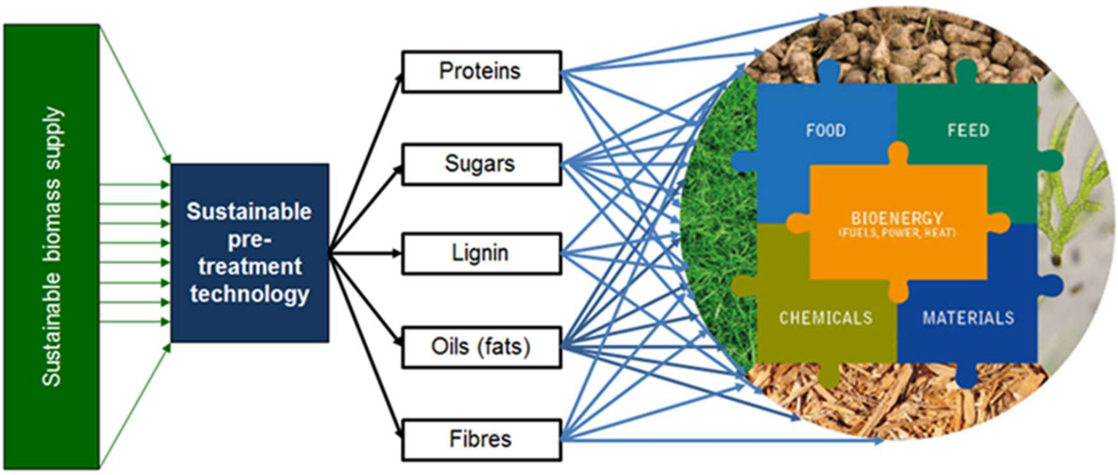
Global biorefinery status report 2022

IEA Bioenergy: Task 42 Biorefining in a circular economy



Global biorefinery status report 2022

Bert Annevelink, Lesly Garcia Chavez, René van Ree & Iris Vural Gursel

With inputs from: Geoff Bell, Michael Mandl, Johannes Lindorfer, Franziska Hesser, Xaver Hilz, Tobias Stern, Solange Mussatto, Heinz Stichnothe, J.J. Leahy, Isabella De Bari, Vincenzo Motola, Aristide Giuliano, Ed de Jong, Johanna Mossberg & Mark Shmorhun

IEA Bioenergy: Task 42 Biorefining in a circular economy

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Summary

The aim of IEA Bioenergy Task 42 'Biorefining in a Circular Economy' is to facilitate the commercialisation and market deployment of environmentally sound, socially acceptable, and cost-competitive biorefinery systems and technologies, and to advise policy and industrial decision makers accordingly.

The Global Biorefinery Status Report (GBRSR) aims to give an overview of recent biorefinery developments. First of all it is based on a summary of data and information that is reported by the representatives of partnering countries member states in the Task 42 Biorefinery Country Reports. This information was extended with important biorefinery initiatives in other countries outside Task 42. So, the status report gives a description of the current situation of biorefinery in a representative selection of countries: how many biorefineries exist, which types, which feedstocks, which technology, what products, etc.

The overall goal of the GBRSR is to provide a scientifically sound source that will help to accelerate further development and the worldwide market implementation of biorefineries in the circular economy, for example by identifying trends and new developments.

Focus is on IEA Bioenergy member countries. However, also other important countries/ continents are described in a qualitative way. An important part of the GBRSR is an analysis of the deployment status of biorefineries in the different areas of the world. Moreover, the report presents both, major technical and non-technical deployment barriers and applied/potential solutions to tackle these barriers. Furthermore, success stories and case studies are identified, and a list of best practices is set-up to learn from for further biorefinery market deployment.

Chapter 2 helps to further understand the concept of biorefineries. A definition is given, followed by the Task 42 classification system and a description of different biorefinery pathways. In Chapter 3 the biorefinery status in the Task 42 countries is given. Per country the following topics are described: i) major stakeholders, ii) relevant policies and policy implementation, iii) general use of biomass, iv) summary of biorefineries, demonstration and pilot plants and finally v) major innovation activities, RD&I activities and funding. Then Chapter 4 contains an analysis of the global deployment status of biorefineries, based on two databases. The analysis concerns geography, and the four elements that are the basis of the biorefinery characterisation: feedstock, process, platform and product types. Major technical and non-technical biorefinery deployment barriers & potential solutions are addressed in Chapter 5. And finally, several key examples of biorefineries in Task 42 countries are mentioned in Appendix 1.

1. Introduction

1.1 IEA BIOENERGY TASK 42 BIOREFINING IN A CIRCULAR ECONOMY

The aim of IEA Bioenergy Task 42 'Biorefining in a Circular Economy' is to facilitate the commercialisation and market deployment of environmentally sound, socially acceptable, and cost-competitive biorefinery systems and technologies, and to advise policy and industrial decision makers accordingly. Task 42 provides an international platform for collaboration and information exchange between industry, SMEs, GOs, NGOs, RTOs and universities concerning biorefinery research, development, demonstration and policy analysis. This includes the development of networks, dissemination of information, and provision of science-based technology analysis, as well as support and advice to policy makers, involvement of industry, and encouragement of membership by countries with a strong biorefinery infrastructure and appropriate policies. Gaps and barriers to deployment are addressed to successfully promote sustainable biorefinery systems market implementation. More information on Task 42 can be found on the website https://task42.ieabioenergy.com/.

