Joint European Biorefinery Vision for 2030

Star-COLIBRI

STRATEGIC TARGETS FOR 2020 – COLLABORATION INITIATIVE ON BIOREFINERIES



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Contents

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The Star-COLIBRI project is funded under the Seventh Framework Programme of the European Union (grant agreement 241535).
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Printed in Europe

Executive Summary

The European Biorefinery 2030 Vision presented in this document is the product of the collaborative effort of the Star-COLIBRI team, involving five European Technology Platforms and five major European research organisations. Achieving this vision is a vital part of the overall evolution of the Biobased Economy. This document provides the information and tools to enable policy makers to build a framework for the development of a sustainable European Knowledge-Based Bioeconomy, with a network of biorefineries playing an essential role.

We can assume that **biomass in Europe will be produced roughly in line with the current patterns of land use**. However, we expect an increase in the cultivation of perennial crops (including forestry) which can have a number of positive impacts, such as increasing soil-water retention capacity and reducing erosion.

In the short term, the main sources of biomass will continue to be traditional agricultural crops (cereals, potatoes, sugar beet and rapeseed) together with wood and dedicated energy crops, with forestry and agricultural waste also playing a role. After 2020, there will be an increasing use of dedicated lignocellulosic crops, both from farms and short rotation plantations on woodland, assuming that technical and economic hurdles have been overcome by then. With the exception of Northern European forests, biomass production areas will continue to be fragmented. Under these circumstances, harvesting and transport costs will become significant factors in the overall value chain.

However, available research suggests that future development of the European biomass sector will be subject to a high degree of uncertainty, mainly depending on crop yields and land availability. Although the extent of yield improvement is not certain, the technical and scientific knowledge which will enable progress is already well established. **The key issue for future biomass production in Europe is therefore land availability**.

The uneven geographical development of agricultural production and demand for both food and feed will influence patterns of global trade in general and the demand for European agricultural exports in particular. In turn this will determine the availability of land to grow biomass as an industrial feedstock. But as food demand puts further pressure on land, availability can be increased by yield improvements, optimisation of biomass production and reduction of losses in the agricultural supply chain. One of the key challenges for Europe is therefore to manage the short- and mid-term constraints on biomass availability without jeopardising long-term sustainability of supply.

The European Biorefinery Vision 2030 has been developed by analysing the various factors that will shape development of the sector, as well as the different biorefinery models themselves. But this must be seen in the context of the overall Biobased Economy, which will see both the development and increasing integration of the relevant industrial sectors.

The overarching vision for 2030 is of a world-leading and competitive Biobased European Economy. The European bioindustry sector in 2030 is innovative and competitive, with cooperation between research institutes and the industrial, forestry and agriculture sectors whilst enjoying the support of civil society.

All links in the value chain profit from this flourishing Biobased Economy. The success of European bioindustry comes from being a world leader in the efficient and flexible utilisation of biomass while having a strong focus on value-added products. By 2030 a significant proportion of the overall European demand for chemicals, energy, materials and fibres is fulfilled using biomass as a feedstock for biorefining technologies:

- 30% of overall chemical production is biobased. For high added-value chemicals and polymers (specialities and fine chemicals) the proportion is more than 50%, whilst less than 10% of bulk commodity chemicals are derived from renewable feedstocks.
- 25% of Europe's transport energy needs are supplied by biofuels, with advanced fuels — especially biobased jet fuels — taking an increasing share.
- The European market for biobased fibre and polymers such as viscose, carbon fibres, nano-cellulose derivatives and bioplastics will continue to grow rapidly. Traditional fibre products such as paper remain 100% biobased.
- A new generation of biobased materials and composites produced in biorefineries allow the production of lightweight, better-performing components for industries including automotive and construction.
- 30% of Europe's heat and power generation is from biomass.

The European Biorefinery Vision 2030

Biorefineries produce a wide spectrum of biobased products which are fully competitive with their conventional equivalents

In 2030 Europe is a Biobased Economy in which biorefineries play an important role. Full-scale, highly efficient, integrated biorefineries allow competitive manufacturing of high-value biobased products.

There is a range of biorefinery types utilising many different types of biomass feedstock and various technology options.

Versatile biomass supply chains

A diverse and flexible biomass production sector supplies biorefineries with a wide variety of agricultural crops, residues (agri-food or urban waste, forestry and agricultural by-products) and dedicated lignocellulosic crops (including forest biomass) together with an increasing volume of algal and aquatic biomass.

Europe's capacity for sustainable production of biomass has increased due to the introduction of new and improved crops, investment in Central and Eastern European agriculture, and new policy, training and cooperation initiatives. In addition, Europe's many millions of small-scale, family owners of woodland harvest their wood more efficiently and profitably, making a greater contribution to European biomass supply.

The demand from biorefineries continues to drive efficiency improvements in the production of food and feed crops.

Europe's versatile biomass feedstocks are an asset to a flexible and resilient biorefinery sector.

A revitalised, competitive and knowledge-intensive rural economy based on biorefineries

European industries have developed an extensive network of regional/rural biorefineries producing food, biofuels and numerous biobased products from local biomass in a sustainable way. This has led to significant economic growth and created millions of jobs in rural areas.

Innovative high-tech companies are prospering around larger regional biorefinery units. They specialise in producing a range of high-value products from biomass fractions and side-streams coming from the main biorefinery process, and create skilled jobs in rural areas. Decentralised, small-scale biorefineries are also part of this development.

Growing integration of biobased industrial sectors

Integration of supply and manufacturing chains and increased collaboration between innovative players from traditional industries such as the chemical, energy, agriculture and forestry sectors combines the key strengths of each sector, creating the critical mass to attract investors, policymakers and young talent. This has become the basis for maximising the value added to biomass streams.

An open and collaborative approach creates synergies in education, research, development and innovation throughout the biorefinery value chain.

Most biorefineries are closely integrated with traditional biomass processing industries. However, some have been established to exploit new value chains, such as aquatic/marine biomass.

A focus on sustainable bioproducts gives Europe a competitive edge

A long-term focus on sustainability and "green" products has given European companies a competitive edge in the global market by 2030.

A combination of progressive standardisation, an environmentally-aware consumer base and widespread eco-labelling ensures that European biobased products are developed to be as sustainable as possible throughout the full product life-cycle. They are designed to be recyclable, biodegradable, or used to generate bioenergy at the end of life. They are manufactured using non-polluting biorefinery production processes.

Biorefineries are highly energy-efficient and make use of mostly zero-waste production processes. They allow European industries to manufacture environmentally-friendly products with small carbon and water footprints.

Versatile biorefinery development routes

Particular biorefinery technologies will have been used as necessary to provide optimal processing solutions for specific feedstocks and end products. The development of biorefineries will of course always remain an enabling technology concept and not a goal in itself.

Flexibility is key. This means processing technologies that can deal with multiple biomass feedstock streams either via a single process or through a combination of several integrated ones. This enables a broad spectrum of valuable, marketable products to be manufactured.

Economic constraints dictate that biorefineries need to be operated efficiently and at low cost. Sustainability criteria also still drive their continued development.

Achieving this European Biorefinery Vision 2030 will require a higher degree of integration, more flexibility and improved sustainability of the future biorefineries. This will only be possible if crucial bottlenecks along the valuechain can be removed. Several strategic research areas must be further developed by 2020 to address these challenges. Identifying these key research areas will be the objective of the Star-COLIBRI Strategic Research Roadmap to 2020.

Introduction

The European Biorefinery 2030 Vision presented in this document is the product of the collaborative effort of the Star-COLIBRI team, involving five European Technology Platforms and five major European research organisations. Achieving this vision is a vital part of the overall evolution of the Biobased Economy. This document provides the information and tools to enable policy makers to build a framework for the development of a sustainable Knowledge-Based European Bioeconomy, with a network of biorefineries playing an essential role.

Although it is not always clear exactly what a biorefinery is and how the concept will evolve over the coming decades, biobased processing of renewable raw materials is increasingly being developed and commercialised. In the introduction, we define what a biorefinery is and put it in the broader context of a Biobased Economy. The chapter "Towards the Biobased Economy in 2030" covers the different industrial realities underpinning biorefining technologies, and analyses the key drivers, opportunities and challenges which will determine how biorefineries can contribute to the development of a Biobased Economy by 2030. Alternative paths for development are described in the following chapter, together with several types of biorefinery that will be well-established in 2030.

The chapter "Vision 2030" puts forward a European Biorefinery Vision for 2030:

- focusing on the development and integration of the various industrial sectors within the context of the overall biobased economy; and
- considering the role of biorefineries within the biobased economy, concentrating on the drivers and models of biorefinery integration and the technological challenges which must be addressed.

This Vision is based on an analysis of the forces that are continuing to shape biorefinery development, as well as the potential contributions of individual biorefinery models.

Several strategic research areas must be further developed by 2020 to address these challenges. These are identified and further discussed in Star-COLIBRI's Strategic Research Roadmap to 2020 for biorefinery implementation.

Biorefinery definition

The term biorefinery (see Figure 1) is widely used nowadays, but it covers a range of industrial realities and is used differently by different stakeholders. Several definitions and explanations have been developed over the last few years according to the context, but the core concept embedded in all definitions is the conversion of biomass into several product streams (materials, chemicals, energy, food and feed) and the integration of various technologies and processes in the most sustainable way.

The definition developed by the International Energy Agency (IEA) Bioenergy Task 42[1] for biorefineries/biorefining has been widely accepted (e.g. within the project BIOPOL[2]) because of its general, all-encompassing character:

"BIOREFINING IS THE SUSTAINABLE PROCESSING OF BIOMASS INTO A SPECTRUM OF MARKETABLE PRODUCTS AND ENERGY"

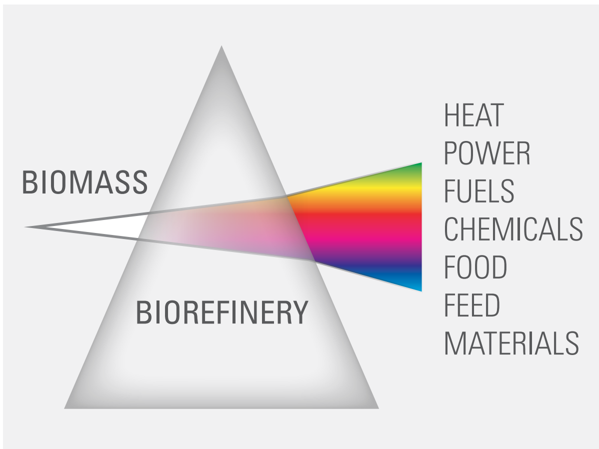


Figure 1: Schematic representation of the biorefinery concept
IEA Bioenergy Task 42 Biorefinery, 2009

This definition, which we will use in this document, uses a number of keywords, the scope of which we define below:

- Biorefinery: covering basic concepts, the facilities themselves, processes, and cluster formation
- Sustainable: encompasses maximising economic efficiency, minimising environmental impact, fossil fuel replacement and also takes account of socio-economic aspects
- Processing: upstream processing, transformation, fractionation, thermo-chemical and/or biochemical conversion, extraction, separation and downstream processing are all included
- Biomass: comprises crops, organic waste, agricultural and forestry waste, wood and aquatic biomass
- Marketable: describes a product for which a market (with quality, volume and price acceptable to consumers) already exists or is expected to be developed in the near future
- Products: includes both intermediates and final products, i.e. food, feed, materials, and chemicals (specialities, commodities and platform molecules)
- Energy: fuels (liquid, gas and solid), power and heat

The biorefinery concept

Using biomass as a sustainable renewable resource is the only way to replace carbon from fossil sources in the manufacture of chemicals, materials and fuels. To make this route competitive with oil-based products, an integrated biorefinery strategy has been developed to optimise the added value from biomass. This strategy applies the approach used in oil refineries to biomass (raw material fractionation, integration of mass and energy flows and integration of processes) to produce a spectrum of products and maximise the overall added value. This approach requires the efficient, valued-added use of the entire biomass stream, generating zero waste.

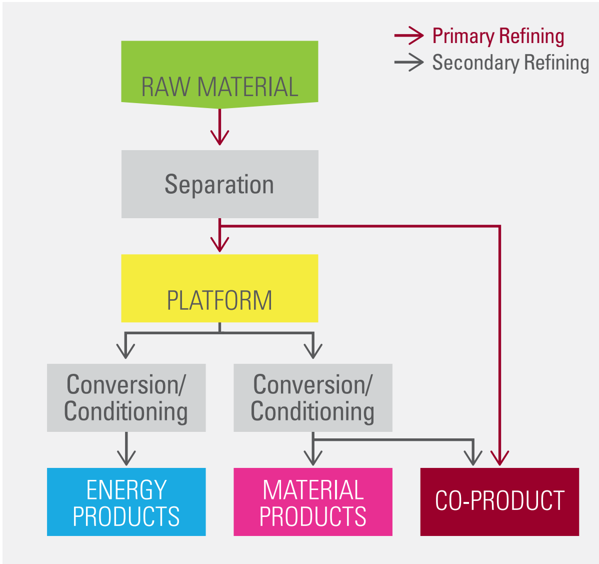


Figure 2: The different components within the Biorefinery Concept (According to IEA Task 42 Biorefinery systematics, 2009; adapted and modified by German Agency of Renewable Resources (FNR)[3])

However, the biorefinery concept (see Figure 2) goes beyond the philosophy of oil refineries, by including sustainability management practices and closed loop processing cycles wherever possible. This aims to mimic the natural, global scale, carbon cycle. There are also natural cycles for water and, at a local scale, minerals, especially nitrogen, phosphorus and potassium (N-P-K), all essential nutrients in agriculture. Unlike carbon, these elements have to be partially left in, or reincorporated into the soil to avoid depletion, and thus — at present — require the use of fossil fuel energy

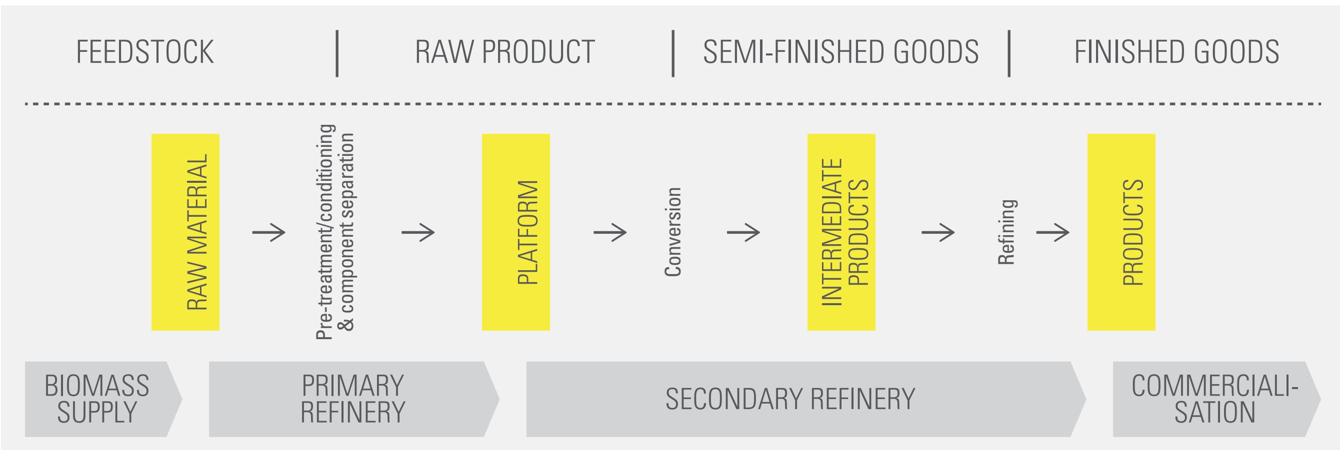


Figure 3: Biomass conversion steps — key and central element of the biorefinery is the platform[5]

to make fertilisers. More generally, the biorefinery concept includes the management of all sustainability issues, including environmental, economic and societal factors.

All biorefineries are biomass-based, whereas not all biomass processing plants are integrated biorefineries. According to the project Biorefinery Euroview[4], "Biorefineries could be described as integrated biobased industries using a variety of technologies to make products such as chemicals, biofuels, food and feed ingredients, biomaterials, fibres and heat and power, aiming at maximising the added value along the three pillars of sustainability (Environment, Economy and Society)."

Most conventional biomass processing plants (such as oil crushing, starch extraction and cellulose pulp extraction) carry out primary biomass refining and, in some cases, a first conversion step (see Figure 3: Biomass conversion steps — a central element of any biorefinery is the platform)[5]. Integrated biorefineries go an important stage further, with the integration of further conversion steps, so moving towards sustainable optimisation (maximising profit and minimising waste).

The broader context for a Biobased Economy and biorefinery development

The development of the Biobased Economy relies on biomass availability. Thus the development of biorefineries for non-food products is directly influenced by a range of factors, including new and existing agricultural production systems, forestry and waste management, the efficiency of food and feed production and the increasing use of biomass for energy (heat and power) generation.

Clearly, food and feed production have to be given top priority when considering biomass use. But improvements in agricultural productivity, land management, logistics and storage can increase the efficiency of the food and feed chain, and so make more land or agricultural (by)products available for non-food use.

