Bioeconomy Cluster SPRING;[29]
- Lithuania (2): Smart Food Cluster (LITMEA);[30] and Agrifood Lithuania;[31]

[18] Cluster webpage: https://www.bioeconomy-austria.at/en/

[19] Cluster webpage: https://www.flandersfood.com/en

[20] Cluster webpage: https://www.wagralim.be/en/

[21] Cluster webpage: https://www.foodbiocluster.dk/

[22] Cluster webpage: https://bioeconomyassociation.org/

[23] Cluster webpage: https://www.bioeconomyforchange.eu/en/

[24] Cluster webpage: https://www.clib-cluster.de/en/

[25] Cluster webpage: https://clube.gr/en/

[26] Cluster webpage: https://gbc.gr/en/

[27] Cluster webpage: https://bioeconomyfoundation.com/

[28] Cluster webpage: https://clicinnovation.fi/

[29] Cluster webpage: https://clusterspring.it/en/

[30] Cluster webpage: https://www.smartfoodcluster.com/

[31] Cluster webpage https://agrifood.it/en/

CASE STUDY 6



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- Portugal: Associação Portuguesa de Bioindústria (P-BIO);[32]
- Slovakia: Bioeconomy Cluster;[33]
- Spain (2): Technological Corporation of Andalusia (CTA);[34] and FOOD+i Agrifood Cluster of Ebro Valley;[35] and
- Sweden: RISE Processum Biorefinery Cluster.[36]

And associated members are:

- Ireland: Circular Bioeconomy Cluster;[37] and
- Spain: BHC BioHubCat.[38]

[32] Cluster webpage: https://p-bio.org/

[33] Cluster webpage: https://bioeconomy.sk/en/

[34] Cluster webpage: https://www.corporaciontecnologica.com/

[35] Cluster webpage: https://www.clusterfoodmasi.es/en/

[36] Cluster webpage: https://www.ri.se/en/processum-biorefinery-cluster

[37] Cluster webpage: https://cbcsw.ie/

[38] Cluster webpage: https://biohub.cat/

EBCA is based on innovation that drives resiliency and competitiveness for bioproducts. The aim is to accelerate the development of bioproducts, the establishment of biorefineries and robust infrastructure that can scale up successful initiatives. EBCA also supports a transition to sustainability that includes promoting regenerative and circular practices for tackling climate change, strengthening regional development, and ensuring responsible consumption and production. At the policy level, the members also work towards harmonizing European frameworks that can improve market access for sustainable bioproducts, ensuring they can compete fairly and efficiently. EBCA provides a unifying voice for its members when collaborating with other international partners (e.g. research and policy networks) to strengthen relationships, share best practices or implement joint projects (EBCA, 2026).

EBCA provides a forum for the exchange ideas and best practices. It organizes visits to different EU Member States to share knowledge and learn about the best technologies to use, the best metrics to analyse the infrastructure, and logistics needed for industrial activities. They also promote dialogue with non-EU bioeconomy clusters. One example is the partnership established in 2025 by the Italian SPRING cluster with BioIndustrial Innovation Canada (BIC) (SPRING, 2025).

Agri-based bioproducts are at the centre of many European strategies and policies to tackle environmental issues and enhance Europe's competitiveness. The aim is to implement sustainable consumption and production schemes and build a regenerative bioeconomy that harnesses rather than diminishes biological resources. EBCA contributes toward the common goals of each Member State's bioeconomy strategy through joint initiatives and collaborative partnerships that accelerate the industrialization and commercialization of bio-based innovations, enhance innovation, competitiveness, and resilience. The bioeconomy strategies will be a key instrument for supporting business models and clusters that facilitate stakeholder participation in strong joint initiatives that contribute to common objectives.

The Green Transitions Unit at the European Commission's Directorate-General for Research and Innovation, supports EBCA and recognizes the importance of bioeconomy clusters in fostering innovation. The public–private partnership CBE JU, the European Green Deal, the Clean Industrial Agreement, are some of the key policy instruments that support this initiative.

The European Union has several other programmes that can provide tools to assess the investment readiness of rural areas for the implementation of bio-based industrial clusters. For example, the self-assessment tool for European Union subnational regions[39] to assess their investment readiness (EC, 2024). Readiness is based on eight critical key success factors for establishing a viable sustainable biochemical industry:

- long-term stability and availability of feedstock;
- infrastructure to handle feedstock and production;
- access to finance;
- skilled workforce, technical expertise, training;
- existence of support institutions;

[39] Participating regions: https://ecrn.net/members/

- strength and availability of regional markets;
- entrepreneurship; and
- public support policies.

The European Commission, under different projects and initiatives, supports subnational governments to:

- map their investment readiness for the production and use of under-valorized or under-utilized resources;
- identify business models (e.g. cooperatives, producer associations, clusters and other higher-level structures) that enhance circularity of local resources, and involve a range of stakeholders, including primary producers in cooperatives or associations within agriculture, forestry and aquaculture, the public sector, and research and academic institutions; and
- stimulate bioeconomy through cooperation and networking for the local creation of value, societal engagement and environmental protection.

This work builds on other tools developed as part of EU-funded projects, such as under the topics 'Realising the potential of regional and local bioeconomies' (RUR-09-2018), from 2018 to 2022, and under Circular bio-based business models for rural communities (RUR-10-2019), from 2019 to 2024.

The adoption of clusters can raise awareness at the subnational level about the potential benefits of innovation and improve understanding of the value of biomass and natural resources. This can ultimately create skilled jobs in rural areas and establish an enabling environment to achieve economies of scale for new bio-based businesses and reduce negative impacts of unsustainable production and consumption (EC, 2024).

3.2. UNDERSTANDING BIOMASS AVAILABILITY IS KEY TO REDUCING COMPETITION

Industries, farmer cooperatives and policy-makers, all need data and evidence to select the best use for the different types of biomasses available, and recognize their impacts and trade-offs. Examples of trade-offs are agricultural productivity vs employment: nutrient recovery from waste and wastewater vs soil, plant, animal and human health: ecosystem services vs land use, or increased income vs inequality.