1.2 GLOBAL BIOREFINERY STATUS REPORT (GBRSR)

The Global Biorefinery Status Report (GBRSR) aims to give an overview of recent biorefinery developments. First of all it is based on a summary of data and information that is reported by the representatives of partnering countries member states in the Task 42 Biorefinery Country Reports. This information was extended with important biorefinery initiatives in other countries outside Task 42. So, the status report gives a description of the current situation of biorefinery in a representative selection of countries: how many biorefineries exist, which types, which feedstocks, which technology, what products, etc.

The overall goal of the GBRSR is to provide a scientifically sound source that will help to accelerate further development and the worldwide market implementation of biorefineries in the circular economy, for example by identifying trends and new developments.

Focus is on IEA Bioenergy member countries. However, also other important countries/ continents are described in a qualitative way. An important part of the GBRSR is an analysis of the deployment status of biorefineries in the different areas of the world. Moreover, the report presents both, major technical and non-technical deployment barriers and applied/potential solutions to tackle these barriers. Furthermore, success stories and case studies are identified, and a list of best practices is set-up to learn from for further biorefinery market deployment.

1.3 APPROACH

The GBRSR was written by a team of Wageningen Food & Biobased Research (WFBR) in The Netherlands. A strong connection was made with the Biorefinery Outlook project, in which the authors of the underlying Global Biorefinery were all involved. The main results of the Biorefinery Outlook project are taken as a basis for the GBRSR. Another important source of information were the country reports and updates of IEA Bioenergy Task 42 itself. Furthermore, the national representatives in Task 42 provided specific information for various chapters, such as the key-examples of biorefineries in the various Task 42 countries (Australia, Austria, Denmark, Germany, Ireland, Italy, The Netherlands and Sweden). Not only Biorefineries at a high TRL level were described, but also new developments with a lower TRL level. Also, specific other activities of Task 42 in the previous Triennium (2019-2021) supplied extra information, like Task 42 activity 1.1 (factsheets), activity 2.1 (barriers) and activity 2.4 (database & mapping). Finally, some major initiatives from other countries were included through contacts with former Task 42 members (especially from the USA and Canada). No direct stakeholder consultation was performed for the GBRSR. However, indirectly this was partly covered by the meetings with stakeholders in the Biorefinery Outlook project. Furthermore, the goal of this report is not to make detailed predictions on the future, so no scenarios were developed.

1.4 CONTENT OF THIS REPORT

Chapter 2 helps to further understand the concept of biorefineries. A definition is given, followed by the Task 42 classification system and a description of different biorefinery pathways. In Chapter 3 the biorefinery status in the Task 42 countries is given. Per country the following topics are described: i) major stakeholders, ii) relevant policies and policy implementation, iii) general use of biomass, iv) summary of biorefineries, demonstration and pilot plants and finally v) major innovation activities, RD&I activities and funding. Then Chapter 4 contains an analysis of the global deployment status of biorefineries, based on two databases. The analysis concerns geography, and the four elements that are the basis of the biorefinery characterisation: feedstock, process, platform and product types. Major technical and non-technical biorefinery deployment barriers & potential solutions are addressed in Chapter 5. And finally, several key examples of biorefineries in Task 42 countries are mentioned in Appendix 1.

2. Understanding Biorefineries

2.1 BIOREFINERY DEFINITION

The biorefinery definition formulated by IEA Bioenergy Task 42 is rather broad: **'Biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy'** (Figure 1). Explaining some of the individual components of this definition is needed. 'Biorefining' can be seen as a concept, facilities, processes or clusters of industries. The term 'sustainable' means that the biorefinery has economic, environmental and social benefit. A 'spectrum' refers to multiple energy and non-energy products. And 'marketable' indicates that there needs to be a current or forecasted market volume at a profitable price. And finally, 'products' can be of the types food/feed ingredients, chemicals, materials and bioenergy.