Over the coming decades, the world will simultaneously face the challenges of assuring food and energy security and adapting to climate change. Foresight studies (the 2009 FAO report *"How to Feed the World in 2050"*[6] and the INRA/CIRAD foresight study *Agrimonde*[7]), conclude that these issues will need major international effort and are unlikely to be solved before 2050. They will clearly still influence biomass availability in 2030.

By 2030, it is estimated that the world population will stand at 8 billion[8]. According to the *Agrimonde* study, the speed of dietary change (particularly increased meat consumption) and investment in agriculture in developing countries will have a major influence on the extent to which they will depend on food imports from OECD countries. These factors will have a strong influence on how much prime arable land is needed for food and feed production (for internal consumption or export) and thus determine the availability of land for non-food crops.

Bioenergy must also be taken into account. Recent energy and climate directives promote renewable energy and provide financial support for its development. Certainly until 2020, and most likely until 2030, most renewable heat and a fair share of renewable electricity will come from biomass sources (wood or agricultural waste) despite the rapid implementation of other renewable energy technologies (such as wind and solar).

In the reference scenario of the IEA's World Energy Outlook (WEO) 2009[9], the share of renewable energy capacity in the overall heat and power sector is taken to be 51% in 2030. 33% of total electricity will be produced from renewable sources, with the share of biomass and waste being 5%. However, this scenario does not allow the goal of limiting global warming to 2°C to be achieved. To stand a chance of meeting this target, even greater use of bioenergy would be needed to cut CO_2 emissions further.

This implies a growing demand for wood and lignocellulosic biomass (agricultural waste, energy crops and waste from timber harvesting and landscape management) for bioenergy, which competes directly with other traditional uses of wood and the emergence of lignocellulosic biofuels and biobased chemicals and materials. The integration of bioenergy generation and other biorefinery models with the supply chain for timber will therefore be important. The various uses of wood and wood products, including biomass fractions, along the whole supply chain needs to be further developed to maximise value generation.

In summary, we can assume that the period around 2030 will be a time of peak demand for biomass. Under these conditions, biomass supply, land availability, energy efficiency and especially carbon efficiency will be key factors in determining the potential for European biorefinery development.

Towards the Biobased Economy in 2030

Society is facing major environmental, social, and economic challenges and these will only increase in coming decades. Their impact will change the way we live and work. The Biobased Economy can help to provide solutions to future challenges, while also generating jobs and business opportunities. The transition from a dependence on fossil fuels to a situation where agriculture will not only continue to provide food security but also a sustainable supply of renewable raw material for industry will be at the heart of the future biobased economy.

The Biobased Economy essentially means sustainable production of biomass and its conversion into a range of food, health, fibre and industrial products, as well as energy[10]. Large industrial sectors such as agriculture and food, forestry products and textiles are part of a long established traditional biobased economy, but are now facing new environmental and competitiveness challenges. Meanwhile, new biomass users are emerging in the energy, fuel, chemical and material production sectors. For maximum overall benefit, the various sectors of the Biobased Economy must be properly connected, since they are all interdependent. Concerted action across Europe will not only generate thriving individual sectors, but strong and effective links are needed to create a Biobased Economy web. This inter-connectedness means that all sectors must be equally strong; one weak link could significantly reduce the overall effectiveness of the web and limit European competitiveness.

Though renewable, biomass is not an infinite resource, and encompasses a difficult group of raw materials to process. It comes from a variety of sources, including algae, annual and perennial plants, trees and waste materials. It is geographically dispersed and has to be harvested or sorted and collected. Availability is restricted by weather, terrain and seasons. In addition, biomass typically has a low bulk density and a relatively high water content (up to 90% for grass), which makes transport expensive. It has to be handled and stored properly to minimise biological degradation and generally has to be pre-treated before processing. Biobased industrial products will only be competitive with their petrochemical-based equivalents if the raw materials are optimally exploited and a variety of value-creating chains having small environmental footprints are developed and established.

Biorefineries have an essential role to play in sustainable production as their primary purpose is to integrate industrial processing of biomass (within or across sectors), thus making bioprocessing more efficient and competitive.

This chapter covers:

- The current status of the various sectors of the Biobased Economy
- The place of biorefineries in these sectors today
- Trends for their development towards 2030
- Opportunities and challenges over the coming decades

Biomass in Europe

Current biomass situation

The European agro-forestry sector is active across the entire continent. It is fairly evenly split between forestry (covering 42% of total European land) and agriculture (a further 40% or 170 million hectares). In Nordic countries, forestry predominates, comprising up to 70% of the land area. Consequently, a **wide variety of biomass** is available in Europe[11] and that which is potentially available for non-food use comes mostly from the agro-forestry sector. The amount of biomass available will depend both on the development of agriculture locally and global food demand, and will be influenced by the outcome of the World Trade Organisation (WTO) Doha Round.

The conversion of natural habitats, such as forest and permanent grassland, to agricultural land is limited by EU directives, to minimise negative impacts on carbon sinks and biodiversity. Therefore, we have to assume that no further land will be brought into production and that **potential land availability for non-food uses in Europe has to be from within the current arable area**.

In 2008, 25% of EU agricultural land was arable (growing annual crops) and 7% was covered by recently planted woodlands. Cereals are typically the major arable crop, accounting for about 59 Mha (million hectares), with one sixth of this area used for wheat. Rapeseed and sugar beet are grown on 5.2 Mha and 1.9 Mha respectively.

Arable harvests are large: for example in 2008 about 300 million tonnes (Mt) of cereals, 19 Mt of rapeseed (with rapid growth since 2003) and 97 Mt of sugar beet. This harvested raw material is today the main source of biomass for non-food use. For instance, in 2008 11Mt of oilseeds, 1.3Mt of sugar, 1.9Mt of maize and 4.2Mt of wheat were used to produce biofuels. 24Mt of vegetable oil were imported, mainly for industrial purposes, and 40% of starch production was used for non-food applications.

Municipal Solid Waste (MSW) and Non hazardous Commercial and Industrial Waste (C&IW) represent a further interesting source of lignocellulosic material. More than 144 million tonnes of biodegradable municipal waste must be diverted from landfill by 2016 in EU Member States[12] to meet present targets.

production from European forestry. The BEE figure takes account of stem wood, primary above-ground residues and primary stump wood. If secondary forestry residues are included the potential energy content rises to 3.3 PJ[14].

Biomass production is not equally distributed across EU Member States. Five countries (Sweden, Germany, France, Finland and Italy) produce about 62% of the total. However, this is to a large extent due to the size of the countries, as well as their extent of forestation[15].

It is important to note that the development of the European Biobased Economy already assumes that a large part of the material generated in both the food and non-food value chains will be used as raw materials further down the chain. The aim is to develop closed-loop processing systems within which as many by-products as possible are processed to add further value. Currently, agricultural residues are mainly used for livestock feed and litter as well as to maintain soil fertility. However these (and other agricultural waste and currently-unused biomass from forest management) can be transformed into added-value biomaterials, biobased chemicals and biofuels, or used as a local source of power or biogas.

CURRENT BIOMASS POTENTIAL FROM EUROPEAN FORESTS

The EUwood final report (2010)[13] estimated potential total biomass production from European woodland in 2010 to be 1,277 billion m^3, including bark. Approximately half of this is stem wood (i.e., derived from the main trunk) and the rest consists of logging residues, stumps and woody biomass from early thinnings in young forests. The potential is, however, reduced to about 747 million m^3 by various environmental, technical and social constraints. After subtracting the wood used directly or processed to produce fibreboard and other materials, the EUwood report estimates that the remaining biomass has an energy potential of 2.56 EJ (exajoules, 10^{18} joules). The BEE project (Biomass Energy Europe) final report gives a similar estimate (2.6 EJ) for potential energy

The European agricultural and forestry sectors are significant biomass producers. They also have a major role in landscape and environmental management, as well as driving the rural economy.

The main challenges for biomass production are:

- To supply food and feed in sufficient quantity and quality for EU consumption and to play a key role in international trade. This will require increasing the productivity of existing farmland while minimising environmental impact: what has been called **'sustainable intensification'**. This is important if we are to avoid taking new land into production and putting further pressure on water resources. This approach also conserves natural habitats, protects biodiversity and maintains carbon sinks.

- To increase **efficiency in the food and feed chain**. For example, biorefining crops harvested for animal feed will reduce the amount going to feed and provide streams of non-feed components for the biobased economy. Another way to increase efficiency is to reduce the amount of food spoilage, which is now as much as 30% of prepared food products.
- To avoid unnecessary waste and recycle unavoidable waste in useful and efficient ways, ideally by having **closed-loop systems of production and further processing of by-products**.
- To anticipate and adapt to long-term production constraints by factors such as **climate change**, and make a major contribution to minimising greenhouse gas (GHG) emissions in the overall context of a sustainable economy.
- To provide the industry with a secure and sustainable supply of raw material by **efficient land use**, appropriate use of whole-crop solutions, exploiting both fertile and marginal arable land, ensuring that both primary products and residues are evaluated for their "renewable carbon" potential and finally by developing sustainable biomass production, as defined by the EU Renewable Energy Directive (RED). Growing dedicated energy or lignocellulosic crops on arable land has to be done sustainably .
- To increase the availability and use of **forestry biomass**, while meeting the wide range of other demands on woodland via their sustainable management.
- To ensure general public acceptance of research and innovation in the Biobased Economy. **Better communication** can improve the public image of the Biobased Economy (and hence help make it a success) by increasing public understanding of the science and technology involved and making scientists, technologists and industrialists aware of legitimate public concerns.

Biomass potentials in 2030

In recent years, there have been several studies on the potential for biomass production in Europe, including biomass quantity mapping scenarios over different time scales (mainly to 2020 and 2050). Unfortunately, as all these studies have focused on bioenergy and biofuels, the biomass potential is only expressed as a calorific value (joules). However, the value derived from biomass conversion is of course not restricted simply to its energy content.

The BEE project report[16] is of particular interest because it reviewed more than 70 European studies, making a critical analysis of methodology, data and sources of uncertainty. The studies analysed biomass potential on regional, national and global scales; approximately 25 focused specifically on EU biomass production. Though the BEE project looked at biomass for bioenergy and biofuels, the results provide a good estimate of the biomass that could be used more generally for biorefineries.

Most biomass resource assessments start by estimating the potential demand. Several scenarios were used to reflect different patterns of development up to 2050. Figure 4 summarises the range of values from studies that covered all biomass categories (forestry, agriculture and residues/by-products) at EU-27 level. **The total potential biomass supply is expected to be between 10 and 60 EJ in 2050.** There is a large range of estimated potential for a given year, but also a general upward trend. Because studies with different time scales are combined it is not possible to make a quantitative estimate of this.

The BEE report provided results for each of the categories mentioned above. As Figure 4 clearly shows, the biomass category mainly responsible for the large range in the estimates is ***"dedicated energy crops"***. This category includes agricultural biomass resources such as sugar- and starch-derived biomass (e.g. sugar beet, wheat and maize), oilseed derived biomass (e.g. rapeseed, sunflower) and lignocellulosic crops (C4-grasses or short-rotation coppice, for example). In contrast, estimates of waste streams from forestry, agriculture and other organic sources cover a narrower range. According to the studies, the forestry potential could be 0.9-2.4 EJ/yr in 2030, while the potential for agricultural residues and other waste could be around 3 EJ/yr.

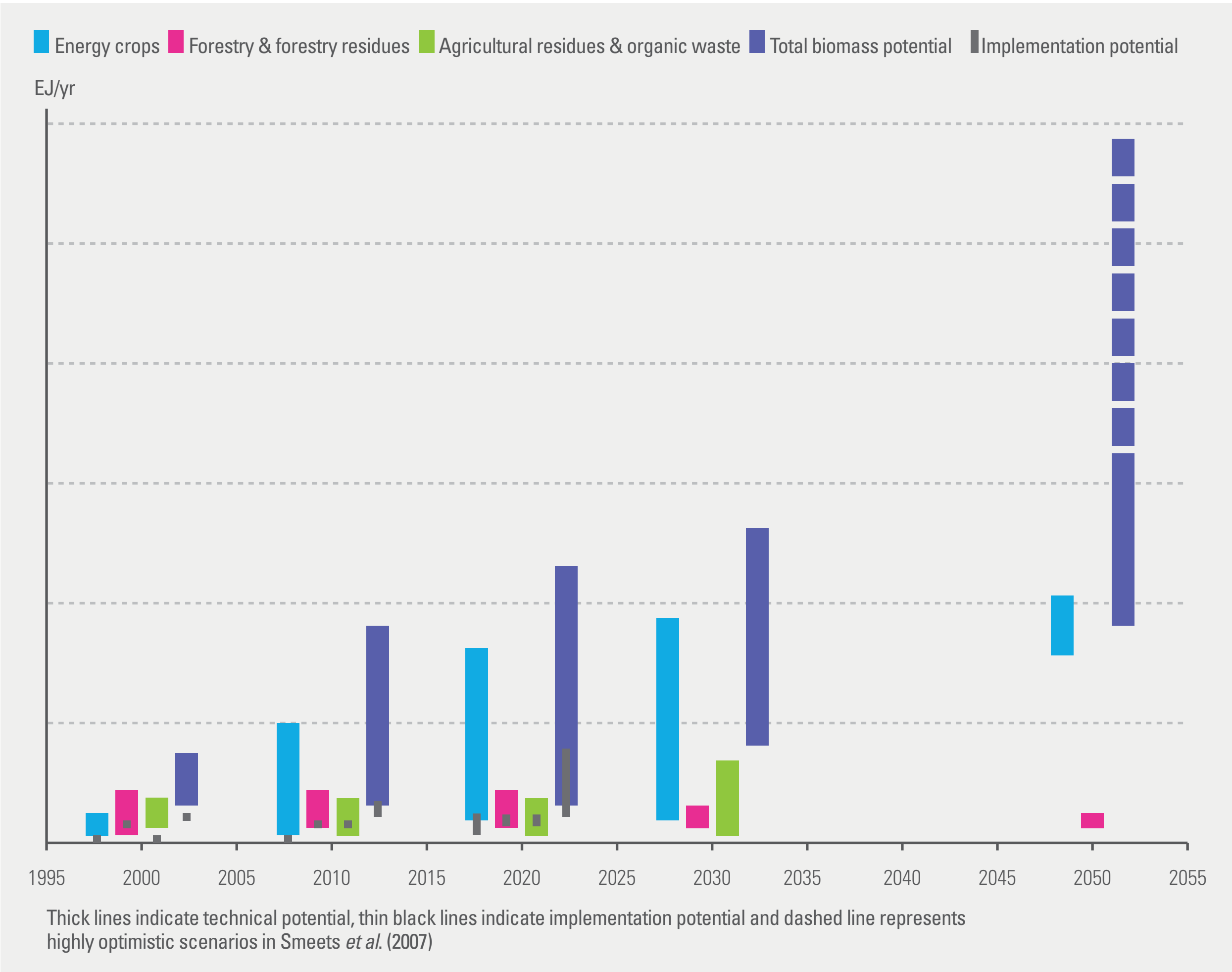
Several other studies[18] [19] clearly show the advantages of lignocellulosic annual crops with a C_4 photosynthesis system (for example, miscanthus and switchgrass) in terms of dry biomass yield (up to 25-30 t/ha with averages around 15 t/ha [20]). Although there is probably significant scope for further progress, the main advantage of perennial crops (such as woodland) at present is their low environmental impact (efficient nitrogen recycling, high Water Usage Effectiveness) and the ability to harvest dry material.

Cereals and sugar beet yield well under European conditions (5-10 t/ha for wheat and over 50 t/ha for beet), while oilseed crops offer lower yields, because of the high energy requirement of lipid metabolism. For all crops, sustainability of production has to be improved. The sustainable use of agricultural and forestry residues (limited removal of residues from fields and forests to avoid depletion of carbon from soil) could considerably reduce the amount of land required for biomass production, and thus reduce competition with land for food/feed production or nature conservation.

However, **more diversity in the cropping system will be necessary to produce biomass in a sustainable way** (protecting biodiversity, managing pests and diseases with minimal environmental impact and managing landscapes sensitively). Although there is already significant diversity of supply in Europe, there is a clear need to increase the supply of sustainable biomass from existing sources as well as to increase diversity supply further via development of new sources, facilitated by a better regulatory and innovation framework.

New biorefining feedstocks have recently emerged. For instance, the cereal *Triticale*, a cross between wheat and rye, is already cultivated and has high potential as a raw material in grain biorefineries producing ethanol or other fermentation chemicals, DDGS (dried distillers grains with solubles) as a mid-protein feed supplement, and fibre[21]. Triticale yields well but has limited use in the human food chain and so more potential for industrial uses. Aquatic (marine) biomass (micro-algae and seaweeds) is also an interesting new feedstock, because it does not compete for land suitable for agricultural purposes. It also has high productivity per area unit and a high content of valuable components.