Analysing biomass availability is critical to understand its potential for different sectors and reduce competition and trade-offs. There is a need for global data on bioeconomy, such as biomass availability and its potential for application in different economic sectors (FAO, 2025b). Examples of modelling tools that quantify the bioeconomy and its growth projects exist, and are based on new bioproducts classifications, such as the Monitoring the Bioeconomy (BioMonitor) project of the European Union that helped measuring the bioeconomy within bio-based industries (Cingiz *et al.*, 2023; Wesseler *et al.*, 2026).

Analysis through spatial mapping or local resources assessment can help in this analysis of availability. Having a comprehensive view of this supply of biomass and its potential uses can help prioritize and improve decision-making in the management of natural resources. A clear understanding of biomass availability can reduce the need to make trade-offs in biomass uses and identify the optimal solutions for bioeconomy development and key areas for collaboration within and between industries.

This chapter looks at tools that can support step 2.1 of the *Bioeconomy Toolbox* presented above, regarding biomass availability, current and potential uses, real value, and policy opportunities for improved access to markets and trade. It provides examples on how to calculate biomass availability at the local level and its bioeconomy potential at a global level.

If the analysis is to be done at a global scale, remote sensing and satellite imagery can help in identifying changes in above ground biomass, changes in soil conditions, crop residues being burned and not utilized, and pollution coming from farms and agro-industries. Carbon management plans are being used to define how policies and initiatives can achieve the goal of a low-carbon transition.

If the analysis is done in a well-defined spatial area, modelling tools can be used to assess the challenges involved in the sustainable management of natural resources and biomass in current production systems and identify opportunities for improving sustainability, for example by recycling waste and residues. It is important to consider not only the availability of agricultural biomass, but also the socio-economic impacts associated with its use and potential. Depending on the context, these impacts may affect how biomass is traditionally used in local cultural traditions and in remote areas, marginal lands, or rural areas that lack industry and access to markets (Natarajan *et al.*, 2016).

Listed below are examples of tools and approaches that can be used to map the local bio-resources and model what would be the best uses of the available biomass into the wide bioeconomy.

SPATIAL MAPPING OF LAND COVER

- **Land use and land cover maps**

  A proxy of global biomass production can be obtained by mapping satellite images to define the distribution of human activities and natural areas that relate to biomass (e.g. agricultural land/forests). The two measures are used to describe the physical materials (land cover) and human activities (land use) present on the Earth's surface. Land use refers to how land is utilized by people, (e.g. agriculture, urban settlements, or forestry) Land Cover represents the natural and physical elements (e.g. vegetation, water, or buildings).

  The information on biomass availability obtained through the land use and land cover classification can be refined with the addition of international or national datasets of information in each class (e.g. data on the biowaste produced for each crop type; ecosystem classification and above-ground carbon for each ecosystem).

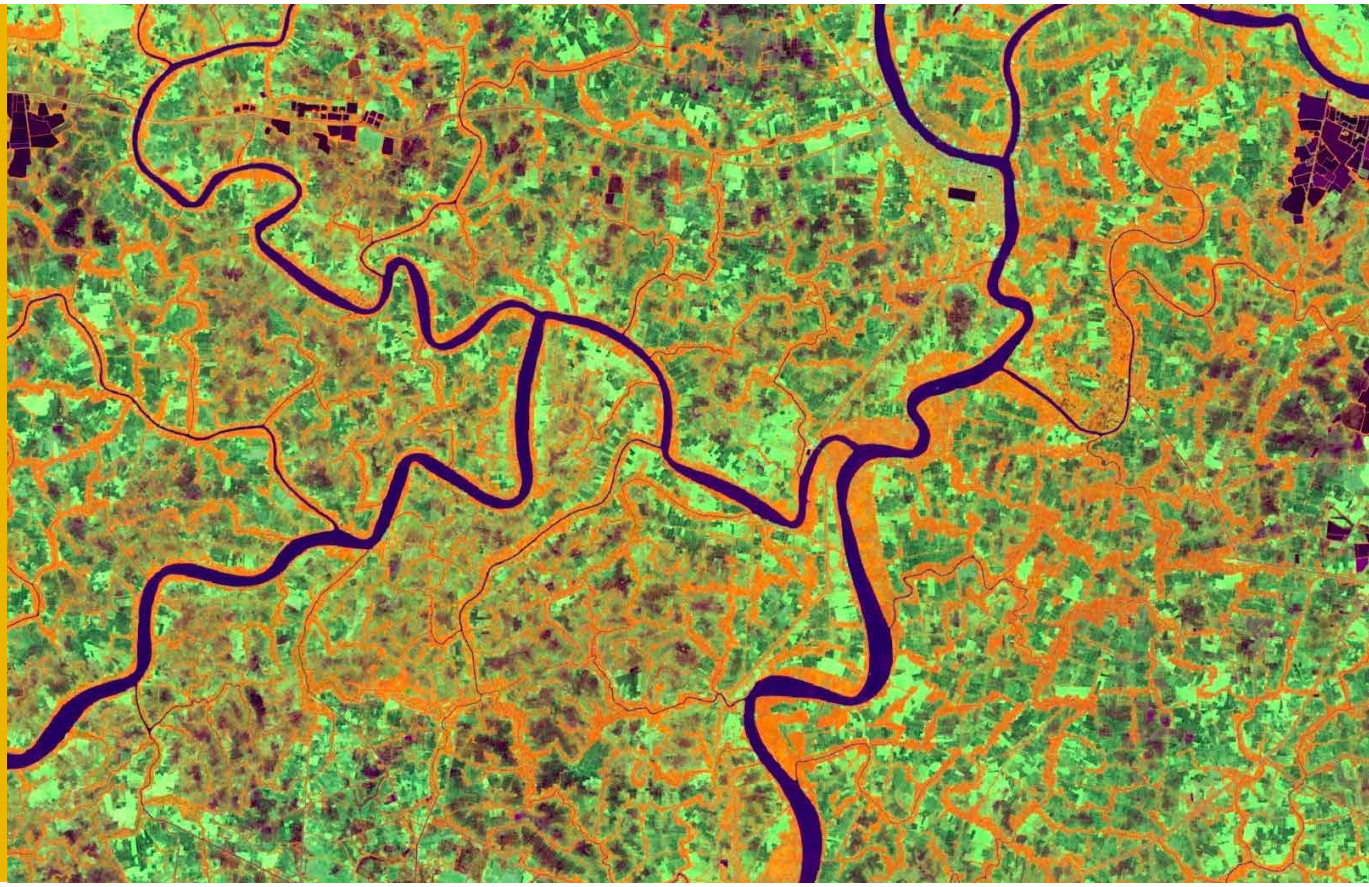
  Different models and tools are available, or can be built *ad hoc*, to illustrate land uses. An example of one of these tools is Dynamic World (WRI, 2025), a near real-time global