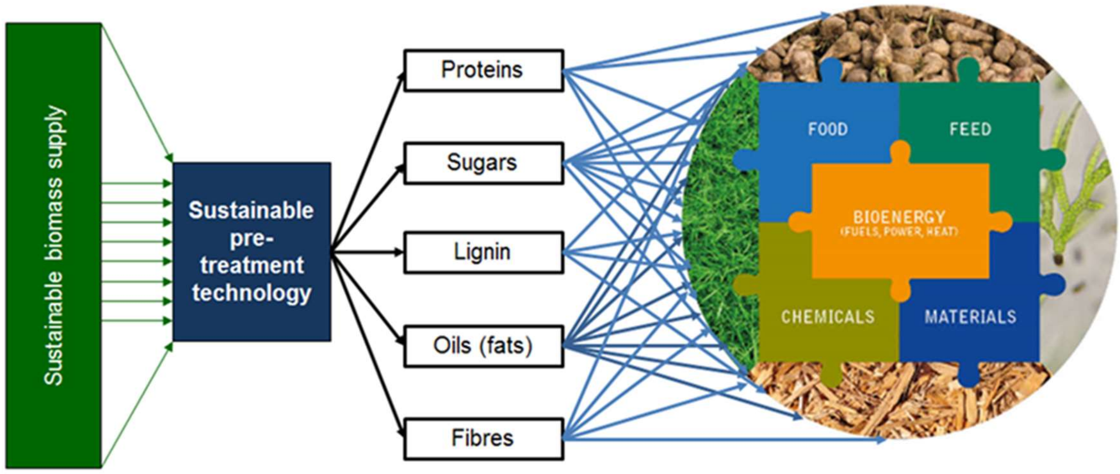


Figure 1. Schematic representation of a biorefinery.

2.2 BIOREFINERY CLASSIFICATION

The IEA Bioenergy Task 42 classification approach was developed from the need of a common way to describe biorefineries with a focus on energy-driven biorefineries[1]. It was a very first attempt to have a standard system available that could facilitate the understanding and further study of different existing and emerging biorefineries. The basis of the original **IEA Bioenergy Task 42 biorefinery classification system** relies on four major features or **category groups: platforms, products, feedstocks and conversion processes**. Table 1 shows the original IEA42 classification system. However, it is good to mention that the original sequence of the categories has already been changed in Table 1 to make it easier to compare its content with the updated version of the classification system that is described in Table 2.

[1] Cherubini et al., 2009. Towards a common classification approach for biorefinery Systems (IEA). Biofuels, Bioproduct, Bioref., 3, 534-546.

A more recent attempt to develop a robust biorefinery classification scheme took place in 2020 via the 'EU Biorefinery Outlook to 2030' project[2]. This study was implemented to support and facilitate the EU Bioeconomy Strategies on the development of sustainable chemical and material biorefineries towards the production of innovative high value bio-based products.[3]

In the EU Biorefinery Outlook to 2030 study, the term biorefining is defined broadly as 'the processing of biomass into a portfolio of marketable bio-based products, which could include co-production of food and feed, chemicals and materials and bioenergy (power, heat/cold, fuels)'.[4]

Table 1. Category groups and relative subgroups used in the original IEA Bioenergy Task 42 classification system [5].

1. Feedstocks	2. Processes		3. Platforms	4. Products
Dedicated feedstocks: • Sugar crops • Starch crops • Lignocellulosic crops • Oil crops • Grasses • Marine biomass Residues: • Oil-based residues • Lignocellulosic residues • Organic residues and others	Thermochemical processes: • Combustion • Gasification • Hydro-thermal upgrading • Pyrolysis • Supercritical Biochemical processes: • Fermentation • Anaerobic digestion • Aerobic conversion • Enzymatic processes	Chemical processes: • Catalytic processes • Pulping • Esterification • Hydrogenation • Hydrolysis • Methanization • Steam reforming • Water electrolysis • Waster gas shift Mechanical/physical processes: • Extraction • Fiber separation • Mechanical Fractionation • Pressing/ disruption • Pre-treatment • Separation	C5 sugars C6 sugars Oils Biogas Syngas Hydrogen Organic juice Pyrolysis liquid Lignin Electricity and heat	Energy products: • Biodiesel • Bioethanol • Biomethane • Synthetic biofuels • Electricity and heat Material products: • Food • Feed • Fertilizer • Glycerine • Biomaterials • Chemicals and building blocks • Polymers and resins • Biohydrogen

[2] Biorefinery Outlook, 2021. EU Biorefinery Outlook to 2030 for deployment. Studies on support to R&I policy in the area of biobased products and services, LOT3. Expert report written by E4tech, WUR, BTG, FNR &ICONS, 394 pp.

[3] Biobased chemicals and materials range from high-value added fine chemicals such as pharmaceuticals, cosmetics, food additives, etc., to high volume materials such as general bio-polymers or chemical feedstocks (i.e. building blocks)

[4] In the IEA Bioenergy Task 42 definition Biomass can be crops, aquatic biomass, forestry, primary (agro/forest) – secondary (process) and tertiary (post-consumer) residues, etc. This framework therefore will be very useably for political decision making for upcoming R&I needed for the implementation of the Green Deal.

[5] Cherubini et al., 2009. Towards a common classification approach for biorefinery Systems (IEA). Biofuels, Bioproduct, Bioref., 3, 534-546.

In the Biorefinery Outlook study, the IEA Bioenergy Task 42 biorefinery classification system was taken as a reference, modified and extended[6] to improve the understanding of chemical and material driven biorefineries. The Biorefinery Outlook classification was developed by establishing a biorefinery definition, defining a target audience, performing a literature review and undertaking a stakeholder consultation.

The **modified Biorefinery Outlook to 2030 classification scheme** is shown in Table 2. A detailed description of all items in the four categories can be found in 'Annex II - WP 1 Classification System Definitions' of the Biorefinery Outlook report.

Modification in sequence of the four category groups

One modification was changing the sequence of the four category groups to **feedstock, conversion process, platforms and products**, in order to facilitate the understanding of the classification for stakeholders with a non-technical background such policymakers and NGO's.