The BEE project compared different types of biomass on a common basis, in terms of their energy value (as EJ=10^{18} Joules). However, as land availability and productivity will be a constraint on total European biomass production, it is important to consider also the practical limits to production.



| **Figure 4 : Summary of biomass potential at European level (by sector and in total)[17]**

Some of the studies reviewed in the BEE project also considered some results in millions of hectares (Mha) of available land. Estimates for 2030 range between 5.8 and 65 Mha across the EU (4 studies). Only one study[22] looks as far as 2040, with an estimate of 108.2 Mha of land available for biomass production in the EU-27.

In 2006, the European Environment Agency (EEA)[23] estimated additional land availability from arable areas (not including woodland) for the EU22 to be from 13-15 Mha in 2010 to 19-25 Mha in 2030 (Figure 5). This surplus agricultural area could be used to cultivate either conventional food crops or lignocellulosic crops specifically for non-food use.

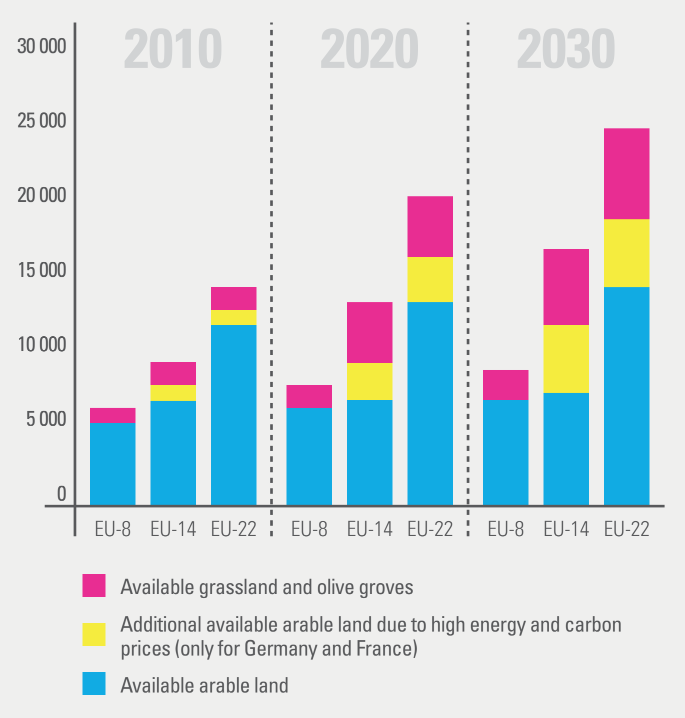


Figure 5 : Land available for biomass production (EEA)

SCENARIOS FOR FOREST BIOMASS

The EUwood[24] project suggests that realistic woodland biomass production could range from 625 to 898 million m^3 per year (overbark figures, i.e. including bark) in 2030. This figure is the total production potential of EU forestry, regardless of end use. After subtracting wood for material use, the energy potential from forests would range from 0.79 to 2.74 EJ in 2030 (Figure 6). The future potential of woody biomass was estimated for three scenarios, which differ with respect to factors such as the political environment and the attitude of society towards the use of wood. The scenarios are:

- High use: strong focus on the use of wood for producing energy and for other uses, effective implementation of current recommendations on use of forestry resources
- Medium use: existing recommendations are not all fully implemented or do not have the desired effect
- Low use: strong environmental concerns about intensification make woodland owners more reluctant to harvest

There are also active initiatives to increase the use of wood in construction materials in place of non-renewable resources. If this is successful, the additional harvest of forestry biomass needed for materials production will not be available for other purposes (energy or biorefining) unless the various products and processes are interlinked (e.g. by recycling construction materials at end of life).

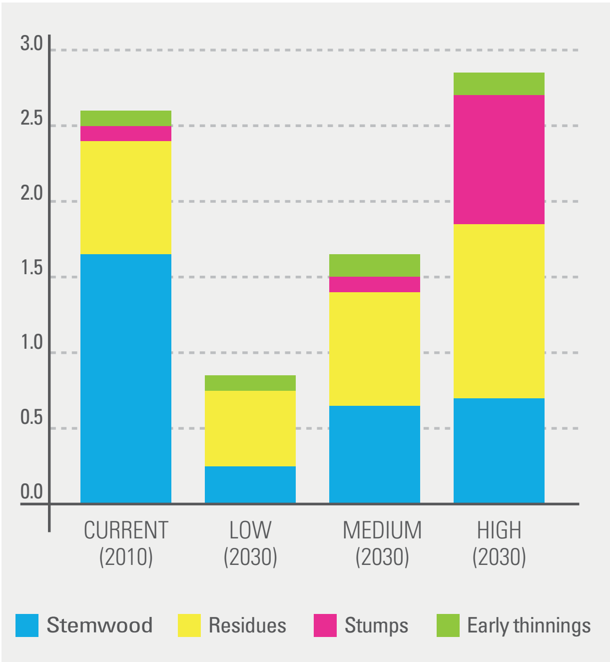


Figure 6: Realisable forest energy potential from European forests. Conversion factor 7.2 GJ/m^3 (EUwood)

CONCLUSIONS

We can assume that **the future production of biomass in Europe will be roughly based on the current land distribution** with an increase in systems based on perennial species[25] (woodland and dedicated perennial crops), the cultivation of which can have a number of positive impacts (e.g. increasing the water retention capacity of the soil and reducing erosion).

In the short term, the main sources of biomass will continue to be traditional agricultural crops (cereals, potatoes, sugar beet and rapeseed), wood and dedicated energy crops, with forestry and agricultural waste also playing a role. After 2020, there will be an increasing use of dedicated lignocellulosic crops, from both farms and short rotation plantations on woodland, assuming that technical and economic hurdles have been overcome by then.

However, available research suggests that future development of the European biomass sector will be subject to a high degree of uncertainty, mainly depending on crop yields and land availability. Although the extent of yield improvement is not yet certain, the technical and scientific knowledge which will enable progress is already well established. **The key issue for future biomass production in Europe is therefore land availability**.

The uneven geographical development of agricultural production and demand for both food and feed will influence patterns of global trade in general and the demand for European agricultural exports in particular. In turn this will determine the availability of land to grow biomass as an industrial feedstock. But as food demand puts further pressure on land, availability can be increased by yield improvements, optimisation of biomass production and reduction of losses in the agricultural supply chain. One of the key challenges for Europe is therefore to manage the short- and mid-term constraints on biomass availability without jeopardizing long term sustainability of supply.

The Agro-Forestry sector

DESCRIPTION OF THE AGRICULTURAL SECTOR

With 12.2 million people employed in 2009, the agro-forestry sector represents 5.5% of total EU employment. It generated €168 billion in 2009 and accounted for 1.6% of the total GVA (Gross Value Added). The importance of this sector in the EU economy is declining, largely due to significant productivity gains for both labour and capital, and the sharp decline in relative prices.

The structure of the agricultural sector varies considerably across Member States and regions due both to geographical factors (including agricultural history, the climate and environmental conditions) and the institutional framework (for land, labour and capital markets). The diversity in the size, farming type and socio-economic performance of agricultural holdings has been further increased by successive EU enlargements. Europe has more than 8 million farmers, but the patterns and drivers of structural change in the EU-12 differ in nature and degree from those in the newer EU-15 Member States. For the EU-12, productivity gains (largely supported by technological progress such as mechanisation and improved crop and animal genetics), as well as general economic pressures, have driven considerable structural adjustments over recent decades. However, the Common Agriculture Policy (CAP) has to some extent cushioned this long-term process, allowing continued structural diversity in the agricultural sector and slowing the decline in the farm labour force.

Agriculture today uses 47% of EU land area. This share is proportionally lower (40%) in predominantly rural areas than in more urbanised ones (53%) because of their greater area of woodland. Between 1990 and 2000, urbanisation led to some loss of agricultural land, especially in regions with major centres of population. This shift was partly offset by a conversion of forest and semi-natural land to agriculture.

CHALLENGES FOR THE AGRICULTURAL SECTOR

Evolution of the Common Agriculture Policy (CAP)

The three main objectives for the future CAP should be:

1: A viable food production capability

- To contribute to farm income and limit its variability, since price and income volatility and natural risks are more marked than in most other sectors and farmers' incomes and profit margins are below the average in the rest of the economy.
- To improve the competitiveness of the highly fragmented agricultural sector and enhance its share of value in the food chain compared to larger downstream players with greater bargaining power. European farmers also face competition in international markets while having to meet often higher environmental, food safety, quality and animal welfare standards.
- To support production in areas with specific natural constraints (such regions are at increased risk of land abandonment).

2: Sustainable management of natural resources and action on climate change

- To guarantee sustainable production practices and secure the enhanced provision of environmental public goods (currently, the value of many of the benefits generated through agriculture are not recognised by the market).
- To increase the efficiency of the food and feed chain.
- To foster green growth through innovation. This means adopting new technologies, developing new products, changing production processes and supporting new patterns of demand, all within the overall context of the emerging Bioeconomy.
- To pursue both climate change mitigation and adaptation actions. Because agriculture is particularly vulnerable to the impact of climate change, enabling the sector to adapt better to the effects of extreme weather fluctuations can help reduce their negative effects.

3: Balanced urban and rural development

- To support employment and the maintenance of the social fabric in rural areas.
- To boost the rural economy and promote diversification to enable local actors to unlock their potential and optimise the use of additional local resources. Decentralised biorefineries, with some processing carried out at farm level, will contribute to rural development and help increase the value added by the agricultural sector.
- To allow for structural diversity in the farming sector, improve operating conditions for small farms and develop local markets, since varied farm structures and production systems contribute to the attractiveness and identity of rural regions.

Achieving all these objectives will require public support for the agricultural sector and the rural economy to be maintained. EU-level policies are therefore needed to ensure fair conditions for farmers with a common set of objectives, principles and rules. A Europe-wide agricultural policy allows budgetary resources to be used more efficiently than individual Member State policies would allow. As well as helping to develop the single market, several other objectives are better addressed at trans-national level, for example cohesion across Member States and regions, cross-border environmental problems, global challenges such as climate change, water management, biodiversity, animal health and welfare, food and feed safety, plant health and public health and consumer interests.

EU competitiveness versus other countries

The EU is a major player in international trade in agricultural commodities and food. With average annual imports worth €81 billion in 2007-2009, the EU is by far the world's largest importer, although its share of total world imports decreased from 21% in 2007 to 19% in 2009. Exports reached an annual average of about €76 billion in 2007-2009, placing the EU on a par with the USA and giving it a share of around 18% of world exports. EU agri-food trade experienced sustained growth in the ten years to 2008, with average annual growth rates of 5.7% for imports and 5.9% for exports. Growth was particularly dynamic in the period 2005-2008. In 2009 trade was profoundly affected by the global economic crisis and EU imports contracted faster than exports, so that the EU agricultural trade deficit decreased substantially from a record €7 billion in 2008 to just €2.5 billion in 2009.

2009 was exceptional as it saw a reversal of the pattern of growth in EU agricultural trade. Exports suffered an 8% drop in value after five years of uninterrupted growth, but imports fell even further, by 13%. While the financial and economic crisis had a strong impact on trade in general, falling prices for commodities and intermediate products in 2009 had a larger effect on the value of imports than exports, reflecting the balance of commodity trading.

Finished products dominate EU agri-food trade. They accounted for 68% of the value of exports and 54% of the value of imports in 2007-2009. While the overall EU agri-food trade balance has been consistently negative in the last decade, with the notable exception of 2006, in the case of consumer products it has always been positive over this period, with the surplus reaching an average of €8.1 billion in 2007-2009. Intermediate products and commodities represented 23% and 9%, respectively, of the total value of EU exports. For imports, these categories had higher shares, of 27% and 19%.

Impact of climate change

Agriculture was responsible for 9.6% of EU emissions of greenhouse gases in 2008 (471 million tonnes of CO_2 equivalent). However, because of improved production methods and reduced numbers of cattle, emissions from agriculture have been decreasing at a faster pace than in other sectors of the economy, at an average annual rate of 0.7% between 2000 and 2008. Also, the production of renewable resources from agriculture amounted to 12 million tonnes of oil equivalent (toe) in 2008 in an area of around 5 Mha. The production of renewable resources by the European forestry sector reached 68 million toe in 2007 and grew at an average annual rate of 4.4% over the period 2000-2007. EU agro-forestry is increasingly contributing to climate change mitigation and adaptation efforts.

Fewer full-time workers

EU agriculture is still largely based on family farms, with more than 80% of the labour force coming from farmers' families. Permanent employees make up only 12% of the labour force. However, a very large share of employment is not full-time: around one third of all EU permanent farm workers (including family members) work less than half time in agriculture and only 37% of them have full-time jobs. The importance of part-time farming is also reflected in the labour used per farm: 55% of EU farms require less than one full time person over the year.

CURRENT SITUATION FOR BIOREFINING

The agricultural sector currently supplies raw materials for starch, sugar and biofuel production. The sugar production chain (from sugar beet) is a particularly efficient one. However, as already discussed, future development of the biomass sector is highly uncertain. What will happen depends on both how world agricultural production develops as well as the global demand for food and feed. These factors will determine the pattern of agricultural exports from Europe, and thus the amount of land potentially available to produce biomass for energy and industrial applications. A major challenge is to manage the short and mid-term biomass availability constraints without jeopardising the long-term availability of biomass in Europe.

OPPORTUNITIES FOR THE AGRICULTURAL SECTOR

- Creating new business models in rural areas
- Creating new markets, and a wider variety of products
- Capturing more value on farms by providing semi-finished goods for biorefineries
- Creating new jobs in rural areas
- New significance of the agricultural sector in the developing bioeconomy
- Post-harvest treatment of produce and logistical solutions for year-round supply of raw materials for biorefineries
- Improving biodiversity by growing a range of crops for biorefineries
- Reducing the need for public subsidies because of improved income streams
- Improving agriculture traits and increasing levels of valuable components in crop varieties developed by genetic modification or other novel biotech breeding techniques

SECTOR DEVELOPMENT TO 2030

- Moving from being solely suppliers of raw material to an agriculture sector which also does primary processing
- Establishment of decentralised energy production in rural areas, generated from solar, geothermal and biomass sources
- On demand provision of agricultural raw materials and semi-finished products to biorefineries. Fractionation technology exists on farms, where storage and logistics solutions have been developed.
- Increased yields per hectare together with sustainable farm management systems, leading to a sustainable increase in efficiency
- Increased efficiency of transformation of raw materials to food and feed products

BOTTLENECKS AND STEPS TO BE TAKEN TO 2030

- Develop a market for agricultural raw materials and semi-finished products for biorefineries
- Estimate the requirement for raw materials and semi-finished products, and devise an efficient interface between the agricultural sector and biorefineries
- Develop decentralised technologies for fractionation, drying, storage, and transport
- Develop the technology needed to increase efficiency in the agricultural sector (cultivation and harvesting technology, precision farming and accelerated breeding of new non-food and multipurpose crops using marker assisted breeding and biotechnology)

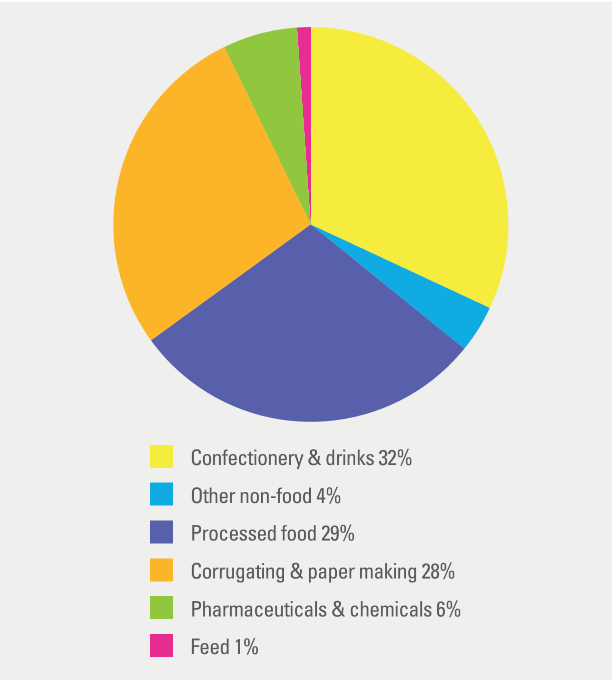
Agro-industries

Industrial products based on agricultural raw materials have traditionally been produced by dedicated primary processing industries. Seed crushers and starch producers are examples of well established industries supplying the chemical and personal care sectors. The main obstacle to further market penetration is price. Some of these industries are described in more detail in the following section.

The starch industry

DESCRIPTION OF THE SECTOR

In the European Union, starch is mainly produced from maize, wheat and potatoes. More than 21 million tonnes of agricultural raw materials, primarily from European producers, are processed every year, and the starch industry is an important customer for European farmers. Native and modified starches, starch saccharification products (e.g. maltodextrins and syrups), as well as by-products of starch production, are used in almost all branches of the food, feed, chemical, pharmaceutical, and paper and paper board industries (see figure 7).



| **Figure 7 — Breakdown of starch usage. Source AAF www.aaf-eu.org**

CHALLENGES FOR THE SECTOR

- Maintaining production output from existing industrial units. Making a smooth transition to future non-food applications.
- Optimising energy efficiency and bioenergy use
- Coping with volatile world cereal and sugar prices

CURRENT SITUATION FOR BIOREFINING

In Europe, the starch-based biorefinery concept has focused on integrated production for food, feed and non-food applications, while aiming for zero waste and getting maximum added value from co-products. It is extracted from cereal grains (and potatoes) and a proportion is converted to glucose, or further processed to high-value chemicals or commodities such as polyols or fermentation products (currently mainly ethanol but also organic acids or amino acids). The oil and protein fractions extracted can be further processed for food and feed applications.