land use and land cover dataset with 10-meter resolution, created through a partnership between Google and the World Resources Institute. Using deep learning and satellite data, it generates over 5 000 images daily, is openly available, and allows users to create customized land cover maps through the joint effort of their artificial intelligence model and Google Earth Engine.

- **Normalized Difference Vegetation Index (NDVI) maps and datasets**

  The Normalized Difference Vegetation Index (NDVI) is a widely used remote sensing indicator that quantifies the vegetation amount and health of vegetation on the Earth's surface and offers a proxy of plant biomass availability. It is calculated using the difference between near-infrared light, which vegetation reflects, and red light, which vegetation absorbs, from satellite or aerial imagery. NDVI values range from -1 to +1. Higher values indicate denser and healthier vegetation, and lower values suggest sparse vegetation, bare soil, or non-vegetated areas (e.g. sand deserts). NDVI, which is a widely used tool for environmental monitoring, agriculture, and land management, supports, the assessment of plant growth, drought conditions, and changes in land cover.

  A freely available NDVI dataset at a global scale is provided by Copernicus (EU Copernicus, 2025), under the EU Land Monitoring Service. Managed by the European Commission, Copernicus is implemented in collaboration with Member States, the European Space Agency, EUMETSAT (the European operational satellite agency for



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monitoring weather, climate and the environment from space), and various EU agencies and research bodies. Copernicus, which combines data from satellites and ground-based sources to provide openly accessible information services, supports public authorities, service providers, and international organizations in improving environmental management. One of its most refined products is the Normalised Difference Vegetation Index (raster 300 m) version 3. It provides raster data models on the whole globe from 2014 to today with a spatial resolution of 300 meters and a temporal resolution of 10 days.

FAO Tools that use spatial mapping

FAO has developed a series of practical tools to facilitate the assessment of bioeconomy potential at country level. One example is Earth Map (Morales *et al.*, 2023), in collaboration with Google. Earth Map is an innovative and free application that enables users to visualize, process, and analyse a wide range of data (e.g. land, climate, fire occurrences, biodiversity, emissions). Powered by Google Earth Engine (GEE), Earth Map has a user-friendly interface for accessing to vast amounts of satellite imagery and geospatial datasets in near-real-time. It does not require coding expertise. Most of GEE application can be directly accessed only through JavaScript. The lack of coding requirements allows a wide range of users (e.g. governments, research institutes, farmers) to easily detect and quantify global and local environmental changes, supporting a transversal informed decision-making for science-based policies and sustainable development. Another important feature of Earth Map is the possibility of observing multiple layers of information on the same geographical area, allowing an easy comparison of different environmental drivers and conditions in the same landscape.

Between the different spatialized datasets accessible through Earth Map, including both NDVI and land use and land cover, an important layer to measure biomass availability and loss is provided by the MODIS Burned Area. This data product provides a monthly global coverage of burned-area information using MODIS Surface Reflectance imagery and 1 Km active fire observations. Each 500m grid cell is assigned a burn date, encoded as the ordinal day of the year, while unburned areas and missing data are assigned specific values. Data on fire distribution, intensity and frequency can enable an accurate monitoring and assessment of burned vegetation biomass, which is highly important as a plant-waste management practice in agriculture in many areas of the world.

BIOMASS PLANNING FOR DIFFERENT BIOPRODUCTS

International Feedstock Reporting Platform

A recent example of an inventory of global biomass resource assessment, is the International Feedstock Reporting Platform (Jacobson *et al.*, 2025) in United States of America (the). Governments often evaluate the future possibilities of sustainable biomass valorization (Jacobson *et al.*, 2025), which can support mapping and planning for bioeconomy potential. The Platform maps sustainable biomass supplies and provides data on current and future sustainable biomass supplies in sixty-two countries, indicating a volume of 2.83 billion dry metric tonnes of biomass resources. The assessment was led by researchers at the United States Department of Energy (DOE) Oak Ridge National Laboratory (ORNL), with funding provided by State Department. The portal aims to assist scientists, policy-makers, and industry leaders in exploring potential sources of biomass as a foundation for a circular and sustainable global bioeconomy and the production of bio-based chemicals, fuels and materials.

Biomass Inventory Mapping and Analysis Tool

The Canadian Government has developed tools for calculating the biomass availability and potential uses (AAFC, 2025c). The Biomass Inventory Mapping and Analysis Tool, BIMAT, is a noteworthy dataset of agricultural residue production (e.g. straw, stover) for a range of products (barley, wheat, flax, oats, corn, canola and soybean) and mill residues (AAFC, 2019; AAFC, 2025d). The BIMAT dataset has a 250m spatial resolution (10km in the public version) and can be used to analyse the trade-offs between biomass uses.

It provides context-specific information on straw requirements for cattle bedding and feeding, the type of tillage used in an area, and the amount of residue needed for the conservation of different types of soil. Territorial planning can be further analysed with the BIMAT because it includes a transportation network dataset for calculating the costs of harvesting and transporting biomass. However, the BIMAT dataset covers the years between 2003 and 2014. To model biomass use, BIMAT can be used in tandem with other tools, such as the Carbon Budget Model CBM-CFS3, is landscape-level modelling framework used for international reporting of the forest carbon balance of Canada's managed forest, which goes to 2050.

Other mapping tools exist for major crops, for instance AAFC's Annual crop and land use inventories as well as spatial density of major crops in Canada (AAFC, 2025d). The Canadian Agrifood Policy Institute (CAPI) also has an Agricultural Web Mapping Application Tool on the land use (CAPI, 2025), which can be used to map agricultural



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land attributes, management practices, and key agri-environmental indicators to inform decision-making in agricultural policy and land use management.