Modification in the feedstock category

The phrasing of the main feedstock categories were changed from dedicated feedstock and residues to primary and secondary biomass feedstocks. The production, processing and use of primary biomass from agriculture, marine, forestry and nature management results in various residues that are covered in different secondary biomass subgroups. Additionally, more specific secondary biomass feedstock subgroups have been created e.g. microbial biomass and recycled sources.

Another change was introduced under primary biomass subgroup, where a differentiation was made regarding the origin of lignocellulosic biomass being either from woodlands (forestry) or from croplands and grasslands.

Modification in the conversion process category

Changes were implemented in some sub-groups. In the Biochemical processes, the conversion of biomass using insects was included (this practice is also known as insect farming). This type of conversion process is mainly used to convert organic residues and waste to intermediates like protein and oil.

In the Mechanical processes, the sub-groups 'Pressing-disruption' and 'Mechanical fractionation' were merged due to the similarity of the technologies of some of the processes into a new sub-group named 'Mechanical and thermomechanical disruption and fractionation'. 'Blending process' was included, because it is a relevant process for the conditioning of feedstocks/process streams to reach certain specifications. Furthermore, 'Mechanical pulping' was added and 'Pre-treatment' was removed.

In the Thermochemical processes the terms 'Hydrothermal Liquefaction' is used instead of 'Hydrothermal Upgrading' and 'Supercritical Conversion' instead of 'Supercritical'. Additionally, the sub-group 'Torrefaction and carbonization processes' was included in the category Thermochemical conversion.

[6] Developed by Stichting Wageningen Research, Institute Wageningen Food & Biobased Research in WP1 (Biorefinery Classification)

Table 2. Adopted biorefinery classification systems in the Biorefinery Outlook project (2021).

1. Feedstocks	2. Processes		3. Platforms	4. Products	
Primary biomass[†]: • Aquatic biomass • Lignocellulosic from croplands and grasslands • Lignocellulosic wood/forestry • Oil crops • Starch crops • Sugar crops • *Other primary biomass Secondary Biomass[†]: • Microbial biomass • Residues from agriculture • Residues from aquatic biomass • Residues from forestry and forest-based industry. • Residues from nature and landscape management • Residues from recycled bio-based products • *Other organic residues	Biochemical: • Aerobic conversion • Anaerobic digestion • Enzymatic process • Fermentation • Insect-based bioconversion • *Other biochemical conversion Chemical: • Catalytic • Esterification • Hydrogenation • Hydrolysis • Methanation • Chemical Pulping • Steam reforming • Water electrolysis • Water gas shift • *Other chemical conversion	Mechanical and thermomechanical: • Blending • Extraction • Mechanical & thermomechanical disruption & fractionation • Mechanical pulping • Separation processes • *Other mechanical and thermomechanical conversion Thermochemical: • Combustion • Gasification • Hydrothermal liquefaction • Pyrolysis • Supercritical conversion • Torrefaction & Carbonization • *Other thermochemical conversion	Biochar Bio-Coal Bio-Crude Biogas Bio-oils Bio-hydrogen Bio-Naphtha C5/C6 sugars Carbon dioxide Lignin Oils Organic Fibres Organic Juice Protein Pyrolytic Liquid Starch Syngas *Other platform	Chemicals: • Additives • Agrochemicals • Building blocks • Catalysts & Enzymes • Colorants • Cosmeceuticals • Flavours & Fragrances • Lubricants • Nutraceuticals • Paints & Coatings • Pharmaceuticals • Solvents • Surfactants • *Other chemical product	Materials: • Composites • **Fibres • Organic Fertilizers • Polymers • Resins • *Other material product Food Animal Feed Energy: • Cooling agents • Fuels • Heat • Power • *Other energy product

* 'Other' is included to enable new concepts, technologies or product categories to be included.
**'Fibres' group can be extended to subgroups according to the application: textile fibres, paper and board fibres, carbon/specialty fibres and other fibres

Modification in the platform category

The C5 and C6 Sugars were combined in one subgroup. New platforms leading to the production of chemicals, materials, food and feed were added: biochar, bio-coal, bio-crude, bio-naphtha, carbon dioxide, organic fibres, protein and starch. Now in total, 17 platforms were proposed in the Biorefinery Outlook project.

Modification in the product category

The original IEA Bioenergy Task 42 classification considers only two product categories, Energy and Materials. In the Biorefinery Outlook project five categories were distinguished: Chemicals, Materials, Food, Animal feed and Energy. The Energy product category in the IEA Bioenergy Task 42 classification was slightly modified to differentiate the functionality of the energy product. From the material section of the IEA Bioenergy Task 42 classification only two products remain (polymers and resins, fertilizers) in the Materials product category, and other products were re-assigned into new product categories. Food and Feed were moved to their own product category and Building blocks and Glycerine were moved under Chemicals product category.

A broader spectrum of sub-groups for bio-based chemicals and materials was implemented. The subgroups are similar to the proposed in the EU Bioeconomy Strategy[7] and the Statistical Classification of Economic Activities in the European Community (NACE) nomenclatures[8].