OPPORTUNITIES

The starch sector needs to develop new markets to grow and is thus focusing especially on processed and value-added products. The development of chemicals using either biological or chemical processing is being done to meet a growing demand for biobased products.

As starch is itself a polymer, there are opportunities to develop new functionalities via chemical modification to respond to the growing demand for biomaterials and biopolymers.

SECTOR DEVELOPMENT TO 2030

The global demand for starch by 2030 is expected to increase by 50%, due to growing prosperity in emerging markets and the expansion in personal consumption in developing countries (especially in Asia). By 2030, global demand is expected to be more than 100 million tonnes, meaning an average annual growth of 2%.

Further growth is expected through the development of additional biobased products including speciality materials and chemicals.

As the starch industry is a primary transformer of biomass and is in full control of its supply chain, it is in a good position to expand its scope to create future diversified starch-based biorefineries.

To fully realise its potential, the starch sector may also develop partly through the integration of new lignocellulosic supply streams, first from processing of residues from existing feedstock and, in the longer term, using dedicated lignocellulosic crops.

BOTTLENECKS AND STEPS TO BE TAKEN UP TO 2030

The major bottlenecks hindering the achievement of this by 2030 will be the cost competitiveness of biobased products made from starch, and scale-up and implementation of the necessary processes. Development will therefore focus on:

- The efficiency of industrial processes
- Reduction of energy and water use
- The use of starch as a polymer for biobased products

The Sugar Industry

DESCRIPTION OF THE SECTOR

Annual sugar production in the EU is 19-20 million tonnes. It is produced in almost all Member States, although France, Germany and Poland together account for more than half of the total 2.1 million hectares of sugar beet are currently cultivated in the EU.

CURRENT SITUATION FOR BIOREFINING

Most production is made into crystallised or liquid sugar for food applications. The residue of sugar beet pulp is used for animal feed, while molasses from the refining process goes into feed or is fermented to produce bioethanol. Sugar is also processed into alcohol for the drinks industry and used by the chemical sector in fermentation processes. Currently only 2% of total sugar production is used in non-food applications.

CHALLENGES

- Competition with sugar cane
- Maintaining production output from the existing industrial units. Making a smooth transition to future non-food applications
- Optimising energy efficiency and bioenergy use
- Improving sustainability and reducing GHG emissions

OPPORTUNITIES

- The sugar sector needs to develop new markets to grow and is thus focusing especially on processed and value-added products. The development of chemicals using either biological or chemical processing is being done to meet a growing demand for biobased products.
- Instead of crystallised sugar for food, sugar could be used as a basis for fermentation. This will lead to simplified processes with lower energy needs and use of all the sugar content for value-added end products.
- There may also be potential for the development of farm-scale/decentralised processes.

SECTOR DEVELOPMENT TO 2030

According to sugar sector analysts Czarnikow[26], the global demand for sugar by 2030 should increase by 50%, due to growing prosperity in emerging markets and expansion of personal consumption in developing countries (especially in Asia). By 2030, global demand is expected to be around 260 million tonnes, requiring a 90 million tonne increase in global production. Brazil alone (a major sugar cane grower) already accounts for 60% of global exports, and its share in the global market is likely to increase.

EU sugar production has decreased by around 17% over the past decade, following the reform of the sugar regime, and it has thus turned into a net importer. Total consumption in Europe is expected to remain stable over the next 20 years. However, Europe will still have a strong role to play in the sugar market. The development of sugar for biofuels and industrial uses represents a significant opportunity for European industries.

BOTTLENECKS AND STEPS TO BE TAKEN UP TO 2030

- Capitalise on synergies between the starch and sugar industries for fermentation applications
- Use the cellulose-based pulp residue for the development of second generation fermentation products

The Oilseed industry

DESCRIPTION OF THE SECTOR

Current oilseed biorefineries produce mainly food and feed ingredients, biodiesel and oleochemicals from oilseeds including rape, sunflower, soybean and olives. In the first step, oilseeds are crushed, mechanically pressed and then usually treated with chemical solvents to separate the vegetable oil from the protein fraction. The protein fraction is mainly used as animal feed. (Biorefinery Euroview[27]).

CURRENT SITUATION FOR BIOREFINING

The valuable vegetable oil can be converted and refined into a variety of products (Biorefinery Euroview[27]). Vegetable oil (or animal fat) is increasingly being used to make biodiesel (fatty acid methyl ester or FAME), via the trans-esterification process, which produces glycerol as a by-product. Chemical and enzymatic modification of vegetable oil produces oleochemicals, such as fatty acids, alcohols, fatty esters, ketones, dimer acids and glycerol. Oleochemicals are primarily used in personal care products or as raw materials and additives in industrial applications[28] such as textiles, lubricants, household cleaners and detergents, plastic and rubber. There is generally no integration of crushers with downstream oleochemical companies.

CHALLENGES

- The low productivity of oilseed crops per hectare is a limit to optimisation of land use
- Reliance on imported feedstocks
- European oilseed crops have only a limited capacity to produce short- and medium-chain fatty acids for industrial processing

OPPORTUNITIES

- Increasing production of added-value compounds including biodiesel and chemicals
- Integration of the crushing and oleochemical sectors
- Development of catalysts for advanced processes (e.g. converting glycerol to a range of chemical end products)
- Development of fermentation processes to make new fatty acids and to increase productivity per hectare (by converting sugar to lipids)

SECTOR DEVELOPMENT TO 2030

World production of vegetable oil is expected to increase by almost 40% from 2010 to 2019[29]. The share of vegetable oil production used for biodiesel production is projected to be around 15% by then, driven by biofuel mandates and consumption incentives in many countries. In non-OECD economies, because of increasing population and income, food use will continue to account for 90% of the 3% annual growth in vegetable oil demand. Over the same period, annual growth in protein meal consumption is projected at 1% in OECD economies, compared with 3.2% in non-OECD economies, driven by the sustained growth and intensification of livestock production.

BOTTLENECKS AND STEPS TO BE TAKEN UP TO 2030

- Key bottlenecks are the oilseed feedstock cost and land availability for increased production.
- Oil crushers and biodiesel producers' focus will be on process cost reduction and value creation through integration with downstream transformation.

Forest-based industries

DESCRIPTION OF THE FOREST-BASED SECTOR

The European forest-based sector provides a range of materials and products, energy crops, recreational activities and other services. All stakeholders whose major business relies on forest-related materials or services, or on forest-based products, are considered part of the forest-based sector. The core of the sector, in addition to the actual forests, is formed by the following major value chains:

- Services and non-wood products from forests
- The wood products chain (including furniture and recycling of wood)
- The paper chain (including pulp making and paper recycling)
- The bioenergy chain
- The wood-based chemicals chain

With an annual production value in the EU-25 of some €550-600 billion, forest-based industries account for about 8% of the total added value in EU manufacturing industry. This sector includes some 16 million forest owners and provides between 3 and 4 million jobs in industry, to a large extent in rural areas and in SMEs.

Europe accounts for 25-30% of world production of forest-based products, producing around 30% of all paper (340 million tonnes), 30% of all recycled paper (200 million tonnes), 25% of all pulp (185 million tonnes), 25% of all sawn-goods (405 million m^3) and 30% of all wood-based panels (200 million m^3)[30]. The forest-based sector is the largest single producer and consumer of bioenergy in Europe. In 2008, biomass-based energy formed 54.4% of total primary energy consumption by the sector (more than 0.67 out of 1.5 million TJ). Most of this energy is generated by Combined Heat and Power installations[31].

CURRENT SITUATION FOR BIOREFINING

Some pulp mills have already transformed their businesses to derive value from compounds extracted from wood, creating higher value from what were previously "energy side-streams". These mills are, in fact, highly innovative and diversified biorefineries.

Integrated pulp and paper mills are currently the best examples of wood-based biorefineries. For more than 100 years, both alkaline and acidic pulping processes have been an important source of numerous chemicals, fractions and materials, in addition to the main product, wood pulp (cellulose). The derived products include kraft and soda lignin, lignosulfonates, vanillin, tall oil and phytosterols, turpentine, furfural, xylose, acetic acid, ethanol and its derivatives, yeast and protein.

Currently, wood-based chemicals are mainly isolated from pulping spent liquors and only a few processes are used to prepare or isolate any chemicals directly from wood or wood residues. Examples include the extraction of bioactive substances or other soluble compounds (such as tannins) from wood or bark. In addition, small volumes of essential oils are isolated from different tree species. Thermal processes are used to prepare tar and certain tar-derived fractions.

CHALLENGES FOR THE FOREST-BASED SECTOR

- The forest-based sector faces significant challenges to its competitiveness. Securing raw materials without compromising the various services provided by woodland will continue to be a demanding task. The use of wood-based biomass for products and energy needs to balance an economic return with minimal environmental impact.
- Access to wood and wood residues is important to the traditional European woodworking industries. A growing European biorefinery sector must not prosper at the expense of wood-based industries such as panel manufacturing, which is a major user of off-cuts. There is therefore an increasing need to use biomass more efficiently. This includes measures like better conversion processes, cascade usage of wood raw material, minimisation of waste energy and wood polygeneration.
- It is vital to pursue the development and design of products that meet present and future customer needs, whilst being recyclable. Process innovations will not only have to support sustainable development but also to improve flexibility in manufacturing whilst significantly reducing capital costs.
- To remain competitive, profitable and become more sustainable, the European forest-based sector has to seize the opportunity to convert gradually to new and emerging technologies.

OPPORTUNITIES

The forest-based sector has opportunities to provide significant social, economic, environmental and technological benefits. It is in a position to significantly increase the use of forest-based materials whilst maintaining other important functions of woodlands, such as fostering biodiversity and providing recreation. Development of processes and high value-added products, increased substitution of non-renewable materials by forest-based materials, as well as the development of green chemicals and increased green electricity production, are major opportunities for the sector.

The pulp and paper industry is currently developing in several directions, based on the use of side-streams from traditional pulping processes. There are several attractive choices for utilisation of solid biomass streams (e.g. forest residues and bark), including:

- Gasification of biomass to produce syngas and further processing to make transport fuels and chemicals, such as Fischer-Tropsch diesel, methanol and dimethyl ether
- Pyrolysis of biomass and upgrading of pyrolysis liquids to bio-oil (and in future, producing other chemicals)

Further interesting high added-value compounds could be extracted or produced by biochemical conversion of by- and co-products of the wood industry.

Spent cooking liquors can be utilised as a raw material for further processing, e.g. black liquor can be used for syngas production. The tall oil produced in the pulping process is currently an important source of chemicals, which can also be converted into transport fuels through esterification and further modification.

There are also several additional opportunities for integrating biorefinery operations into the pulp and paper industry and other wood industry processes:

- More advanced isolation of new pulping by-products from the existing pulp mill process streams e.g. separation of lignin from pulp mill black liquor for use in high quality fuel (fuel oil replacement) and products like carbon fibres
- Modification of the current pulping processes, e.g. insertion of a chips pre-extraction or pre-hydrolysis step before pulping. In these processes, polymeric hemicelluloses or monomeric sugars could be produced for various applications.
- Utilising bio-based residues from recycled fibre processing in biorefinery processes
- Paying more attention to potential ways to modify fibres or cellulose to make new products with novel functional properties
- Integration of biorefinery-type operations into wood industry processes other than pulp and paper making. For example, hemicelluloses and sugars could be extracted from wood raw materials used by the panel industry.
- Isolation of valuable chemicals from different hardwood and softwood barks

Several of these new developments in the forest-based sector, especially those producing biofuels, are already at the pilot or demonstration stage. However, the full potential of biorefinery activities in Europe is far from being fully realised today. European pulp mills will have to adopt these concepts if they want to compete successfully with countries such as Brazil, Canada, the USA and Chile.

SECTOR DEVELOPMENT TO 2030

Entirely new forest-based value chains using the biorefinery concept are envisaged. In order to promote advanced, zero-waste, wood-based biorefinery concepts, the Forest-based Sector Technology Platform (FTP) Biorefinery Taskforce report in 2007[32] pointed out five main research directions. Starting from those five development directions, we propose a more detailed FTP biorefinery vision of progress for 2030.

Selective, efficient separation and conversion processes

Research, demonstration projects and investment are needed for technologies that improve the extraction of chemical components from biomass. **By 2030**, innovative businesses are prospering around larger biomass production units. These businesses specialise in producing a range of different compounds from by-products and side-streams originating from the main biorefinery process. They create new skilled job opportunities in rural areas. By 2030, it is likely that biomaterials such as lignin-based carbon fibres and nano-cellulose fibres, composites and bioplastics may be able to reduce weight and provide new or improved properties in materials compared to, for example, steel and concrete in sectors such as the automotive and construction industries.

Biorefineries as the source for wood-based solid and liquid biofuels

As activities develop in the biofuels sector, the pulp industry's knowledge can be used to speed up these developments further. At the same time, new technological developments and new markets will create additional sources of income for the pulp industry. **By 2030**, we envisage that new biobased fuel products, markets and production systems will have become a reality. The integrated production of second generation biofuels from the pulp and woodworking industries will be an important outcome.

Recycled fibre biorefinery

Besides the wood-based biorefinery, the recycled-fibre biorefinery offers an opportunity to optimise fibre cascades in the pulp and paper industry value chain. Fibres as well as non-fibre residues from (recycled) paper production offer a large potential as a new raw material. **"More from less"** is one of the sector's key mottoes and the vision is to establish profitable, advanced, zero-waste, wood-based biorefineries across Europe. To support this, new systems will be developed to separate and refine organic substances and fibres from wood and waste streams.

Cross-sector synergies with the agricultural, biofuels and chemical sectors

The forest-based sector is striving to develop a new model of integration and cooperation with other sectors in the Bio-based Economy. **By 2030**, collaboration with the agriculture and chemical sectors, in particular, will create new synergies and open up new market opportunities.

The socio-economic impact of biorefinery development

The consequences of policy and legislation for the biobased sector, as well as the effects of a new biorefinery industry upon value chains, markets and society should be studied in an integrated way. **We envisage that, by 2030**, the new market models that should be developed will be viable even after temporary subsidies have ended and that the emerging biorefinery sector will have proved its value to society at large, fulfilling any policy goals that have been set.

Outlook for 2050

New advanced, zero-waste biorefineries could realise the forest-based sector's potential to become carbon neutral as a whole around 2050. Looking at the total carbon footprint of the sector in terms of production, transport, landfill, bioenergy production and carbon sequestration and storage, the potential for carbon neutrality clearly exists. Major steps towards this target should have been taken by 2030. The sector itself will have to develop more efficient technologies, implement new ways of working, generate energy more efficiently, use raw materials more effectively and use biorefining as one of the concepts that will enable the goal to be achieved.

BOTTLENECKS AND STEPS TO BE TAKEN UP TO 2030

The Forest-based Sector Technology Platform has identified a set of research areas in which progress is needed to realise their vision and to meet the challenges ahead. In the Strategic Research Agenda of the Platform[33] entirely new forest-based value chains based on the biorefinery concept are envisaged, and potential research areas, examples of activities and research approaches are presented. The following major areas for research have been identified:

- Developing innovative products to fit with changing markets and meet customer needs
- Developing intelligent, efficient and lower energy manufacturing processes
- Enhancing availability and use of forest biomass for products and energy
- Meeting the multifunctional demands on forest resources and their sustainable management

Energy sector (heat and power)

DESCRIPTION OF THE SECTOR

The turnover of the EU energy sector (covering electricity, gas, steam and hot water supply) was €940 billion in 2007. There were more than 26,800 companies in the sector, employing some 12.2 million people, and the industry contributed €200 billion of value added.

Economic growth has always been fuelled by primary energy use. However, the direct coupling of GDP and energy demand has changed to some extent, and Europe has recently seen a slow decline in the energy intensity of the economy (see Figure 8).

The current target for the share of renewable energy in gross final energy consumption at EU level is 20% by 2020. The latest figures published by Eurostat show the current share to be 10.3%[34]. The energy sector will have to continue to move away from fossil energy sources in order to meet its goals.

OPPORTUNITIES

- Valuable compounds can be extracted from biomass prior to combustion in combined heat and power (CHP) plants integrated with biorefineries. For example, the biomass fuelling a CHP plant can first be used as a feedstock for biofuel or chemical production processes, with only the residue being burnt. The CHP plant can then provide energy for the higher value biofuel or biobased chemical production process and/or for external use. Biomass can be converted into higher value products either by a combined pre-treatment and biochemical route or by a thermochemical route such as gasification and syngas processing.
- Biogas production can offer higher added value than direct combustion for heat and power. The gas could be fed directly to the mains supply or further refined into other products, depending on market values.
- A carbon-free renewable energy supply, such as from solar panels or wind turbines, can also be integrated into the biorefinery.
- Development of multipurpose energy crops.