Innovation in agriculture is a key focus area for both the public and private sectors in Canada. Another notable example of this collaborative approach was the Agricultural Climate Solutions Living Labs initiative, launched in 2021 by AAFC. This programme aimed to foster innovation through partnerships among various stakeholders in Canadian provinces, with a focus on best practices that can be replicated across province or country. By leveraging soil mapping and sequestration data, experts from local soil health Living Labs could implement sustainable and regenerative agricultural practices that enhance soil health and promote environmental resilience. This collaborative effort highlights the importance of integrating scientific expertise with practical farming methods to address the challenges posed by climate change and ensure long-term agricultural sustainability (AAFC, 2025e).

FAO Tools that use biomass assessment and planning

FAO has several tools for assessing the potential of biomass for different uses. One example is the Bioenergy and Food Security Assessment tool (BEFS), which supports decision-making related to the investment potential to produce bioenergy from crop and livestock residues at country level to meet renewable energy targets and policies. This assessment is sector-specific, but it is considered part of bioeconomy because it is based on a previously undertaken comprehensive mapping of all available residues. The assessment process also considers trade-offs with food security and other biomass uses by engaging with stakeholders at the national level (e.g. primary producers) to introduce mechanization for the collection and pre-treatment of residues.

For Egypt and Türkiye, an FAO analysis has identified available residues and the types of bioenergy that were cost competitive, the most promising locations and profitable operations, as well as policy recommendations for the development of the specific technology forward (Maltsoglou *et al.*, 2016; Rincon *et al.*, 2017). In Türkiye, the assessment included quantities of major crop residues in each of the country's 81 provinces (both collected residues and residues spread on the field, in tonnes/year). This included both primary residues (hazelnut shell and husk, groundnut husk, cotton stalk, cattle and chicken manure) and secondary residues (maize cob and husk, pistachio shell, soybean husk, sunflower heads and rice husk). The assessment included the demand for energy, available residues from different crops, the demand, and the net present value for each technology (e.g. briquettes production, direct combustion, biogas) to generate profitability zone maps, using the techno-economic assessment of the BEFS tool.

In the case of the assessment in Egypt, the governorates of Behra, Sharkiya, Dakahlia and Kafr-El Sheikh were found as the most suitable locations for bioenergy from agrifood residues, using the same analyses described above. In each province, the assessment covered the crop and livestock residues available in the field and generated in processing facilities, the techno-economic assessment of bioenergy options (e.g. direct combustion, cogeneration, briquettes and pellets, and biogas) as well as electricity capacity, price, costs, and demand. The technologies identified were combined heat and power using rice straw, sugar cane bagasse or maize stalk, and briquettes from pruning, and biogas from manure. The assessment informed the government on how bioenergy could help meet its target of 20 percent of electricity from renewable energy.

FAO provides additional guidance on how to improve sustainable accessibility to the crop and livestock residues with most potential to be profitable and available constantly. The BEFS tool results are complemented with other FAO tools such as the Global Soil Carbon atlas that allows for estimates to be made of the soils that need crop residues or the waste materials that need to be improved before using that biomass for other purposes.

3.3. SUBNATIONAL BIOECONOMY STRATEGIES AND POLICIES ENHANCE THE ENABLING ENVIRONMENT FOR BIOECONOMY INNOVATION

This chapter provides an overview of some subnational bioeconomy strategies. Using the different elements outlined in the previous chapter, some selected strategies are presented, focusing on how to identify bioeconomy potential in a given territory, and the range of supporting mechanisms that policy can provide to improve the technological, organizational and human capacities to meet the growing demand for bioproducts. Policies are needed to develop bioeconomy clusters, bioindustries and markets for bioproducts. There are many subnational level strategies dedicated to bioeconomy to foster collaboration between stakeholders and promote integrated and sustainable economic growth. Examples not covered in the case studies or in this chapter but that reflect interesting sub-national bioeconomy strategies include Australian Queensland Biofutures 10-Year-Roadmap and Action Plan (2016), the Waikato region of New Zealand economic development strategy that identifies the bioeconomy as one of the region's key economic priorities, or the upcoming sub-national bioeconomy strategies of California (the United States of America) and Tarapaca (Chile) that are currently being developed.

Having flexible regulations, building new international value chains, promoting collaboration with financial institutions, and strengthening partnerships between producers and industry are needed to leverage local competitive advantages. These actions can create significant opportunities to develop integrated business models in bioeconomy that integrate social entrepreneurship with environmental preservation in communities and add value to local resources. These models can be for example cooperatives and higher-level structures like hubs or clusters that together optimise resource use efficiency, establish biorefineries, recover value from waste, exchange resources, innovate towards bio-based resources, value the local economy and provide services (Salvador *et al.*, 2023). However, factors at the stakeholder level (e.g. lack of awareness, inadequate collaboration, and out-dated infrastructure), frequently make it difficult for such models to be adopted (Bröring and Vanacker, 2022). Also, policies that introduce bioproducts in the market at lower prices than their alternatives, could result in a great increase in consumption that in turn rises prices as well as biomass extraction. Policy should consider the local and global market contexts when advancing subnational bioeconomy systems from local bioproducts (Salvador *et al.*, 2022).

These policies can be at the subnational level or at inter-regional or cross-border levels. For example, a forest, a lake, or a biome can encompass subnational administrative districts of different countries. These territories can be of economic interest for different stakeholders, prompting them to work together. In recent years, a great number of subnational bioeconomy strategies have been developed or are in the process of being developed, to manage natural resources at local level promoting rural development.

Distinct ecological characteristics and socio-economic priorities in different areas reflect the stakeholders' priorities for bioeconomy development. Colombia, for example, has explored subnational bioeconomies and their potential in Antioquia, Valle del Cauca, as well as applications in different agro-ecological zones and socio-economic conditions in the Pacific, Caribbean and the Amazon, including the FAO Colombia Bioeconomy Strategic Plan for the Colombian Amazon (PEBAC 2030) (Canales, Trujillo and Purkey, 2021; Alviar *et al.*, 2021; Lutta *et al.*, 2025).