2.3 BIOREFINERY PATHWAYS

The biorefinery classification systems find their applicability in the establishment of biorefinery conversion pathways. According to IEA Bioenergy Task 42 a 'conversion pathway' is a useful term to describe how the feedstocks are converted to products via platforms (intermediates) and conversion processes. The IEA Bioenergy Task 42 considers the platform feature as the most relevant element in defining and distinguishing the biorefinery conversion pathways because these intermediates form the heart that can lead to different end products and their combinations.

The main benefits of defining biorefinery conversion pathways are: i) to facilitate the understanding of the origin and production of different marketable bio-based products, ii) to enable users to distinguish between different types of biorefineries, iii) to provide more specific and recognizable information for different stakeholders, and iv) to facilitate the study of current and emerging biorefineries systems.

In the Biorefinery Outlook project, the following eleven '**biorefinery pathways**' were defined:

A. One platform (C6 sugars) biorefinery using sugar crops
B. One platform (starch) biorefinery using starch crops
C. One platform (oil) biorefinery using oil crops, wastes and residues
D. Two-platform (pulp and spent liquor) biorefinery using wood
E. Three platform (C5 sugars, C6 sugars and lignin) biorefinery using lignocellulosic biomass
F. Two-platform (organic fibres and organic juice) biorefinery using green biomass
G. Two-platform (oil and biogas) biorefinery using aquatic biomass

[7] European Commission, Directorate-General for Research and Innovation, A sustainable bioeconomy for Europe : strengthening the connection between economy, society and the environment : updated bioeconomy strategy, Publications Office, 2018, https://data.europa.eu/doi/10.2777/792130
[8] https://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Table 3. Biorefinery pathways as described in the Biorefinery Outlook project (2021).

		Name	Feedstocks	Conversion Processes	Platforms	Products	TRL
Bottom-up approach	A	One platform (C6 sugars) biorefinery using sugar crops	Sugar crops	Extraction, fermentation, (chemical conversions)	C6 sugars	Chemicals, polymers, food, animal feed, ethanol (building block or fuel), CO_2, power and heat	9
	B	One platform (starch) biorefinery using starch crops	Starch crops	Extraction, fermentation, (hydrolysis, chemical conversions)	Starch	Chemicals, (modified) starches, polymers, food, animal feed, ethanol (building block or fuel) and CO_2	9
	C	One platform (oil) biorefinery using oil crops, wastes and residues	Oil crops, waste/residue fats, oil and greases[a]	Pressing, transesterification, (hydrolysis, chemical conversions)	Oil	Chemicals (fatty acids, fatty alcohols, glycerol), food, animal feed, fuels (biodiesel and renewable diesel)	9
	D	Two-platform (pulp and spent liquor) biorefinery using wood	Lignocellulosic crop, wood/forestry, residues from agriculture and forestry	Mechanical processing, pulping, combustion, (separation, extraction, gasification)	Pulp, spent liquor	Materials (pulp and paper, specialty fibres), chemicals (turpentine, tall oil, acetic acid, furfural, ethanol, methanol, vanillin), lignin, power and heat	9-7
Top-down approach	E	Three platform (C5 sugars, C6 sugars and lignin) biorefinery using lignocellulosic biomass	Green biomass[b]	Pre-treatment, hydrolysis, fermentation, combustion, (thermo-/chemical conversions)	C5 sugars, C6 sugars, lignin	Chemicals, lignin products (materials, aromatics, pyrolytic liquid, syngas), ethanol (building block or fuel), power and heat	8-7
	F	Two-platform (organic fibres and organic juice) biorefinery using green biomass	Aquatic biomass	Pressing, fibre separation, anaerobic digestion, combustion, (upgrading, separation)	Organic fibres, organic juice	Materials, chemicals (lactic acid, amino acid), animal feed, organic fertilizer, fuels (biomethane, ethanol), power and heat	5-7
	G	Two-platform (oil and biogas) biorefinery using aquatic biomass	Natural fibres (e.g. hemp, flax)[b]	Extraction, anaerobic digestion, combustion, esterification, (hydrolysis, chemical conversions)	Oil, biogas	Chemicals (fatty acids, fatty alcohols, glycerol), nutraceuticals, food, organic fertilizer, biodiesel, power and heat	5-6
	H	Two-platform (organic fibres and oil) biorefinery using natural fibres	Lignocellulosic biomass[c], MSW	Fibre separation, extraction, (chemical conversions)	Organic fibres, oil	Materials, chemicals (fatty acids, fatty alcohols, glycerol), nutraceuticals, cannabinoids, food and biodiesel	4