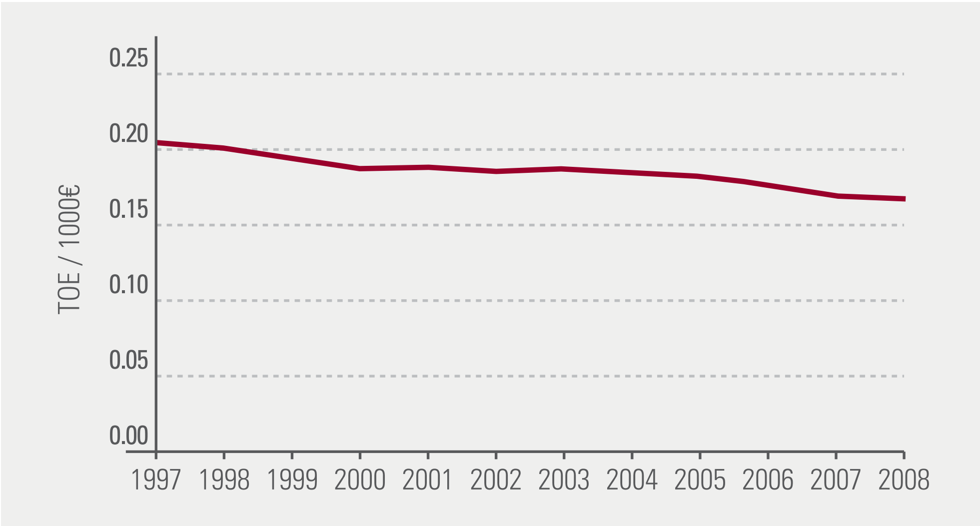


Figure 8: Energy intensity of the economy in the EU27, expressed as tonnes of oil equivalent of energy per unit of GDP

CHALLENGES FOR THE SECTOR

Today, the energy sector faces significant challenges in the form of feedstock availability (and price) and the need for climate change mitigation. Future shortages of energy feedstock will be due not only to the decline in reserves of fossil fuels such as oil and coal, but also to increasing competition for biomass, waste streams, vegetable oils and non-food crops from other industrial sectors. In parallel, climate change mitigation efforts will drive changes in the energy sector via policy instruments such as emission trading schemes and taxes on CO_2 emissions. These dual challenges are the main drivers of decarbonisation of power generation and reduction of CO_2 emissions.

SECTOR DEVELOPMENT TO 2030

According to the World Energy Outlook (WEO) 2009 reference scenario, total primary energy demand in the EU will rise slightly from 1,757 Mtoe in 2007 to 1,781 Mtoe in 2030. Primary energy demand globally is projected to grow at a rate of 1.5% per annum, however. European demand for electricity is projected to grow by 0.9% annually, from 244 Mtoe to 300 Mtoe by 2030. Heat demand is envisaged to grow at a similar rate (0.8% per annum) from 58 Mtoe in 2007 to 71 Mtoe.

The growth in demand in the EU will naturally require an increase in power and heat production capacity. Based on the WEO 2009 reference scenario, the total capacity will increase 1.2% annually, growing from 804 GW (GigaWatt) in 2007 to 1,067 GW in 2030. Wind power is expected to grow the most, its share of total capacity increasing from 7% to 23% over this period. The share of solar power will also grow significantly, rising from 1% to 8% from 2007 to 2030. Greater production of biomass will increase its share from 2% to 4%. Reliance on natural gas will continue, with its contribution rising by 1% to 23%. Overall, roughly half (46%) of the installed power and heat capacity in 2030 will be based on wind and natural gas.

Coal-fired power and heat capacity in the EU will, according to the WEO, diminish from 200 GW in 2007 to 158 GW in 2030. Coal's share of the total will decline from a dominant 25% to 10%. At the same time, oil-fired capacity will become smaller still, with its share decreasing by 7%.

The most significant changes in patterns of electricity generation alone up to 2030 will be in the shares of coal, nuclear and wind power. Coal-fired and nuclear electricity, which currently dominate the market, will each see declines of 9%, from 31% to 22% for coal-fired stations and from 28% to 19% for nuclear. Their current shares will be replaced mostly by wind power, followed by solar and gas. Wind power's share grows from 3% to 15% during the time-frame, while the share of solar electricity rises from essentially zero to 3%. Gas-fired capacity meanwhile rises from 22% to 25% and becomes the dominant source of power. Hydro power's share of total generation will rise from 9% to 10%, with biomass and waste together increasing their share from 3% to 5%.

The amount of biomass and waste directed into heat and power generation will increase quite rapidly, at a rate of 2.7% per annum, from 2007 to 2030. In energy terms, these annual biomass and waste flows will grow from 8 Mtoe to 70 Mtoe over this period. This represents only part of the total primary energy demand on biomass resources, as the amount used by other sectors grows from 38 Mtoe to 113 Mtoe. All in all, the total use of biomass and waste will grow, while its share of the heat and power sector increases as production capacity allows.

BOTTLENECKS AND STEPS TO BE TAKEN UP TO 2030

As the various heat and power generating sectors are forced to compete for feedstocks, resource limitations will generate bottlenecks. Market forces will determine the balance of biomass use for heat and power and added-value products according to their relative profitability. A scarcity of biomass and waste may make its efficient procurement an increasingly important step in the value chain.

Biofuels industry

Whilst there are many potential ways to decarbonise the power generation sector, the possibilities for transport are much more limited. Liquid biofuels are likely to provide the main renewable alternative, at least for long-haul transport and aviation, well into the future.

DESCRIPTION OF THE SECTOR

Global production was 34 Mtoe in 2007, which is still only 1.5% of total road transport fuel[35]. The USA is now the world's leader in fuel ethanol production, with Brazil second. Total world production of biodiesel is around 25% of ethanol production, and this is concentrated in the EU.

Liquid biofuel production in the EU amounted to 12 Mtoe in 2009, or about 4% of the road transport energy market. Biodiesel, mainly produced from rapeseed, predominates at about 9.6 Mtoe in 2009. Ethanol is mainly produced from wheat and to a lesser extent sugar beet, with a total output of around 2.3 Mtoe in 2009[36]. These two fuels are commonly referred to as first generation biofuels. In addition, small amounts of pure vegetable oil and biogas are used in the transport sector and about 1.4 Mtoe/a of renewable diesel (hydro-treated vegetable oil, or HVO) production capacity will be available by the end of 2011.

CHALLENGES FOR BIOFUELS IN EUROPE

The three top level challenges facing the European biofuels sector are:

- Securing future mobility by contributing to the overall mix of transport fuels
- Reducing greenhouse gas emissions
- Increasing biomass supply by a more efficient use of existing feedstocks and by enlarging the feedstock base

If current trends continue until 2030, diesel will increase its proportion of the total road transport fuel used in Europe at the expense of petrol; fuel demand will also increase in the aviation and marine sectors. As a result, we would expect to see insufficient diesel production capacity to meet demand and an overcapacity of petrol production. This imbalance creates a risk to the security of European supply, but could also present substantial opportunities for European biodiesel, aviation and marine biofuel suppliers.

The challenge is to increase substantially the production of biofuels by using innovative processes and technologies that are both competitive and sustainable, as part of the overall move towards reduced GHG emissions. It will be necessary not only to improve the GHG balance of currently available biofuels along the whole value chain, but also to promote the transition towards second generation biofuels. These will be produced from a wider range of feedstock, will not compete with the food chain, and will be a more cost-effective way to reduce CO_2 emissions.

Ensuring a sustainable and secure supply of feedstock will be critical to the success and long-term viability of biomass-based technologies. Issues to be addressed include improving productivity, developing reliable supply chains, certification and maintaining market stability for agro-forestry commodities. These challenges are not specific to the bioenergy and biofuel sectors and need to be addressed in a coherent way across all sectors of the bioeconomy.

The other specific challenges facing the sector are:

- A range of conversion technologies may be needed (mechanical, thermochemical, biological or chemical) to deal with the range of potential feedstocks.
- A set of sustainability-related tools and data is needed to ensure that appropriate legislation, standards and certification schemes are rooted in sound science, and based on transparent and relevant data.
- The acceptance and credibility of the biomass sector must be improved by strengthening communication channels, particularly between the agro-forestry, fuel and energy sectors. Effective communication with the public to get societal approval is also crucial.
- Economic competitiveness needs to be improved.

CURRENT SITUATION FOR BIOREFINING

Much of the existing biorefinery network has a strong link to biofuel production, particularly:

- Co-production of feed (DDGS) from ethanol and pressed cake from biodiesel
- Co-production of glycerol from biodiesel, used in the cosmetic and chemical industries
- Co-production of CO_2 from ethanol manufacture, used for horticulture or soft drinks

OPPORTUNITIES

For innovative future biofuel value chains short/mid term (2020 horizon) applied R&D should focus mostly on pilot- and demonstration-scale projects, leading to the first commercial-scale use of new technologies (reference plants). These should be able to use a range of feedstocks and/or produce higher added-value end products, in line with EU sustainability targets. The development of algal feedstocks and the application of synthetic biology to catalyst development offer new feedstock and technical options for biofuel value chains.

SECTOR DEVELOPMENT TO 2030

The profitability of biofuel production has been highly dependent on oil and bio-feedstock prices: volatility in crude oil prices has prevented biofuels from becoming competitive with fossil fuels. Biofuel production is therefore still directly dependant on a supportive regulatory framework, and this will continue over the next decade, even as second generation biofuels come on stream.

The EC study "EU 27 - Energy and transport outlook to 2030" presents a breakdown of the development of the transport fuel market (Table 1). In 2030, the demand for transport energy is projected to be 28% higher than in 2005. The amount of passenger traffic is expected to increase at an annual rate of 1.4%, while the volume of freight transport is projected to grow by 1.7% per year over the same period. Road freight and aviation are the fastest growing transport sectors.

In 2010, the European Road Transport Research Advisory Council (ERTRAC)[37] proposed targets of 25% biofuels and 5% electricity to power road transport by 2030, together with an overall 50% more efficient road transport system. This is a considerable challenge for biofuel production in Europe: 40 to 50 Mtoe of biofuel per year would be needed (assuming an annual increase of 1.2% in energy consumption in the transport sector[38]).

Large-scale use of biofuels is expected by 2020-2030. Market shares of different biofuels (both current and advanced) will change, as will market segmentation. Hybrid vehicles and pure electric cars will become more important for short journeys. Biofuels will maintain and expand their role in the freight transport, aviation, and marine sectors. Increasingly strict engine emissions standards and greater technical demands will drive the development of improved biofuels and increased flexibility of fuel type.

Share of transport (%)	1990	2005	2010	2020	2030
Gasoline	57.7	38.4	35.2	31.4	29.3
Diesel	41.1	58.8	58.9	58.9	58.9
LPG	1.2	1.5	1.8	2.0	2.1
Biofuels	0.0	1.1	3.9	7.4	9.4
Gas	0.1	0.2	0.2	0.3	0.3
Electricity	0.0	0.0	0.0	0.0	0.0
% change per year	1990-2000	2000-2005	2005-2010	2010-2020	2020-2030
Gasoline	-0.3	-2.8	-0.4	-0.2	-0.3
Diesel	4.0	4.2	1.4	1.0	0.4
LPG	3.0	4.5	4.6	1.9	0.8
Biofuels		38.7	30.9	7.7	2.8
Gas	5.3	7.1	5.0	3.2	2.0
Electricity				12.8	5.1
Total road	**1.8**	**1.3**	**1.3**	**1.0**	**0.4**

Table 1: Trends of energy consumption in road transport [39]

The vegetable oil chain producing first generation biodiesel represents the least energy efficient use of European farmland (in 2007, around 1,400 litres oil equivalent per ha in comparison to 4,000 litres oil equivalent per ha with ethanol obtained from sugar crops or BtL [biomass to liquid] from lignocellulosic raw materials[40]). Taking account of this, the cost of feedstock and the need for GHG emissions reduction, it is likely that vegetable oil biodiesel will be increasingly replaced by Biomass to Liquid (BtL) diesel (Figure 9) and diesel from hydrogenated pyrolysis oil from lignocellulosic feedstock.

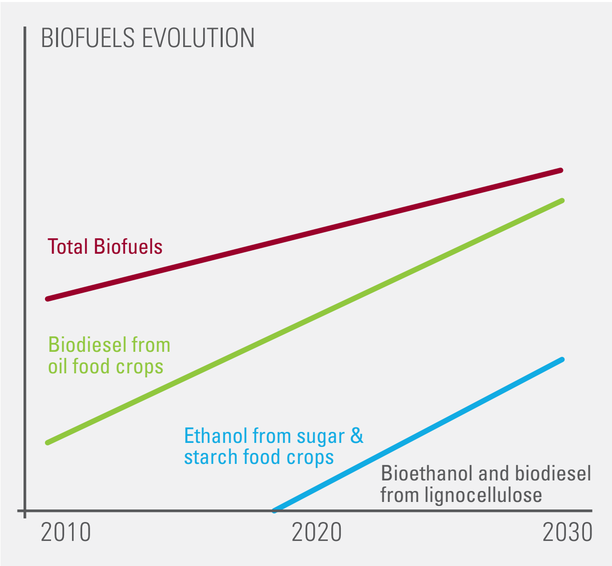


Figure 9: Biofuels repartition evolution in Europe up to 2030

The processing of lignocellulosic feedstock will also generate large quantities of lignins which will either be used as an energy source or, preferably, used to make added-value industrial products such as chemicals and materials, using the biorefinery approach. Increasing use of biorefinery concepts will reduce production costs and make biofuels more competitive.

Some new second-generation biofuels could be in commercial production by 2030. As raw materials, they will use lignocellulosic food crop residues, forest and wood residues and, in the longer term (after 2020) dedicated lignocellulosic crops. The proportion of lignocellulosic biomass used will increase because of their higher energy yields compared with food crops, the potential to grow them on marginal land and environmental benefits (such as lower input needs).

However, full exploitation of this potential may require significant investment in plant breeding and development of the appropriate agricultural management practices and expertise, so the scale of cultivation of dedicated lignocellulosic crops in Europe by 2030 remains uncertain. To cover the demand for biomass, it will be necessary to consider imports (provided that they meet EU sustainability criteria).

BOTTLENECKS AND STEPS TO BE TAKEN UP TO 2030

A large land area will be needed to supply the biomass for biofuel production. Since significant expansion of the land given over to non-food crops is unlikely, the increased demand for biofuels will have to be met by **importing biomass** (or biofuel) into Europe and by **increasing the energy content/productivity of biomass per surface unit**. To arrive at optimal solutions, the full value chain needs to be considered, from the field or forest to the vehicle fuel tank.

In summary, the main bottlenecks to be overcome by 2030 are:

- Enlarging the feedstock base (including by developing GM lignocellulosic crops)
- Developing processing technologies able to deal with a wider range of feedstocks and increasing the efficiency of conversion to valuable biofuels and other products
- Minimising overall energy consumption and improving the environmental footprint of biofuels

These new processing technologies cannot be developed on an industrial scale on a stand-alone basis but only as part of commercial value chains, which integrate process schemes from feedstock to end products. Because of the scale of investment needed and the various risks involved (including technology, feedstock and end product prices and regulatory framework evolution), financing the development of innovative bioenergy/biofuel technologies is a major obstacle for their large-scale commercialisation.

The Chemical industry

DESCRIPTION OF THE SECTOR

Biobased compounds such as amino acids, lipids, organic acids and vitamins, which find applications in the pharmaceutical, food and feed, detergent and cosmetic sectors, form a well-established part of the existing bioeconomy. There are also biobased platform chemicals such as 1,3-propandiol and fumaric, malic, succinic and itaconic acids, currently used in the manufacture of some polyesters or as food acidulants.

As outlined in the OECD bioeconomy report[41], as well as the many uses of traditional materials such as wood and cotton, newer biobased polymers can be used to manufacture packaging and containers, fabrics and more durable components such as electronics casings and car components. While there are some specialised, niche materials, the most important biomaterials to date are bioplastics, manufactured from natural biopolymers.

Although biobased polymers and plastics are still in their infancy, this industry has been growing rapidly, driven by new synergies and collaborations. Global production capacity for biobased polymers was estimated to be 360 million tonnes in 2007, with an annual market growth rate of 48% in Europe and 38% globally. Recent developments in processes combining biotechnology and chemical synthesis are leading to the emergence of materials such as ethylene from bio-ethanol[42] but their higher production cost currently limits their commercial viability to some specific sectors such as packaging.

The enzyme sector can be considered a subsector of the chemical industry. It uses modern biotechnology to produce the enzymes needed by other bioindustry sectors. Enzymes are very versatile tools, and each is specific to a particular industrial process. Europe has become the world leader in their development and production. Around 64% of all enzyme companies are located in the EU, and the main producers by volume are in Denmark. Danish companies in fact account for almost half of worldwide enzyme production. Most of these enzymes are used in the food (30%-45%) and detergent (33%) sectors. The textile and pulp and paper industries account for about 8%-14% and 1%-3%, respectively. Enzymes for fine chemical production make up another 5% of the world market[43].