Local governments should have the right capacities to promote rural growth and to accelerate sustainable and commercially viable local biomass projects. An example in the Malaysian state of Sarawak is 'Invest Sarawak',[40] a state-owned investment and international trade promotion and industry development agency, formulated in 2016 the Sarawak Biomass Industry Development Plan. The Plan promotes technologies to maximize the real biomass opportunity for the State based on multi-feedstock options. Recently Sarawak Biomass Industry has attracted investors' interest from Singapore, China, Japan to develop biomass plants from waste to energy through the conversion of agricultural wastes, such as oil palm empty fruit bunches and kernels, wood and municipal wastes as feedstock. This model was replicated in other Malaysian settings such as the Sabah Biomass Industry Development Plan.

Subnational strategies, plans or initiatives are embedded into national or regional strategies, which often seek to develop rural areas and guide economic growth through the industrialization of agrifood sectors (FAO, 2025c). For example, Japan's Bioeconomy Strategy promotes dedicated biocommunities at subnational level to improve biomass valorization, waste reduction and industrial competitiveness. This objective is then reflected in domestic policies that facilitate access to global markets and sustainable trade and improve livelihoods at the local level. For example, public procurement of bioproducts can support in accessing markets and availability and support consumer awareness. A primary objective common to many strategies is promoting rural development and industrialization and scaling up technologies that improve competitiveness and sustainability of agriculture-based bioeconomy products. In some countries, the aim is to re-industrialize rural areas through bioeconomy development. This may be done for example by repurposing old industrial sites that are often polluted industries into bio-based activities and creating new opportunities for local communities, or applying phytomanagement solutions for contaminated and saline land while producing intermediate and high-value end bioproducts, as can be seen in the EU project *IASIS - Curing contaminated and saline land with Industrial crops and producing biomass for high-value applications,* which recommends viable value chains of sustainable biomass for using it as feedstock for bioproducts while remediating contaminated or saline soil.

Other initiatives applied by local governments are market pull and push mechanisms. Examples of feedstock and technology 'push' mechanisms are access to feedstocks, support for pilot and demonstrations, research and development, technology clusters, support for SMEs. Examples of market 'pull' mechanisms are targets, public procurement, standards and labels, taxes, subsidies. According to the Organisation for Economic Co-operation and Development (OECD, 2018), there are certain lines of intervention that imply both push and pull measures, including:

- regional clusters;
- metrics, definitions and terminology;
- skills and education;

[40] Invest Sarawak website: https://investsarawak.gov.my

- public acceptance and raising awareness; and
- governance and regulation.

OECD (2025b) has also recommended public–private collaboration as an important element in bioeconomy development. Public–private partnerships can connect local and global actors to improve competitiveness. Industrialization of rural areas also helps the private sector realize the value of biomass (e.g. residues and waste) and support financing investments in bioproducts. At the policy level, public–private partnerships help in the implementation of enabling environment measures and incentives, support rural areas to make the most out of their resources, connect them to global markets and enable them to make more informed decisions about production, processing and distribution and marketing to consumers.

Policy-makers should ensure that right and just conditions exist for local communities and farmers in areas in the process of industrialization. They should create the enabling environment for new bio-based businesses and provide advisory services that guide them through different options for producing biomass that makes sense for producers. This could include biomass for the emerging markets and bio-based industries, while ensuring sustainability in the operations. Therefore, having not only national or local, but also a global public–private partnership can improve access to new markets and serve as an outreach and matchmaking platform with local communities and farmers, and increase the sustainability of bioeconomy operations and build trust for improved circularity.

TWO AMAZONIAN STATES IN BRAZIL ARE DEVELOPING DEDICATED PLANS AND COLLABORATING WITH OTHER COUNTRIES

Brazilian states in the Amazon are developing bioeconomy strategies. For example, the government of the State of Para, developed a bioeconomy strategy in 2021 and an action plan in 2022 (Governo do Estado do Pará, 2021, 2022). Gomez San Juan (2024) provides an overview of the strategy and highlights that it follows a conceptual alignment process based on the valorization of the knowledge and culture of the original populations and traditional communities.



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The objective of the strategy is to develop low-emissions sector and support poverty eradication through the 'socio-bioeconomy'. During COP30 the Bioamazon Valley was launched, a hub for the bioeconomy in the State for deploying a large innovation ecosystem, integrating equipment and developing policies. It is organised around the Amazon Bioeconomy Park, the Amazônia Museum, and other programmes to encourage research, education, and training of workforce. A Memorandum of Understanding[41] was signed by the States of Para and California, to share research and expertise on wildfire prevention and response, and to promote sustainable value chains and bioeconomy innovation ecosystems that help sustainable land management.

Another Brazilian State, the Amazonas, has a bioeconomy strategy and has recently launched in April 2026 its action plan. Several studies and reports have been carried out by the Government and consultancy agencies to create guidelines for developing a short-, medium-, and long-term framework for bioeconomy in the State (Governo do Estado do Amazonas, 2025, 2026).

In addition, the Hub Bioeconomia Amazônica, coordinated by the Fundação Amazônia Sustentável (FAS) in partnership with the Green Economy Coalition, has been created to support the development of a bioeconomy policy for the State of Amazonas. The Hub Bioeconomia Amazônica seeks to promote an inclusive and sustainable bioeconomy by amplifying the voices of Indigenous and local communities and integrating traditional knowledge with innovative practices (Amazon Bioeconomy Hub, 2024). The Hub operates as a collaborative effort involving non-governmental organizations, academic institutions, private sector stakeholders, and community representatives. Representatives from the government of the State of Amazonas participate at the workshops and activities of the Hub. Amazonas is putting great effort into establishing a bioeconomy strategy for the State, as it is an area that relies heavily on the Amazon forest's resources; resources that are increasingly at risk from illegal exploitation and the impacts of climate change. In August 2025, the World Bank Board of Directors approved a project of almost USD 600 million for the State for mobilizing finance for the bioeconomy (World Bank Group, 2025).