	I	One platform (syngas) biorefinery using lignocellulosic biomass and municipal solid waste	Lignocellulosic biomass[c]	Pre-treatment, gasification, gas conditioning, chemical conversions	Syngas	Chemicals (methanol, hydrogen, olefins), waxes and fuels (F-T biofuels, gasoline, LNG, mixed alcohols)	7-8
	J	Two platform (pyrolytic liquid and biochar) biorefinery using lignocellulosic biomass	Lignocellulosic biomass[c], organic residues, aquatic biomass	Pyrolysis, separation, combustion, (gasification, cracking, extraction)	Pyrolytic liquid, biochar	Pyrolysis oil (for materials, chemicals, food flavourings, syngas, biofuels), biochar, power and heat	4-5
	K	One platform (bio-crude) biorefinery using lignocellulosic, aquatic biomass, organic residues	Lignocellulosic crop, wood/forestry, residues from agriculture and forestry	Hydrothermal liquefaction, upgrading	Bio-crude	Chemicals and fuels	4

a. Waste/residue fats, oils and greases belong to category "Other organic residues"
b. Green biomass and Natural fibres belong to category "Lignocellulosic from croplands and grasslands"
c. Lignocellulosic biomass includes Lignocellulosic from croplands, wood/forestry and residues from agriculture

H. Two-platform (organic fibres and oil) biorefinery using natural fibres
I. One platform (syngas) biorefinery using lignocellulosic biomass and municipal solid waste
J. Two platform (pyrolytic liquid and biochar) biorefinery using lignocellulosic biomass
K. One platform (bio-crude) biorefinery using lignocellulosic biomass, aquatic biomass and organic residues

For the definition or establishment of these pathways only the platform(s) that arise from primary refining (or primary conversion) were used, as shown in Table 3. For each biorefinery pathway, several **process variants** exist as a result of the secondary refining process, and of the way co-products and residual materials are processed. The naming of the biorefinery pathways is standardized by using the number and name of primary platform and the name of the feedstocks. The downstream platforms and name of the products are not included into the naming of the biorefinery pathway as several variants are possible from the primary platforms to end-products for each biorefinery pathway.

The biorefinery pathways were divided into **two general categories** according to how the biorefineries develop:

- bottom-up approach, considers the extension and/or upgrading of conventional existing biomass processing facility (e.g. sugar, starch, oil and pulp mill), or;
- top-down approach, considers new industrial value chains with highly integrated systems.

The biorefinery pathways based on the **bottom-up approach** (A-D) are demonstrated at commercial scale (TRL9). On the other hand, the pathways based on the **top-down approach** (E-L) are mostly at a lower degree of maturity at least for the production of chemicals and/or materials. Some of these pathways that are at low Technology Readiness Levels (TRLs) still require support at different stages (fundamental research, applied research, piloting or demonstration) before they can reach commercial application.

There is one pathway that was not included in the list of pathways in the Biorefinery Outlook project because it is currently being developed only towards the production of energy products and in very early stage towards chemicals. That is the ‘One platform (bio-coal) biorefinery using lignocellulosic biomass’.

In the Biorefinery Outlook report (2021) illustrative examples for each of the eleven pathways are provided for commercial, demonstration and pilot biorefineries. So we refer to that report for more details. Here we only show one **example** of a biorefinery pathway (D), and how this can have different process variants. The description of **‘Pathway D. Two-platform (pulp and spent liquor) biorefinery using wood’** is given in Figure 2 and 3. The first diagram shows the processing via Kraft pulping and second diagram via Sulphite pulping and the process variants towards slightly different bio-based products. Examples of facilities of Pathway D are shown in Table 4.

In the Biorefinery Outlook project, the biorefinery classification system and the biorefinery conversion pathways were used in the analysis of the European[9] plus 10 non-EU countries[10] database.

[9] WP4 – EU and global biorefinery deployment “database” – developed by BTG Biomass technology group BV based on the JRC biorefinery database: https://datam.jrc.ec.europa.eu/datam/mashup/BIOBASED_INDUSTRY/index.html
[10] 10 countries: USA, Canada, Australia, New Zealand, Japan, Brazil, China, India, Thailand, Norway, Switzerland, United Kingdom

Table 4. Examples of commercial facilities for biorefinery pathway D Two-platform (pulp and spent liquor) biorefinery using wood.

Facility	Description	Feedstock	Products	Process variants
Lenzing, Austria[11]	Wood is processed through sulphite pulping into dissolving wood pulp for textile, nonwoven and industrial applications.	Beech wood	Dissolving pulp, acetic acid, furfural, xylose, lignosulfonate, sodium sulphate, soda ash, heat and electricity	1, 2, 4
Borregaard, Norway[12]	The conversion of the old sulphite pulp mill uses different components of wood to produce lignin products, speciality cellulose, vanillin, bioethanol and microfibrillar cellulose.	Spruce wood, woodchips	Specialty cellulose, micro fibrillated cellulose, lignosulfonates, vanillin, ethanol, acetic acid, heat & electricity	1, 2, 3, 4, 5
Stora Enso, Sunila Mill, Finland[13]	Offers a variety of pulp grades to meet the demands of paper, board and tissue producers. Tall oil and turpentine are also produced.	Softwood	Pulp, lignin, tall oil, turpentine, heat and electricity	1, 2, 4
Domtar, USA [14], CelluForce[15]	Kraft pulp mills pulp with lignin separation. Produces nanocrystalline cellulose and tall oil and turpentine are attained as by-products.	Pine wood	Pulp and paper, specialty pulp, nanocrystalline cellulose, tall oil, turpentine, lignin, heat and electricity	1, 2, 3, 4
Alberta Pacific Forest Industries, Canada[16]	Kraft pulping process is converted into high purity methanol. Plant exports excess electricity to grid.	Aspen, poplar, spruce, pine	Pulp, methanol, heat and electricity	1, 6