CURRENT SITUATION FOR BIOREFINING

Today, biorefining operations in the chemical industry are based largely on either sugar or starch and vegetable oil. Integration of primary and secondary processing of the raw material remains limited. The chemical industry uses sugar or starch for fermentation or chemical processing as a "green" alternative to oil-based feedstocks to make products with the same functionality and performance[44].

Raw materials for oleochemical production come from the well-established world market for vegetable oil and there is no integration with the companies doing the primary processing of the oil. Most biobased chemicals and oleochemicals are high value-added, speciality chemicals.

Some integration of biomass primary processing with chemicals manufacture is emerging, with the diversification of product streams from some agro-industries (e.g. starch producers) towards chemical intermediates (lactic acid, succinic acid, etc.) and speciality chemicals (e.g. polyols)[45].

Choice of the right starting molecules to minimise energy inputs and capital costs — as is the practice in the petrochemical industry — can help to build efficient processes and extract greater value from some biomass-derived chemicals. One example is the use of glycerol to produce epichlorhydrin: Solvay has built two factories since 2007. This process produces the bulk chemical without the need for chlorine, which reduces energy needs considerably. Another example of the use of appropriate molecular structures present in plants is the manufacture of amino acids from biomass residues[46].

CHALLENGES

The chemical industry will face a number of challenges between now and 2030. Although there is a lot of disagreement on the level of reserves and rate of extraction of oil, there is general agreement that the long-term price trend will be upwards and that market volatility will increase. Though higher oil prices might have the greatest impact on low value applications and commodities, the increased uncertainty and volatility in the market is also likely to result in the chemical industry exploring other feedstock sources, including biomass and recycled materials.

The second trend driving the use of new feedstocks in the chemical industry is the strengthening of health, environmental and GHG emission reduction legislation, especially in Europe. This legislation and an increased awareness of environmental issues in the market might drive the development of innovative products and processes, some of which will be biobased or biological. It might also increase the adoption of renewable energy for chemical processing.

OPPORTUNITIES

In the chemical industry, an important step towards increasing the share of biobased chemicals is the creation of biotechnological and chemical platform intermediates based on the use of renewable carbon sources. These biobased intermediates can serve as the building blocks for a portfolio of end products (organic chemicals) currently produced from fossil raw materials.

Specific opportunities for the chemical sector lie in:

- The development of the lignocellulosic feedstock value chain, together with the development of lignocellulosic biofuels
- The development of renewable versions of existing platform chemicals (such as ethylene and butene)
- The use of plant components that have molecular structures similar to bulk chemicals now produced from oil and natural gas
- The development of new molecules with new applications and functions
- The integration of biotech and chemical processes to improve overall efficiency
- The development of interconnections between the network of regional/rural biorefineries and specialised material streams in the chemical industry
- Development of a portfolio of intermediates which biorefineries can deliver to processing sites

Such developments will contribute to product innovation in the chemical industry, but also result in overall more efficient and cost-competitive biobased processes.

With enzymes playing a crucial role in many other industrial sectors, there is significant potential for the EU to build on its global leadership in the production and development of biobased products and processes. In the production of many chemicals, biological processes can often replace one or more chemical steps. Biological processes have several advantages over traditional chemical synthesis, including greater specificity, milder processing conditions (such as lower temperature and pressure, and less extreme pH), lower energy use, and reduced waste and environmental impact. Despite these advantages, the uptake of biotechnology in chemical manufacturing to date has been limited, due to the high costs of enzymes and of building or modifying production facilities.

SECTOR DEVELOPMENT TO 2030

For the chemical industry, oil-based chemistry will still be dominant in 2030. However, the industry will use a growing proportion of renewable raw materials. By 2020, agri-food by-products and agricultural waste will become more commonly used. In 2030, as a logical step towards sustainability and eco-efficiency, we can expect a majority of the biomass used in the chemical sector to come from waste, agri-food by-products and dedicated feedstocks.

Based on USDA/OECD figures (as shown in Table 2) the biobased share of global chemical production is expected to reach 22-28% in 2025, and we can expect a gradual increase subsequently, with a share of perhaps 30% by 2030.

Biobased chemicals

In 2030, many key chemical intermediates will be produced from biomass using a biological and/or chemical process. These biobased intermediates can then be used in a range of downstream processes, such as the production of solvents and polymers.

Biobased materials and polymers

Most high-performance polymers will also be produced from biomass. These biobased polymers will be competitive with the petrochemical route and in many cases will even offer higher performance and permit new applications. Because of higher costs, it is likely that this major evolution of the industry will have a smaller impact on mass market products and commodities such as high volume polymers (e.g. PE and PP) or their corresponding monomers (ethylene and propylene). These chemicals will still largely be fossil fuel-derived or be imported from countries where biomass raw material cost is low (e.g. Brazilian sugar cane).

The sugar used as a raw material for biotech processes will come first from food starch or sugar crops and then increasingly from the hydrolysis of lignocellulosic biomass. And for cellulosic bioethanol production, the lignin by-product will form the basis of a new process stream for commercial production of fibres, polymers and aromatic molecules.

A number of new biocatalysts and advanced fermentation processes will be developed: these will be faster, less expensive and more versatile than comparable chemical catalysts. Many processes will rely on speciality enzymes tailored to specific production processes and environmental conditions.

In summary, biobased chemistry will become an economic reality. Processes using starch and plant oils will have become more efficient and enjoy larger market shares. Significant moves to biobased products will occur first in **speciality products and niche markets** where the returns are higher, but as technology evolves and production costs drop, they will gradually move into bulk markets.

A number of technologies can contribute to the development of competitively priced bulk chemicals from biomass, in particular:

- New biotech-based anaerobic fermentation processes, using low cost sugars[48]
- Using molecules from biomass which are structurally related to the target chemicals and converting them via chemical or biological processes will help reduce both the number of process steps and the energy requirements[49]
- Genetic modification of plants to express bulk chemicals or their precursors (e.g. lysine and itaconic acid in potato)[50]

BOTTLENECKS AND STEPS TO BE TAKEN TO 2030

According to the USDA, biobased chemicals will make up 30% of the chemical sector by value by 2030. However, this share will not be reached with a "business as usual" approach. Instead, it requires a strong commitment from industry, policymakers and the research and innovation community.

Development will need to focus on:

- Resource efficiency and the development of renewable alternatives
- New routes for cost-competitive plug-in building blocks from biomass
- Improving competitiveness and increasing availability of biomass feedstock, for example by breeding better-adapted, dedicated crop varieties, pre-processing/compaction of biomass for more efficient transport, and more efficient processing of lignocellulosic biomass
- Reducing the costs of biological processing through increased efficiency and the integration of processes to minimise energy, water, and raw material use
- Integrating chemical and biological processing steps
- Exploiting specific molecular structures from plant components
- Developing biotech crops which express useful intermediate chemicals.

	2005			2010			2025		
Chemical sector	**Total value**	**Biobased value**	**Biobased share (%)**	**Total value**	**Biobased value**	**Biobased share (%)**	**Total value**	**Biobased value**	**Biobased share (%)**
Commodity	475	0.9	0.2	550	5-11	0.9-2.0	875	50-86	50-86
Speciality	375	5.0	1.3	435	87-110	20.0-25.3	679	300-340	44.2-40.1
Fine	100	15.0	15.0	125	25-32	20.0-25.6	195	88-98	45.1-50.3
Polymer	250	0.3	0.1	290	15-30	5.2-10.3	452	45-90	10.0-19.9
All chemicals	**1,200**	**21.2**	**1.8**	**1,400**	**132-183**	**9.4-13.1**	**2,183**	**483-614**	**22.1-28.1**

Table 2: Projected value of world chemical production 2005, 2010 and 2025[47]

Note: values in billion USD

Towards biorefineries in 2030

Possible biorefinery development routes

The main variables which differentiate potential routes for the development of biorefineries up to 2030 are:

- Integration of biorefining into existing industrial value chains (bottom-up approach) *or* development of new industrial value chains (top-down approach)
- Upstream *or* downstream integration
- Feedstock: biomass produced locally *or* imported biomass or intermediates
- Biorefinery scale

Existing or new value chains?

In 2030 there will be many large-scale biorefineries. Most of these will have developed through integration into existing industrial value chains (bottom-up approach).

Different types of biorefinery will be developed based on specific sector requirements or geographical constraints (biomass type, quality and availability, infrastructure, local industries etc.). The choice of technology options (processes, feedstocks, location and scale) for each biorefinery will be made by the owners and operators, based on their particular competitive advantages (available industrial equipment, technological and industrial know-how or access to biomass, for example). Biorefinery development will be driven by the demands of leading players from the sectors that were described in Chapter 2 (agro-industries, forest-based industry, the energy and biofuels sectors and the chemical industry).

However, another interesting possibility is that biorefineries may develop as part of new industrial value chains (top-down approach). These would be newly developed, highly integrated, zero-waste sites that can produce a broad variety of products for different markets from a range of pre-treated and pre-separated (lignocellulosic) biomass fractions. Usually, the whole biomass crop would be used (e.g. woody material, cereal grain and straw, fresh grass). At present, this approach is still largely at the pilot or demonstration stage (e.g. a lignocellulosic biorefinery in Leuna, Germany). However, further research and development will lead to commercial scale operations by 2030. Ideally these biorefineries for new industrial value chains should be developed in an existing industrial park to profit from the existing infrastructure.

Clearly, the sustainability and competitiveness of the different value chains will depend on close collaboration with the industrial sector supplied, together with highly integrated production processes.

Upstream or downstream integration?

The integration of biorefineries into industrial value chains (whether existing or new) will be driven by either upstream players (producers and transformers of biomass), or downstream customers (producers of intermediates and final products). Whichever is more important will help shape the biorefinery network and especially its location: either closer to the biomass supply or closer to the distribution network and final market.

Biomass supply: local or imported?

There will be a range of biorefinery types in Europe, sited where their particular biomass requirements can be easily supplied.

- Biorefineries based on wood (locally produced biomass) are likely to be developed in Northern Europe or in densely forested rural area in Western, Central and Eastern Europe ("Mid-Europe").
- Biorefineries based on typical agricultural crops (cereals, sugar beet, oilseeds and dedicated non-food crops) are likely to be developed in rural areas of Mid-Europe.
- Biorefineries based on imported biomass will be established mainly in or very near to large ports (such as Rotterdam).
- The development of biorefineries in Southern Europe is more difficult to predict. They could be either near ports or develop in rural areas if appropriate dedicated crops are grown.

The BIOPOL (2009) project gave some predictions about the most likely regions for biorefinery development based on biomass availability and supply. The main conclusions were: "Western Europe has the best prospects for biorefinery development. It has: high agricultural yields, vast amounts of lignocellulosic agricultural side streams, considerable forestry and good possibilities for the marketing and sale of biorefinery-based side products. Countries in the East of Europe have good opportunities to improve agricultural yields. Thus they could become interesting countries for biorefinery establishment. Northern Europe is currently a natural market leader of lignocellulosic biorefinery due to the presence of large forests.

Biorefinery scale

The optimal scale for each biorefinery will depend on constraints such as logistics, production costs and the minimum size of individual processes. Scale will have a major impact on the types of industrial biorefinery and their geographical distribution:

- Large-scale integrated biorefineries, mainly based on thermochemical process, are likely to emerge in Northern Europe and/or be associated with large ports.
- Small/medium scale integrated biorefineries, mainly based on biotech processes, are likely to emerge in rural areas across Europe.
- Decentralised biorefineries will also emerge in all regions, as a consequence of the development of a network of pre-treatment units.

Scale also has a major impact on technology choice and industrial strategy. Basically, there are three possibilities:

- Small/medium-sized production facility
- Medium/large production facility linked to a network of decentralised primary processing plants (biomass fractioning and/or concentrating units). Low cost, decentralised pre-treatment plants (e.g. fast pyrolysis, torrefaction) combined with centralised biorefineries improve the overall biomass supply chain. High energy density feedstocks overcome low density biomass problems, can be transported further at an acceptable cost and can be processed in bigger biorefineries to take advantage of economies of scale.
- Very large production facility, located near a port and using mainly imported biomass

Fast pyrolysis liquids could also be co-fed to processes in conventional refineries, taking advantage of economies of scale.

Biorefinery concepts in 2030

Some of the more traditional types of biorefinery have already been established on an industrial scale and these were described in Chapter 2 (covering the current situation in the different industrial sectors). They are based on an extension and/or upgrading of existing industrial plants. However, other, newly emerging biorefinery concepts will be developed and implemented by 2030. In 2011, they are still only in the research, development or pilot/demonstration stage.

The next sections describe the main biorefinery concepts (both existing and new) that we envisage being used in 2030. Of course, many variations (and even combinations) of these individual concepts are possible. No unique biorefinery type is described for processing waste (e.g. municipal waste), because this raw material stream is assumed to be integrated into some of the other biorefinery types.

Starch and Sugar Biorefineries

DESCRIPTION

The starch and sugar biorefinery processes starch crops, such as cereals (e.g. wheat or maize) and potatoes, or sugar crops, such as sugar beet or sugar cane. In Europe, the main application of this biorefinery is currently the production of starch derivatives, ethanol and organic acids, with the protein stream being used for food and feed and other co-products mainly going to animal feed, according to the section on biorefinery concept Figure 10 shows the processes schematically.

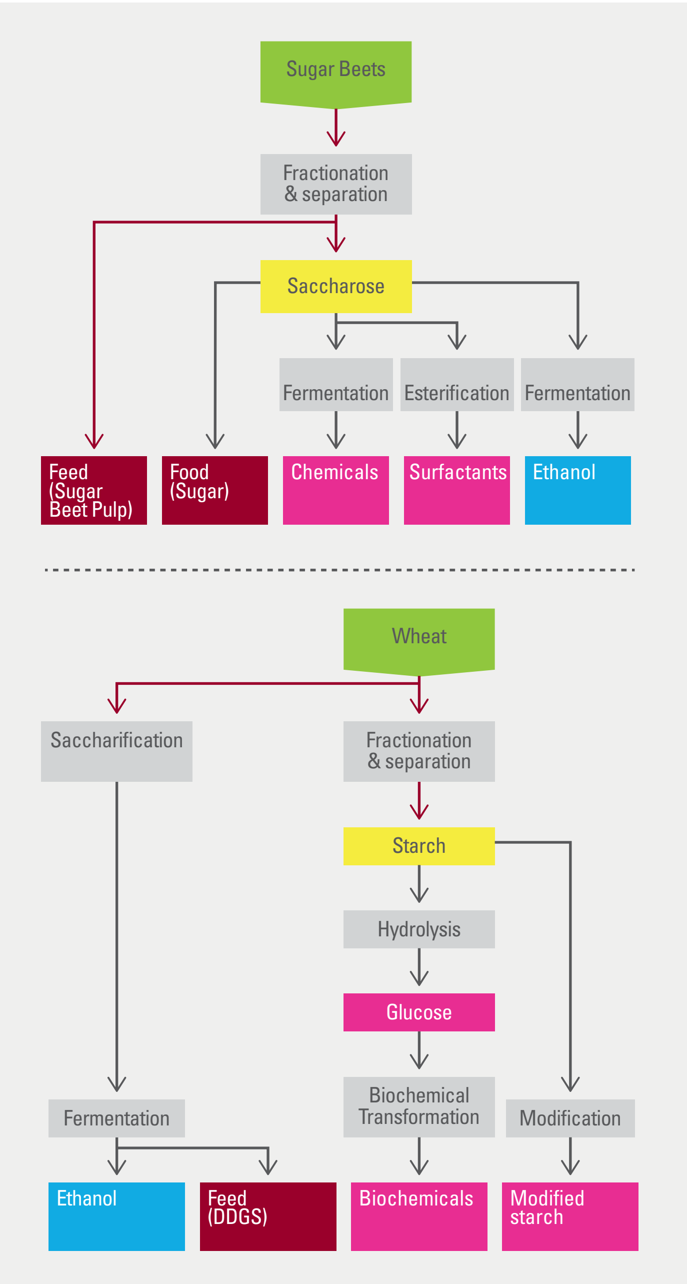


Figure 10: Schematic diagrams of Sugar Biorefinery (top) and an example of a Starch Biorefinery (bottom) (modified from IEA Bioenergy Task 42 Biorefinery systemetics [51])

This model is likely to remain largely unchanged up to 2030, although by then it will be dealing with a greater range of feedstocks and products. Starting from a process stream based on starch and sugar crops, the plants will progressively use lignocellulosic feedstocks and integrate the fractionation processes by 2030. The first step will be the integration of cereal straw into the supply chain, followed by the use of dedicated lignocellulosic crops (mainly arable).

There will be a diversification of products from sugar and starch-derived C6-sugars (hexoses) towards other alcohols, chemicals and organic acids, as new biological and chemical processes to produce platform chemicals become available and competitive. A specific route currently under development, and likely to be commercialised by 2030, is the fermentation of sugar to lipids, which could be used by the oleochemical industry or to produce jet fuels, providing further integration potential between existing value chains.