During the G20 meeting held in Brazil (December 2023 to November 2024), the Brazilian Ministry of Foreign Affairs coordinated a meeting on the G20 Initiative on Bioeconomy in Manaus, the Amazonas State's capital. During the meeting, panel discussions were held on a range of subjects, including bioeconomy for traditional and rural communities and indigenous peoples[42], including presentations of policy actions by Australia and Canada, the sustainable use of forests for bioeconomy, the uses of water for bioeconomy, and the role of bioeconomy as a facilitator of productive recovery, environmental regeneration and bioremediation.

Also, subnational states from different South American countries are collaborating in a biome-wide initiative for the Amazon forest with the support of the Green Climate Fund's Amazon Bioeconomy Fund (2022–2029) with the support of the Inter-American Development Bank and aims at supporting around 190 000 direct beneficiaries and 57 299 bio-businesses, 58 percent of which with female majority ownership. The Amazon Bioeconomy Fund, which encourages private investment in several countries of the region, focuses on six key areas of bioeconomy:

[41] Memorandum of Understanding between California and Pará, signed on November 10, 2025: https://www.gov.ca.gov/wp-content/uploads/2025/11/Final_Para-CA-MOU_11.10.25.pdf

[42] For more information on the meeting: https://www.gov.br/g20/en/news/g20-in-manaus-international-indigenous-peoples-and-traditional-communities-as-part-of-the-bioeconomy-agenda

sustainable agroforestry, native palm cultivation, non-timber natural forest products, growing native species for timber, aquaculture, and community-led nature tourism (GCF, 2021). For the whole Latin America and the Caribbean, another example is a project led by the Economic Commission for Latin America and the Caribbean (ECLAC) that aims to articulate clusters in different sectors in a platform that connects stakeholders and promote joint actions between clusters (ECLAC, 2025).

SUBNATIONAL STRATEGIES IN THE EUROPEAN UNION ARE SUPPORTED BY COLLABORATIVE PROJECTS

As of 2022, 32 subnational strategies in the EU-27 were fully dedicated to bioeconomy, 83 were bioeconomy-related sectoral strategies (including 11 agricultural strategies with a focus on bioeconomy), and 209 were strategies where bioeconomy was embedded. Besides, there are 10 published multi-regional strategic frameworks, nine of which dedicated to the bioeconomy, and promoted through EU programmes like Interreg and Smart Specialisation Strategy. Beyond EU-27 countries, there are nine bioeconomy-dedicated strategies at subnational level in Europe (Haarich and Kirchmayr-Novak; 2022, EC, 2025a). Also, the European Committee of the Regions (CoR) has adopted a draft opinion on June 2026 for a stronger regional and local role in implementing the EU's Strategy and organized a Territorial impact assessment workshop.

Subnational strategies are gaining momentum in European countries. They can support a bottom-up approach to bioeconomy development, and/or respond to the overarching national bioeconomy strategies, serving as effective mechanisms for localized implementation efforts. There are different approaches to local bioeconomy development that reflect different drivers, different capacities, and different concept of bioeconomy (Spatial Foresight *et al.*, 2017). These bioeconomy types are:

- Driven by good capacities in research such as innovation in biotechnology, biochemistry, agricultural engineering, etc.



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- Driven by abundant natural resources, for instance eco-tourism, sustainable agriculture, and bioproducts.
- Driven by existing value chains, often based on strong primary production and the diversification of higher added-value markets. They often develop decentralised biorefineries and small-scale technologies close to where biomass is produced.
- Driven by new specialised value chains, innovative business models, developing new products such as from alternative fibres or algae.
- Driven by a strong industrial biotechnology focus, such as chemical products, development of new technological conversions, advanced manufacturing, and circular business models.
- Driven by integrated development, liking primary producers with industry and combining value chains, with a view to transition into an integrated economic model, including by business-to-business models.

The policy measures most frequently cited in EU subnational strategies are related to funding for research and innovation, and governance. Other important policy measures indicated are awareness raising activities that provide information on bioeconomy; the promotion of bioeconomy-specific infrastructure (e.g. pilot and demonstration facilities); training; public procurement to stimulate demand; legal provisions; and labels, certification or standards. The governance provisions included in the documents aim at ensuring policy coherence across sectors, actors, governance levels and timeframes. Policy measures targeting collaboration (e.g. facilitation of bottom-up initiatives or measures to enable multistakeholder involvement and dialogue) are included in many of the policy documents as are monitoring and reporting measures (Haarich and Kirchmayr-Novak, 2022; HaskoningDHV, n.d.).

Also, project-level interventions provide platforms for inter-regional collaboration among areas from different countries that share a biome or a resource. To develop competitive and sustainable value chains for agri-based bioproducts, cross-sectoral value chains (bioeconomy value webs[43]) are often developed, such as the EU Interreg Programme. The European Territorial Cooperation Programmes (Interreg) are a key EU instrument to develop multi-country bioeconomy at subnational level (Korosuo *et al.*, 2024). Currently, there are 73 bioeconomy-related projects in 28 Interreg programmes (Interreg, 2025a). Examples of these inter-regional projects include (Interreg, 2025b):

- Interreg Alpine Space: Innovation Express for Circular Bioeconomy Value Chains (INNOBIOVC) project;
- Interreg Baltic Sea Region: Bridging the Gap between Research and Education in the Circular Bioeconomy (BREC) project;
- Interreg Central Europe: Circular BioEconomy Market Uptake and Policy Support in Central Europe (BIOECO-UP) project;
- Interreg Danube: Developing INnovative Alliances for Management, Innovation, and Collaboration in European BioEconomy (DINAMIC DANUBE) project;

[43] In value webs, often shaped into clusters, biomass resources (e.g. crop residues and animal waste) are shared by a range of industries and factories, where local biomass productivity and marketing is increased.

- Interreg Euro-Mediterranean: Systemic circular bio-economy solutions to support start-up and social driven innovation in rural areas (BIOSTARS) project;
- Interreg Italy-Slovenia: Shared circular bioeconomy approaches for the valorisation of dairy supply chain by-products (DAIRY+) project;
- Interreg North-West Europe BIOponic BOOST to PROfessionally produce sustainable and local food (BIOBOOST-PRO) project; and
- Interreg South-West Europe: Comprehensive recovery of agriculture and forestry waste: New scalable multi-product biorefineries (NEWPOWER) project.