[11] Lenzing, https://www.lenzing.com/sustainability/production/biorefinery
[12] Borregaard, https://www.borregaard.com/
[13] Stora Enso, https://www.storaenso.com/en/about-stora-enso/stora-enso-locations/sunila-mill
[14] Domtar, https://www.domtar.com/en/who-we-are/all-locations/plymouth-mill
[15] CelluForce, https://www.celluforce.com/
[16] Alberta Pacific Forest Industries Inc., https://alpac.ca/index.php/about/products

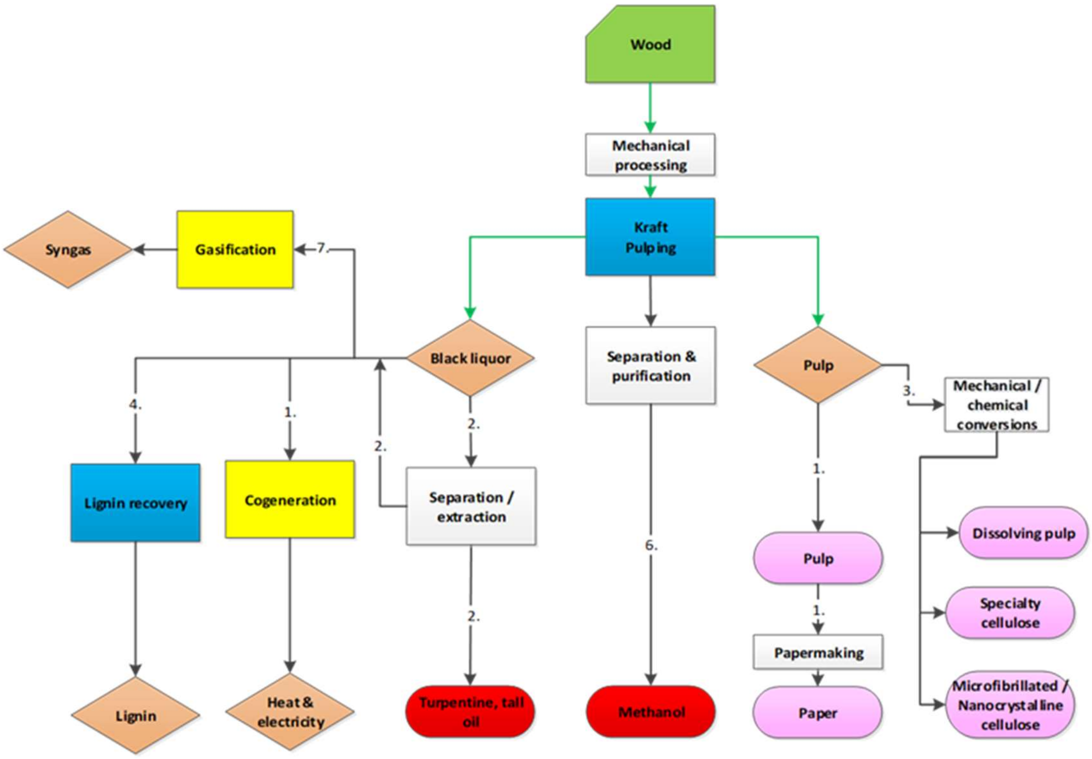


Figure 2. Biorefinery pathway D, process variant via Kraft pulping.