With the introduction of lignocellulosic feedstocks, co-products of lignocellulose degradation will become more valuable: mainly lignin, C5-sugars (pentoses) from hemicellulose and C6-sugars, mainly from cellulose. The lignin will initially be used as an energy source by co-generation, and later might begin to be used as the feedstock for processes based on new chemistry. Pentoses will first be converted into ethanol. However, the yield is limited, and the development of a new C5-chemistry (by biotech and/or chemical processes) might allow the production of higher value chemicals (2020-2025 horizon). C6-sugars will not only be used for production of bioethanol or higher alcohols, but will increasingly be converted by fermentation and chemical processing to other, higher value chemicals. This development is likely to occur several years after the C5 switch (2025-2030) as the European market for bioethanol will still be increasing during this period.

POSSIBLE DEVELOPMENT ROUTES

Agro-industries have long been involved in sugar extraction, starch fractionation, fermentation and distillation. With this level of expertise, they can easily integrate biotech processes for first and second generation bioethanol and, at a later stage, other fermentation products.

The feedstock quantities used at each biorefinery location are in the range of 200,000 to 400,000 tonnes/year of dry biomass. These requirements should be met from locally produced feedstock, which makes for easier management of sustainability parameters in the overall production chain (carbon sequestration, nitrogen and other mineral nutrient cycles).

This model will lead to the development of small/medium scale rural biorefineries close to agricultural areas producing the required biomass. These rural starch and sugar biorefineries will be established in the most efficient production and supply areas. "Mid Europe" (from West to East Europe) is ideal for this.

Small-scale biorefineries that produce ethanol, biogas and protein for animal feed or human food are being developed at a scale of 10,000-50,000 tonnes of primary dry weight inputs[52].

Starch and sugar biorefineries may also be located at major centres for grain and sugar import. These are likely to focus on product diversification rather than the integration of lignocellulosic streams.

Oilseed Biorefineries

DESCRIPTION

Oilseed biorefineries (Figure 11) currently produce mainly food and feed ingredients, biodiesel and oleochemicals from oilseeds such as rape, sunflower, and soybean.

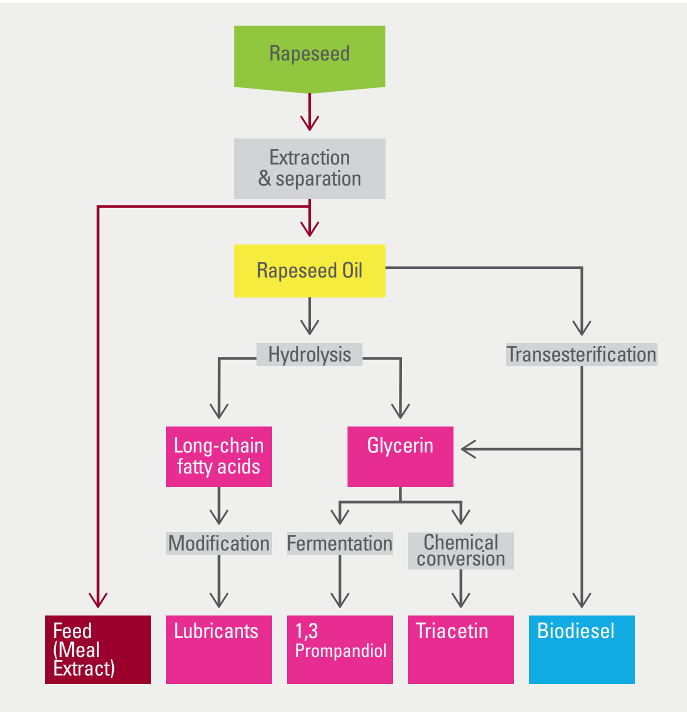


Figure 11: Schematic diagram of an example of an oilseed biorefinery. According to IEA Bioenergy Task 42 Biorefinery systemetics[53] modified by German Agency of Renewable Resources (FNR)

POSSIBLE DEVELOPMENT ROUTES

The oilseed agro-industry will change significantly over the next twenty years. In 2011, the major focus is on first generation biodiesel and the development of oilseed biorefineries with multiple product streams. With glycerol as the major by-product, a clear target is to develop an integrated process stream to make value-added products from this raw material. However, the development of oilseed biorefineries by 2030 will feature the introduction of new oleochemical process streams, based on long chain fatty acids from European oilseeds (mainly rapeseed and sunflower) and the progressive integration of these processes into the biodiesel production chain. This trend will be reinforced by the continuing evolution of European biofuel production, in particular the decreasing relative importance of first generation biodiesel due to its inefficient use of farmland.

With decreasing financial support for biofuels, and higher environmental constraints, it is likely that small-scale production of biodiesel from oilseeds will disappear or be used only for local energy requirements (e.g. for farms or rural communities). At the same time, medium/large scale production will increasingly focus on higher added-value applications such as jet fuels and oleochemicals.

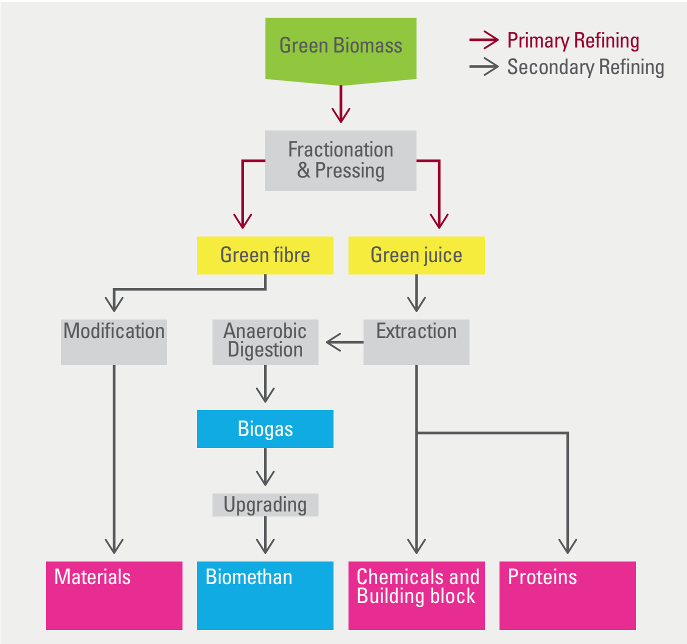


Figure 12: Schematic diagram of a green biorefinery[55]

Green Biorefineries

DESCRIPTION

A green biorefinery processes wet biomass, such as grass, clover, lucerne or alfalfa. This is pressed to obtain two separate product streams: fibre-rich press juice and nutrient-rich pressed cake (see Figure 12). The pressed cake fibres can be used as green feed pellets or as a raw material for chemical production. The pressed juice contains valuable compounds such as proteins, free amino acids, organic acids, minerals, hormones and enzymes. Lactic acid and its derivatives, ethanol, proteins and amino acids are the most profitable end-products which can be made from this stream[54]. The pressed juice residues are mainly used to produce biogas, itself then used to generate heat and electricity.

POSSIBLE DEVELOPMENT ROUTES

A current example of a pilot facility for the green biorefinery concept is the production and demonstration plant operated by Biowert GmbH in Brensbach, Germany. In this facility, insulating material, reinforced composites for production of plastics and biogas for heat and power are all produced from grass in an integrated process.

In 2030 many of these smaller-scale green biorefineries will be set up, as new industrial value chains are established in regions that traditionally produce high quantities of wet biomass, such as grassland areas.

Lignocellulosic Biorefineries

DESCRIPTION

In 2030, biorefineries processing a range of lignocellulosic biomass will be well established. There are two primary process routes: thermochemical and biochemical (see Figure 13).

The **thermochemical** approach uses heat to convert lignocellulosic feedstocks to syngas, which is then used to produce transport fuels and chemicals. Many different biomass types will be used as feedstock for this type of biorefinery: dry agricultural residues (e.g. straw, peelings, and husks), wood, woody biomass, and organic waste (e.g. waste paper, residues from waste paper pulping and lignin). These are relatively dry biomass feedstocks and well-suited for new thermochemical conversion processes such as gasification. Vegetable oils are also suitable feedstocks. Depending on the heating conditions, so-called pyrolysis liquids or pyrolysis oil can also be formed. These are easy to handle (with good storage, atomisation and pressurisation properties) and transport and can be used as liquid fuels.

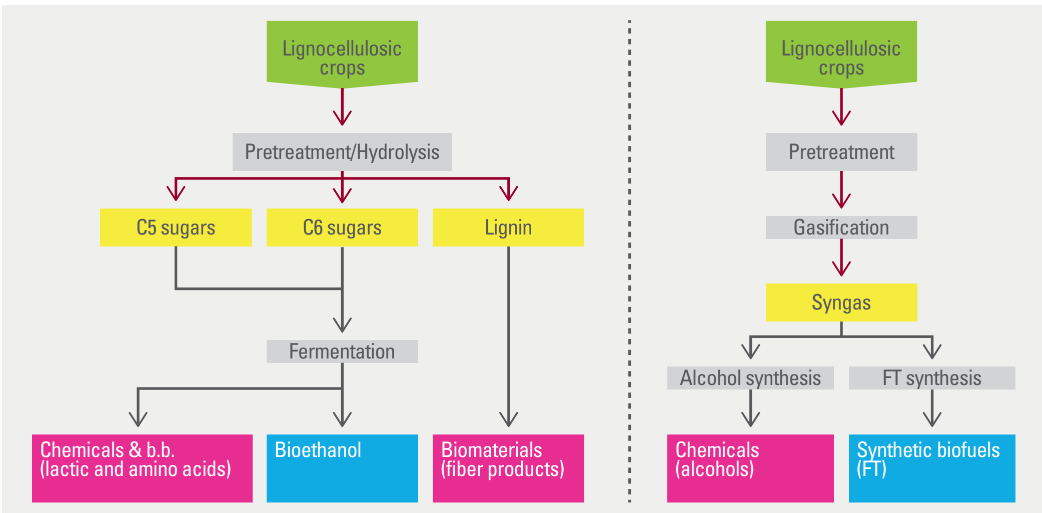


Figure 13 : Schematic diagram of the biochemical approach (*left-hand side*) and the thermochemical approach (*right-hand side*)[56]

Another option is the **biochemical** approach which uses a primary biological refining step to fractionate lignocellulosic raw material into three separate raw material streams: cellulose, hemicellulose and lignin. These fractions then go into three separate process streams and are converted into value-added products. Cellulose can be hydrolysed to produce sugars which are then used as a fermentation substrate to make alcohols (e.g. ethanol), organic acids and solvents. The hemicellulose fraction can be converted to xylose, gelling agents, barrier agents, furfural and, further downstream, to nylon. Finally, lignin can be used to make binders and adhesives (glyoxalised lignin, for example, is being studied as a potential alternative to formaldehyde-containing resins for applications such as fibreboard panels). Alternative uses are the production of fuels or carbon fibres and as a feedstock for syngas production, itself a valuable feedstock for a range of uses.

NATURAL FIBRES

In 2005 (the latest year for which figures are available) 40,000 — 50,000 tonnes of biobased composites (not including wood) and 30,000 tonnes of natural fibres were used in the European automotive industry. Raw materials were about 65% flax and 10% hemp from Europe, with imports accounting for the remaining 25%. Compression moulding using a 95:5 ratio of fibre to resin is the dominant processing technology, used to produce a range of lightweight, high-quality components.

A second category of successful products is hemp-based insulation materials. In the European Union, 3,000 to 4,000 tonnes are produced and used annually, mainly in Germany, France and the UK.

POSSIBLE DEVELOPMENT ROUTES

The forestry-based pulp and paper industry has long experience of the logistics of production and use of woody and lignocellulosic biomass. It is therefore a good candidate for the introduction of thermochemical (gasification) processes, to convert woody biomass (forest biomass and residues or dry organic waste) to second generation biofuel and/or chemicals from syngas. The industry also has access to a large amount of lignin, which is currently mainly used as an energy source. Greater value will be obtained by integrating processes for the chemical conversion of lignin. An in-depth study of lignin structure is needed to make the most of this raw material.

Agriculture is another source of lignocellulosic biomass. A range of agricultural residues and dedicated crops will be processed in lignocellulosic biorefineries, either as part of newly-developed industrial value chains, or to provide additional raw material streams for sugar/starch biorefineries. Agricultural lignocellulosic crops and residues are more likely to be processed via the biochemical route. It is assumed that the technical and economic barriers to lignocellulosic biomass fractionation will be solved over the current decade, and that both approaches will lead to commercially-viable lignocellulosic biorefineries by 2030.

In 2030, oil companies will have invested heavily in large-scale industrial biorefineries based on thermochemical processes at their existing oil refinery sites, located near major European ports. The required biomass will be imported as well as being locally-sourced. The oil companies will also be interested in hydrogen from syngas for hydrogenation of heavy crude oil. The gasification units will also be used to produce higher-value chemicals by catalytic processes.

Feedstock represents a large fraction of biorefinery operating costs, with the total amount needed determined by the scale of the biorefinery. Production costs are tied to land values and the profitability of alternative crops influences the willingness of farmers to grow them. Biorefineries will only be built when provision of feedstock can be guaranteed, which means that farmers need to be persuaded to devote their land to non-food crops for decades. This requires the establishment of a sustainable value chain, which combines security of supply with an adequate return for farmers.

Aquatic (marine) Biorefineries

DESCRIPTION

Aquatic biomass (micro-algae and seaweed) is an interesting new biorefinery feedstock, characterised by high productivity and a high content of valuable components, including lipids, proteins, polysaccharides and other specific biomolecules (see Figure 14). Aquatic biomass cultivation and processing are integrated into regional or local supply chains. The varied composition of micro-algae and seaweed makes them highly suitable feedstocks for biorefining, with end-products ranging from fuels and bulk chemicals to speciality chemicals and food and feed ingredients.

ALGAE

Micro-algae, like some other microorganisms and plants, produce storage lipids in the form of triacyglycerols (TAGs). These can be used to synthesise fatty acid methyl esters, used as biodiesel. Micro-algae represent a very attractive alternative to terrestrial oilseed crops because of their higher productivity and the fact that they are not grown on arable land. Other attractive features are their unique composition, including the ability to accumulate large quantities of oils, and the great variety of species and possible end-products. Algal cultivation can also be combined with waste water treatment systems, and use of CO_2 from flue gas and sources of low-temperature waste heat.

Typical products made from micro-algae include:

- Oils for food applications, including nutraceuticals such as omega-3 fatty acids
- Oils and derivatives for non-food applications such as transport fuels and chemicals
- Proteins and derived products (amino acids and other nitrogenous chemicals)
- Other bulk chemicals (e.g. ingredients for coatings)
- A range of speciality high value products

SEAWEED

The cultivation of seaweed could be a significant source of biomass in the future. Terrestrial biomass for the production of fuels, fibres and other products may be limited because of competition with food production. Expansion of biomass cultivation to the sea would increase both the total availability for non-food and non-feed purposes and the potential share of biomass in the future renewable energy supply.

POSSIBLE DEVELOPMENT ROUTES

In 2030, several commercial biorefinery concepts for integrated algae- and seaweed-based production chains will exist for:

- Feed for aquaculture, including recycling of nutrients
- Production of food or food ingredients and co-products
- Biofuels and co-products

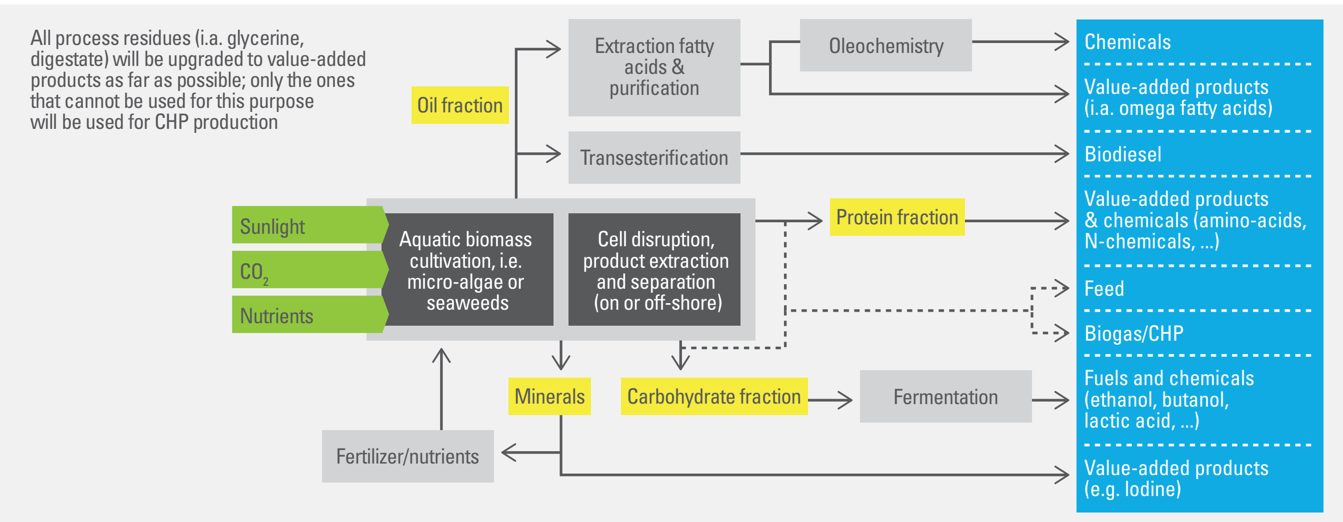


Figure 14: Schematic diagram of an aquatic (marine) biorefinery[57]

They will most likely be developed from new industrial value chains and be based close to the algae production area (coastal or inland). Algal biorefineries dedicated to food/feed production will be small units, whereas those for biofuel production will probably be medium scale. However, some algal processing might be integrated into oil-based biorefineries, as part of feedstock diversification (especially for diesel and oleochemicals production).