Another example of inter-regional collaboration supported by the European Union is the LIFE programme for environment and climate action, where common climate challenges make necessary to develop cross-border strategies. An example is the LIFE 3.0. LIFE22-IPC-ES-LIFE-PYRENEES4CLIMA/101104957 project, which targets seven territories of the Pyrenean massif on a transition towards an innovative circular bioeconomy (e.g. circular tourism, marketing of local agricultural and pastoral products by creating short value chains) and integrating local populations and governments (EC, 2025b).

Additionally, the European Union has trans-national initiatives driven by the private sector, such as cross-border clusters (Korosuo *et al.*, 2024). Examples include:

- Bio Innovation Growth mega-Cluster (BIG-Cluster), a cross-border bio-based innovation cluster in the Flanders region of Belgium, the Kingdom of the Netherlands (the) and the German state of North Rhine-Westphalia.
- The bioeconomy Pilot in the Vanguard Initiative established by ten European subnational regions as a showcase of industry-led interregional cooperation, co-creation, and co-investment led by Lombardy (Italy) and Randstat (Kingdom of the Netherlands (the)).

AN AGRIFOOD STRATEGY ON BIOECONOMY IN THE PROVINCE OF MANITOBA, CANADA

The provincial government of Manitoba supports the development of bioproducts industry (Manitoba Agriculture, 2021). Innovative agrifood systems are a priority for the government and, through its Life Sciences Strategy[44], it sets main objectives for bioscience advancement, including research and innovation on agricultural biotechnologies for plant and animal health, soil improvement, biomaterials and other applications for increasing the value-added processing.

One of the initiatives of the provincial government is the development of a Bioeconomy Action Plan Framework, which focuses on developing the agricultural sector through innovation in bioeconomy and increasing value-adding processing (Manitoba Agriculture, 2024). The Action Plan was developed in 2024/2025 through a strategic partnership for bioeconomy in the Province, the coordination of industry stakeholders and outreach to identify opportunities and challenges for leveraging available biomass generated from the value-added and agriculture sectors. Also, the Manitoba Agriculture Department promoted the Byproducts Directory to

[44] For more information on the strategy: https://manitoba.ca/jec/files/lifesciencesstrategy.pdf

industry stakeholders to identify biomass waste potential and investment opportunities in bioeconomy, as well as participated in the Innovation and Byproducts roundtables and was part of the organizing committee of the 2024 Manitoba Protein Research Symposium (Manitoba Agriculture, 2025a).

The Action Plan outlines key milestones and timelines implementation, including as the first key milestone the development of a Manitoba Agriculture Bioeconomy Research Whitepaper in 2025/2026. Other key deliverables of the Plan are a biomass inventory map/dashboard and a stakeholders' event on building a bioeconomy cluster (Manitoba Agriculture, 2025b). Overall, the Bioeconomy Action Plan Framework has a long-term vision to promote research and innovation, support business to commercially scale up in bioeconomy, and collaborate with local communities to promote Manitoba's interests in bioeconomy with all local jurisdictions.

The Whitepaper will inform both the private and public sectors, by strategically enhancing networking opportunities in the Canadian and international bioeconomy sectors, attract and retain investments, nurture research and innovation leading to new markets, support decision making, and inform the department in engaging with public stakeholders and shaping policies and government programs in bioeconomy (Manitoba Agriculture, 2025a, 2025b).

A key objective of the Whitepaper is to study opportunities for value-added cluster development in Manitoba. Subject to stakeholder consultations, the Bioeconomy Action Plan Framework will include a Manitoba cluster/corridor study to identify potential bioeconomy corridors and key bioeconomy value chains in Manitoba. Beforehand, biomass opportunities have to be mapped and discussed, to analyse and propose potential bioeconomy corridors, discuss potential cluster approach and present investment opportunities for the local bioeconomy sector (Manitoba Agriculture, 2024, 2025b).

There are around 5 million tonnes of available biomass per year in the Province (IISD, 2018). Manitoba produces diverse types of biomasses with a wide range of uses. Currently, agricultural waste, grasses and cattail (*Typha* spp.) are used for livestock bedding and compost. In Manitoba's current market, biomass is used to make pellets for burning. However, with new technologies, there are opportunities to use the biomass for other uses, including building materials, biogas through anaerobic digestion, and ethanol fuel from gasification (IISD, 2018).

According to experts from seven clusters interviewed for the development of the Action Plan, the sectors with most potential for bioeconomy are:

- bioplastics;
- pharmaceuticals;
- food and feed additives;
- bio-composites;
- construction and building materials;
- cosmetics;
- aromatics; and
- lubricants.

With the support of a dedicated strategy, Manitoba protein industry has secured over USD 0.73 billion (CAD 0.99 billion) investments and created 1 072 new jobs since 2019 and more are expected in the medium-term (Manitoba Agriculture, 2019). Manitoba is also developing its agro-industries for protein production, including the construction of aquaculture facility or Arctic Char, expected to create 224 new jobs, the promotion of the Province pea processing plant, which is the world's largest, and the improvement of infrastructure in the pork production sector.

These developments and investments are needed to develop transformative bioproducts. With abundant biomass resources from agriculture, forestry and other sources, Manitoba is well positioned to take advantage of opportunities associated with the commercialization of sustainable bioproducts. Estimates from 2019 indicate that in the Province, biofuels represent around 52 percent of bioeconomy; biomaterials 38 percent; and biochemicals 10 percent (Manitoba Agriculture, 2021).

These actions conducted by the Manitoba government seek to meet the challenges involved in bioeconomy development. This includes establishing clusters, providing financial incentives, and forming bioeconomy-dedicated partnerships. In this way the Province is trying to make easier for industries to expand and access international markets including overseas.



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Chapter 4. Conclusions: how subnational strategies and clusters can help upscaling bioproducts development

Developing bioeconomy presents a significant opportunity for rural areas to become more competitive, resilient, and environmentally sustainable. By focusing on agri-based bioproducts, communities can add extra value to local resources, diversify incomes, and participate in new markets that support both climate action and biodiversity. However, success depends on practical actions, collaboration among policy-makers, producers, and local organizations and the consumer demand for bioproducts promoted by local actors.