The development of micro-algae technology by 2030 will require large research programmes and the aquatic biorefinery concept will be a very important part of this. Significant R&D will be needed to optimise yields and enable the projected improvements in land and water use efficiency to be realised. Current constraints on algal biomass production include the suitability and availability of low-cost land, a suitable climate for algae growth and the cost and efficiency of harvesting. Using CO_2 emitted by, for example, power plants to boost algal growth may be advantageous both to increase productivity and as a contribution to greenhouse gas emissions reduction.

For aquatic biomass, several biorefinery processes seem to be appropriate. The choice of processing route will depend on the type of feedstock (different seaweed species) and the possibilities for process integration. Hydro Thermal Upgrading (HTU, heat treatment to increase the energy density of wet biomass), anaerobic digestion to methane, and fermentation to produce ethanol are some possible processes[58].

Molecular farming to provide new feedstocks for biorefinery

DESCRIPTION

Molecular farming is a system which uses plants to produce value products (for example human proteins and other therapeutic proteins) together with co-products for feed and non-food uses. With traditional systems based on microbial or animal cells, or transgenic animals, plants provide an inexpensive and convenient system for the large-scale production of valuable recombinant proteins without compromising product quality or safety. Plant seeds and fruits also provide naturally sterile packaging for valuable therapeutics and guarantee an extended storage life. Another advantage of plants is that no plant pathogens are known to infect humans.

The potential of this approach has been demonstrated over the last 15 years through the sustained efforts of a growing number of European research groups and by the commercial success of several first generation products, launched into established market sectors[59] (see Figure 15). Several plant-derived biopharmaceutical proteins are in the penultimate stages of commercial development. These include antibodies, vaccines, human blood products, hormones and growth regulators[60]. Valuable intermediates such as lysine and itaconic acid have been expressed in GM potato[61].

POSSIBLE DEVELOPMENT ROUTES

With an increasing number of products in development, molecular farming in plants will have come of age in 2030. There will be a move beyond R&D to applications and the development of product-oriented platforms, enabling the commercialisation of new classes of products. This will create new opportunities for European agriculture and related sectors as the plants used for molecular farming are new high-value crops.

However, several constraints that hinder the widespread use of plants as bioreactors remain to be addressed. These include the quality and homogeneity of the final product, the challenge of processing plant-derived pharmaceutical macromolecules under good manufacturing practice (GMP) conditions, and concerns about safety. Molecular farming in plants will only realise its huge potential if these constraints are properly addressed and overcome through rigorous scientific studies.

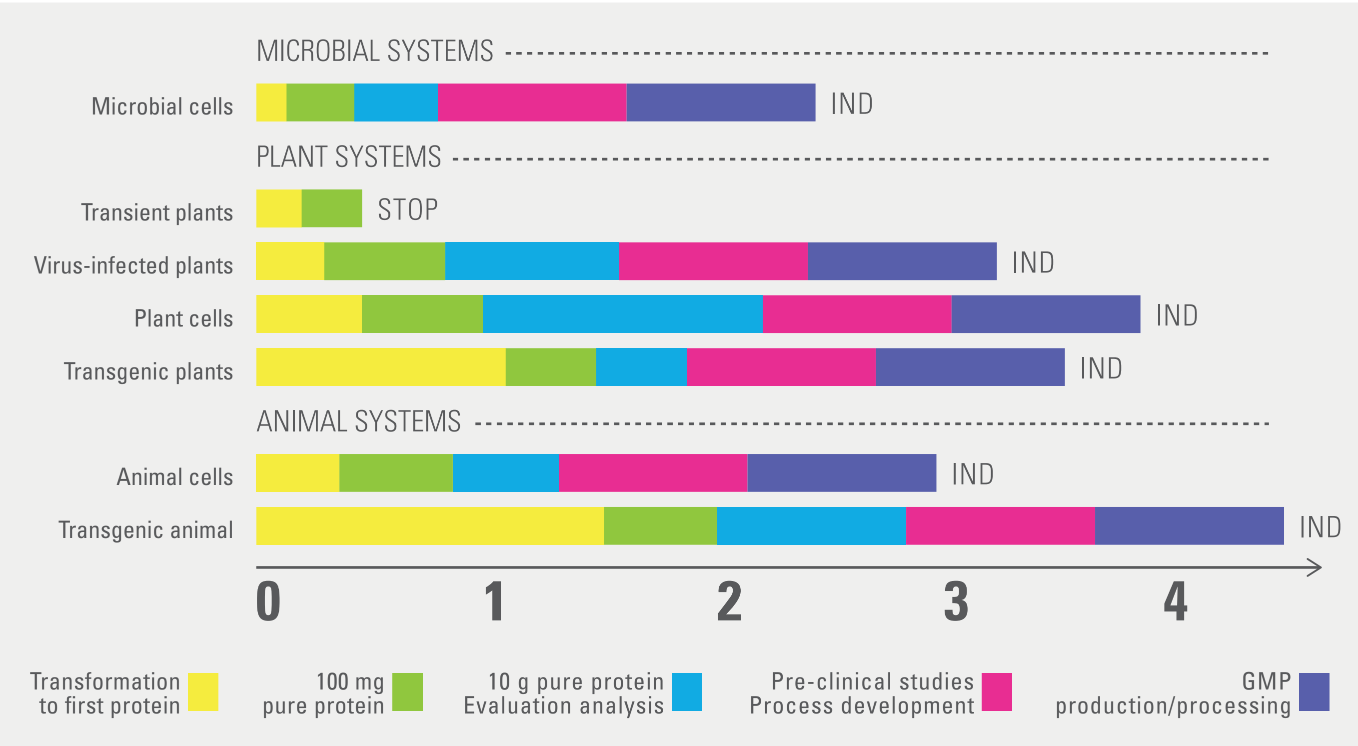


Figure 15: Performance of plant-based production systems in comparison to other commercial platforms for the production of recombinant proteins. [abbreviation: IND, Investigational New Drug] [62]

The commercial success of molecular farming depends on technology, economics and public acceptance. The most significant driver of the new sector is the expected reduction in production costs, which will have significant knock-on effects on the overall biopharmaceutical market, and little market resistance is expected. At present, European politicians and the public seem unwilling to accept biotechnology-derived foods, but biopharmaceuticals are more likely to meet with approval. The enforcement of strict regulatory measures will help with this, but the fact that molecular farming is not intended for crops destined for the food chain is probably the biggest factor.

Although still in its infancy, the molecular farming sector has already enjoyed considerable growth and has attracted a large amount of investment. At present, it comprises around a hundred small companies, each focusing on the development of a few products. In some cases, there are already productive collaborations with pharmaceutical companies, such as the agreement between Meristem Therapeutics and Solvay Pharmaceuticals to develop plant-derived human gastric lipase.

Despite the current regulatory framework being unclear, plus a general industry inertia, the molecular farming route to plant-derived pharmaceuticals is now bringing the prospect of inexpensive veterinary and human medicines closer than ever before. We assume that the constraints that hinder the widespread use of plants as bioreactors will be overcome through rigorous and detailed scientific studies in the current decade, and that commercially viable molecular farming feedstocks for biorefineries will be developing by 2030, enabling the production of high-value compounds, plus co-products for feed and non-food uses.

Vision 2030

The European Biobased Economy in 2030

EUROPE IN 2030 IS A WORLD LEADING AND COMPETITIVE BIOBASED ECONOMY

The European bioindustry sector in 2030 is innovative and competitive, with cooperation and support between research institutes, manufacturing industry, the forestry and agriculture sectors and the support of civil society.

All links in the value chain profit from this flourishing Biobased Economy.

The success of European biobased industry comes from being a world leader in efficient and flexible utilisation of biomass while having a strong focus on added-value products.

By 2030, a significant proportion of the overall European demand for chemicals, energy, materials and fibres is fulfilled using biomass as a feedstock for biorefining technologies:

- 30% of the chemicals market is biobased. For high added-value chemicals and polymers (specialities and fine chemicals), the proportion is more than 50% but less than 10% of bulk commodity chemicals are derived from renewable feedstocks.
- 25% of Europe's transport energy needs are supplied by biofuels, with advanced biofuels — especially biobased jet fuels — taking an increasing share.
- The European market for biobased fibres and polymers such as viscose, carbon fibres, nano-cellulose derivatives and bioplastics will continue to grow rapidly over the coming decades. Traditional fibre products such as paper remain 100% bio-based.
- A new generation of biobased materials and composites produced in biorefineries reduce weight and allow other improvements to components for industries including automotive and construction.
- 30% of Europe's heat and power production is based on biomass.

This vision is summarised from the point of view of the different Technology Platforms in Figure 16.

The European Biorefinery Vision 2030

A WIDE SPECTRUM OF COMPETITIVE BIOBASED PRODUCTS COMES FROM BIOREFINERIES

In 2030, Europe is a Biobased Economy in which biorefineries play an important role. Full-scale, highly efficient, integrated biorefineries allow competitive manufacturing of high-value biobased products.

There is a range of biorefinery types utilising many different types of biomass feedstock and various technology options.

VERSATILE BIOMASS SUPPLY CHAINS FOR BIOREFINERIES

A diverse and flexible biomass production sector supplies biorefineries with a wide variety of agricultural crops, residues (agri-food or urban waste, forestry and agricultural by-products) and dedicated lignocellulosic crops (including forest biomass) together with an increasing volume of algal and aquatic biomass.

Europe's capacity for sustainable production of biomass has increased due to the introduction of new and improved crops, investments in Central and Eastern European agriculture, and new policy, training and cooperation incentives. In addition, Europe's many millions of small-scale, family owners of woodland harvest their wood more efficiently and profitably, contributing more to the European biomass supply.

The demand from biorefineries will help drive further efficiency improvements in the production of food and feed crops.

Europe's versatile biomass feedstocks are an asset to a flexible and resilient biorefinery sector.

A REVITALISED, COMPETITIVE AND KNOWLEDGE-INTENSIVE RURAL ECONOMY BASED ON BIOREFINERIES

European industries have developed an extensive network of regional/rural biorefineries producing food, biofuels and numerous biobased products from local biomass in a sustainable way. This has led to significant economic growth and created millions of jobs in rural areas.

Innovative high-tech companies are prospering around larger regional biorefinery units. They specialise in producing a range of high-value products from biomass fractions and side-streams coming from the main biorefinery process and create skilled jobs in rural areas. Decentralised, small-scale biorefineries are also part of this development.

GROWING INTEGRATION OF BIOBASED INDUSTRIAL SECTORS

Integration of supply and manufacturing chains and increased collaboration between innovative players from traditional industries such as the chemical, energy, agriculture and forestry sectors combine the key strengths of each sector, creating the critical mass to attract investors, policymakers and young talent. This has become the basis for maximising the value added to biomass streams.

An open and collaborative approach creates synergies in education, research, development and innovation throughout the biorefinery value chain.

Most biorefineries are closely integrated with traditional biomass processing industries. However, some have been established to exploit new value chains, such as aquatic/marine biomass.

A FOCUS ON SUSTAINABLE PRODUCTS GIVES EUROPE A COMPETITIVE EDGE

A long-term focus on sustainability and "green" products has given European companies a competitive edge in the global market by 2030.

A combination of progressive standardisation, an environmentally aware consumer base and widespread eco-labelling ensures that European biobased products are developed to be as sustainable as possible throughout the full product life-cycle. They are designed to be recyclable, biodegradable, or to be used to generate bioenergy at the end of life. They are manufactured using non-polluting biorefinery production processes.

Biorefineries are highly energy-efficient and make use of mostly zero-waste production processes. They allow European industries to manufacture environmentally-friendly products with small carbon and water footprints.

VERSATILE BIOREFINERY DEVELOPMENT ROUTES

Particular biorefinery technologies will have been used as necessary to provide optimised processing solutions for specific feedstocks and end products. The development of biorefineries will of course always remain an enabling technology concept and not a goal in itself.

Flexibility is key. This means processing technologies that can deal with multiple biomass feedstock streams either within a single process or through a combination of several integrated ones. This allows the production of a broad spectrum of valuable, marketable products.

Economic constraints dictate that biorefineries need to be operated efficiently and at low cost. Sustainability criteria also still drive their continued development.

MANUFUTURE – AGRICULTURAL ENGINEERING AND TECHNOLOGY PLATFORM (AET)[63]

- European agricultural technology for field work and livestock husbandry leads the world. Electronics, automation and robotics are widely used. Wireless communication technologies offer access to dispersed farming facilities and link them to decentralised web-based processing and information sources.
- Renewable energy sources like biobased fuel and hydrogen (for fuel cells) are widely used. New power train systems include decentralised electric drives. Tractors and self-propelled farm machinery are fully automated. Automatic data gathering for documentation purposes and for improved farm management is a fundamental component in all farm equipment technologies.
- Harvesting technology has changed from the simple collection of field crops to on-the-go pre-processing or quality-dependent sorting into different hoppers, even for animal feed.
- The technology associated with cattle, dairy, pig and poultry husbandry has changed to networked systems. Sensors are used to monitor behavioural parameters as well as health and fertility.

PLANTS FOR THE FUTURE TECHNOLOGY PLATFORM[64]

- More of our economic prosperity in 2030 will be based on agricultural produce. Not only will farmers supply a larger population, but much of the economy will also be based on the crops they grow to provide new foods, biofuels, and biomaterials. They will become the gatekeepers of the Biobased Economy.
- Scientific and technological progress, especially in plant biotechnology and genomics, will have to play a role in achieving this transition, in particular to cope with the constraints of limited availability of arable land, climate change and increased seasonal variability of the weather.
- The long tradition of European innovation, coupled with diverse crop types and production methodologies, provides Europe with a good opportunity to develop a larger number of crops that not only perform well across a wide range of climatic zones, but are also able to meet specialised regional needs.
- It is imperative that new technologies can be used to ensure a competitive position for Europe in the emerging global bioeconomy. The overall objective is to transform plants into green factories for the production of biobased chemicals and energy.

FOREST-BASED SECTOR TECHNOLOGY PLATFORM (FTP)[65]

- While playing a key role in a sustainable society, the European forest-based industries have doubled the value added from their services and products. At least 50% of the increase originates from products not yet in production.
- The growth rate in European forests has increased by 20% through better adherence to good forest management practice.
- Energy-efficiency has increased by at least 25% from 2010 levels, and the sector has become completely independent of fossil fuels.
- Growth has been fuelled in a number of ways: the development of new chemicals, biofuels and materials as well as improved functionality of existing materials; textiles and speciality fibres derived from wood form a growing global market segment; new concepts for building with wood have considerably increased market share for sustainable construction materials in Europe; new multi-functional products for packaging, printing and communication provide added value for the consumer, the environment and society as a whole.

SUSTAINABLE CHEMISTRY TECHNOLOGY PLATFORM – INDUSTRIAL BIOTECH (SUSCHEM IB)[66]

- Providing the innovative drive for Europe. Chemistry does not just deliver raw materials; it is a major source of innovation in areas from clothing to energy, electronics and pharmaceuticals.
- Investing for sustainable development. Chemistry improves the eco-efficiency of products and processes to optimise the use of resources and minimise waste and environmental impact.
- In 2030 an increasing number of chemicals and materials will be produced using biotechnology in one or more processing steps. Biotechnological processes are used to produce chemicals and materials impossible to make by conventional means, as well as making existing products in a more efficient and sustainable way.
- Biotechnology allows for the increasingly eco-efficient use of renewable resources as raw materials for industry, and enables a range of sectors to manufacture products in an economically and environmentally sustainable way.
- European industry will be innovative and competitive, with sustained cooperation and support between the research community, industry, agriculture and civil society.

EUROPEAN BIOFUELS TECHNOLOGY PLATFORM (EBTP)[67]

- Large-scale deployment of biofuels is expected by 2030. Biofuels will maintain and expand their role in heavy duty transport, aviation, and the marine sector.
- The absolute and relative amount of biofuels in 2030 is difficult to predict, as the policy framework will continue to play a key role in market deployment.
- The European Road Transport Research Advisory Council (ERTRAC, 2010) presented the objective of shares of 25% biofuels and 5% electricity in road transport by 2030, together with a 50% more efficient road transport system.
- The implementation of biorefinery concepts in the transport fuel sector reduces the net biofuel production cost by co-producing value-added products from crop and process residues, increasing overall market competitiveness and ecological chain efficiency.

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Electronic versions of our Joint European Biorefinery Vision for 2030 and our European Biorefinery Joint Strategic Research Roadmap to 2020 can be found on our website at:

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Proofreader and editor
Martin Livermore

Design:
Sandy Lemoine — www.studio-moustache.be
Photos — Gerti G. / s11 / Rina H. / KONG / photocase.com

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SEVENTH FRAMEWORK PROGRAMME

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