The following recommendations are directed to policy-makers and private sector actors from all countries who are seeking to develop more competitive and connected rural bioeconomies in ways that are tailored local contexts, in particular at subnational level.

Recommendation 1.

Given their economic, social and environmental value, bioproducts from crop and livestock residues, from innovative feedstock in multi-sector biorefineries to serve as ecosystem services such as soil cover, or as alternatives to burning or waste, should be central to rural development pathways. Rural communities, producer groups, and entrepreneurs need the tools to identify the best opportunities for adding value to non-food biomass in ways that respect local landscapes and livelihoods.

Recommendation 2.

When it comes to deploying technologies on the farm or in a rural area, three pathways can be used to achieve sustainable bioeconomy:

- using renewable bioproducts to eliminate pollution by designing the agricultural system following bioeconomy principles;
- circulating products and materials, using efficient production technologies, and valorizing biomass (waste, residues and processing by-products); and
- regenerating soil and biodiversity, ensuring sustainable economic viability for different products and services, and contributing to the security of biomass supply over time.

Recommendation 3.

Collaboration platforms that unite multiple farmers, processors, and entrepreneurs to pool resources, share knowledge, and jointly tackle challenges can encourage landscape-level collaboration and optimize resources and coordinate around shared goals. They create local value chains, enhance processing, and generate rural employment, helping rural areas compete and diversify their economic base. In particular:

- Integrated biorefineries that produce a range of agri-based bioproducts, and clusters that do so by business-to-business models are promising vehicles for upscaling innovation in crop and livestock systems and valorizing waste, co-products and local biomass.
- Clusters can influence and are influenced by policy. First, clusters can be the drivers of bioeconomy. They can follow bottom-up approaches in the development of national policies that capitalize on the opportunities within the industrial bioeconomy.
- Innovation in business models can foster the transition to a circular, sustainable, and inclusive rural bioeconomy by enhancing public–private collaboration and dialogue, improving communication amongst private stakeholders, and optimizing the use of residual and waste biomass.

Recommendation 4.

Robust data is key to implement tailored management strategies that optimize nutrient cycling, soil care, biomass valorization, and efficient resource use. Monitoring tools, in particular new advances in information technology, are a promising tool to guide farm-level decisions and connect with broader territorial approaches to sustainability. These tools should be used to inform local planning, avoid resource conflicts, and measure the impacts of new bioproducts. Carefully measuring the social and environmental trade-offs of biomass use for food, feed, fibre, and fuel needs, supports local decisions ensuring that they take into account biodiversity, soil health, and pollution reduction.

There is a need to accommodate the various interpretations and visions of bioeconomy and the sectors included under the broad umbrella framework of bioeconomy, and draw lessons learned and capture regional specificities for rural development. GIS can also be used to conduct a 'cluster analysis' that identifies areas with large concentrations of land cover that are approaching harvesting. This system allows the identification of potential bioeconomy clusters, based on the amount of biomass and the proximity to a marketplace.

Bringing bioproducts from agricultural biomass to the market still faces challenges and better awareness is needed of the environmental, economic and social benefits that support sustainable development and the transition to a more circular agrifood system.

Inclusivity and social benefits of these technologies should also be better communicated. Enhancing biotechnology systems in rural areas, such as developing biomanufacturing clusters and agricultural biotechnology incubators, can stimulate innovation and create new job opportunities in local communities. In addition, actively involving small-scale farmers and women-led enterprises in the bioeconomy, supported by targeted training programmes and improved access to finance, can promote more inclusive and balanced economic development.

Recommendation 5.

At subnational administrative levels, the bio-based industrialization of rural areas can be facilitated by subnational governments' strategies, policy mechanisms and private sector business models that can stimulate market pull and push (e.g. public procurement by local governments).

Policies and business plans should be designed allowing innovation to come from communities and business groups who understand their specific landscapes and resources, as well as informed by robust data for natural resources monitoring and decision-making tools.

The role of subnational governments is of utmost importance for bringing together local stakeholders, providing relevant information and other public goods, leveraging local resources, articulating with relevant national institutions, and bringing coherence between local bioeconomy initiatives and national bioeconomy strategies. Cooperation between subnational governments is also important to fostering the exchange of experience and lessons learned.

Producer groups and local enterprises should engage actively with local institutions to build capacity and negotiate fair access to feedstock, technical knowledge, and new market entries. Also, policy should provide clear pathways for local communities to access new technologies and research, make innovation practical for producers, such as by supporting demonstration projects and sharing results, and fostering partnerships between research institutions and rural business clusters.

Strengthening the enabling environment, through local partnerships, cluster development, targeted investments, and adaptive policies, will help agrifood systems unlock more value from biomass while addressing pressing social and environmental needs. By focusing on integrated approaches, transparent monitoring, and shared benefits, policy-makers and producer groups can lead the transition to a sustainable bioeconomy that ensures food security, protects the environment, and drives growth for rural communities.

Moving forward, there is a need for more global dialogue and knowledge exchange between local governments, rural industrial clusters and other key actors for bioproducts development, to steer a bottom-up bioeconomy development.



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This publication highlights the potential of bioeconomy to foster competitive, resilient, and sustainable rural areas. Integrated and market-driven bioeconomy policies and initiatives at the subnational level can help establish more competitive and connected agrifood systems. Focusing on bioproducts derived from biomass generated by crop and livestock systems, this publication provides examples from different countries where subnational bioeconomy policies and initiatives have been incorporated into a broader bioeconomy framework.

These policies and initiatives support multistakeholder institutions, clusters and hubs, and integrated biorefineries that produce a range of agri-based bioproducts. They can increase the commercial value of crop and livestock waste, co-products, and locally available biomass, while diversifying rural incomes without compromising food security and while taking local contexts into account. To better reflect local and regional conditions and priorities, clearer definitions, metrics, and terminology are needed, along with investments in skills and education, awareness-raising activities on the importance of waste upcycling, and the establishment of rural governance mechanisms.

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