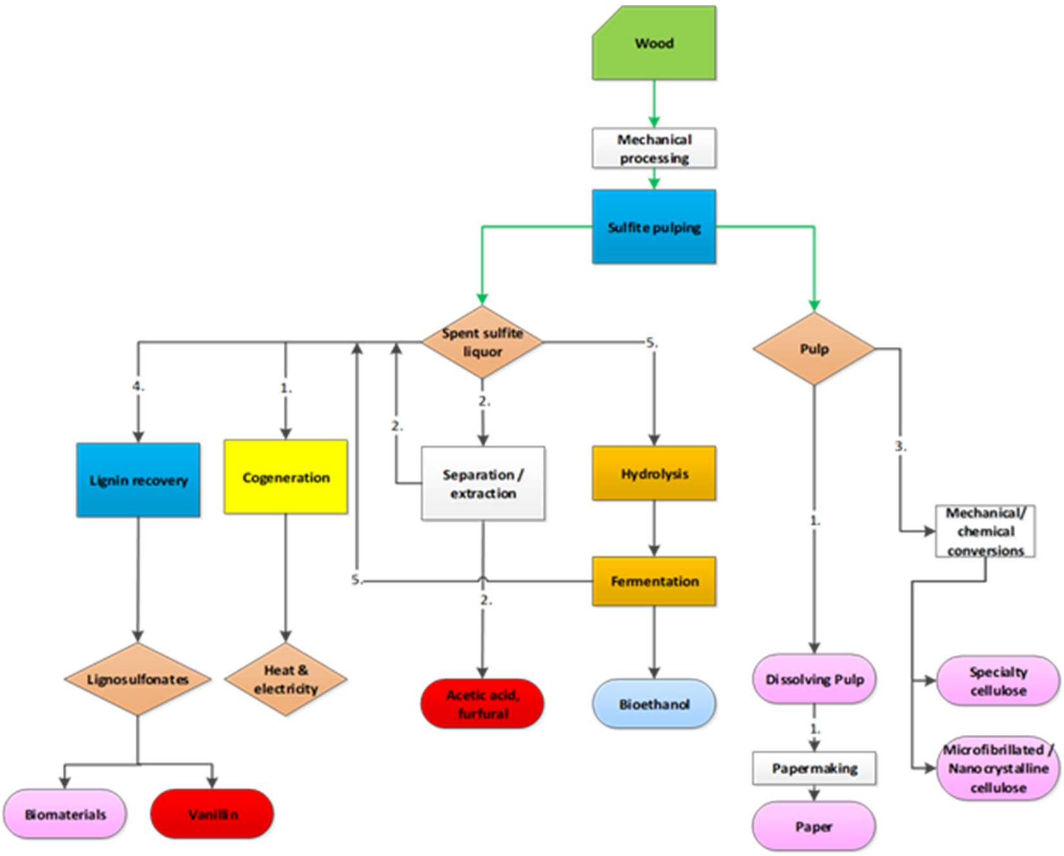


Figure 3. Biorefinery pathway D, process variant via Sulphite pulping.

3. Biorefinery status in the Task 42 country reports

3.1 TASK 42 COUNTRY REPORTS & UPDATE REPORTS

Task 42 biorefinery country reports are being produced every three years by the member countries. These country reports are summarized in this chapter with the objective to provide a general overview of the current direction and position of each country towards the development of the biorefinery concept. Regular update reports containing more detailed information of a selection of recent developments in the member countries have been presented at Task 42 meetings each year and these have also been used. The following information per member country is included In this summary:

1. Introduction
2. Major stakeholders
3. Relevant policies and policy implementation
4. General use of biomass
5. Summary of biorefineries, demonstration and pilot plants
6. Major innovation activities, RD&I activities and funding

3.2 AUSTRALIA

Introduction

Australian natural resources include important fossil reservoirs (primarily coal and natural gas) which are the main source for Australian energy generation. However, Australia's electricity sector is undergoing a substantial transition to cleaner energy and lower emissions through a combination of roof top solar, large scale solar and wind. Transport is an area of opportunity, particularly if it is supported by a robust domestic biofuels industry.[17]

Major Stakeholders

Australia's transition to lower emissions by increasing renewable energy in a competitive way has encouraged government institutions and companies to work together to build the Australian's future energy system.

Governmental entities:

- Australian Renewable Energy Agency (ARENA), with three investment priorities: integrate renewables into the electricity systems, accelerate hydrogen, support industries to reduce emissions
- Clean Energy Finance Corporation (CEFC)
- Queensland Government

[17] Biofuels and Transport: An Australian opportunity. A special report from the CEFC and ARENA.

Universities and Research Institutes:

- Queensland University of Technology
- Sydney University
- University of New South Wales
- Macquarie University
- CSIRO
- Melbourne University
- University of Queensland

Industrial partners:

- Manildra Group
- Wilmar
- United Petroleum
- Southern Oil Refining
- Microbiogen
- Leaf Resources
- Licella
- Ethtec Technologies Limited

Relevant Policies and policy implementation

Australia does not have a formal biorefinery target. However, the current Government policies are targeting a 26% to 28% CO_2 reduction below 2005 by 2030. In October 2021, the Federal Government announced it is now targeting a 100% reduction by 2050. The plan is to be driven by technology rather than mandates, and will be successful if technology can lower renewable costs to less than that of traditional fossil fuels. Reduction is to be driven through various tools including:

- Climate Solutions Fund: It aims to boost the supply of Australian carbon credit units (carbon credits).[18] This fund offers landholders, communities and businesses the opportunity to run new projects that reduce or remove greenhouse gas emissions from the atmosphere.
- Snowy 2.0 pumped hydro: This project involves linking two existing dams through two tunnels and an underground power station (using solar and wind energy).[19] The main objective is to provide energy generation at a low-carbon emissions and lower cost.
- A second undersea power interconnector between Tasmanian and the mainland: the objective is to provide more hydroelectric power generated in Tasmania into the national electricity market.[20]
- National Strategy for Electric Vehicle: the aim is to promote greater electric vehicle uptake to reduce greenhouse gas emissions and urban air pollution from the road transport sector.[21]
- Bioenergy Roadmap development by ARENA: the roadmap will identify the role that the bioenergy sector can play in accelerating Australia's energy transition, stimulating regional development, enhancing energy security and reducing emissions.[22]

General use of biomass

Biomass is used widely in Australia for non-energetic purposes. Industries that use biomass for non-energetic purposes include paper and pulp manufacturing, grain food production, silage for animal feed, sugar cane to crystal sucrose (bagasse is typically converted into energy but often inefficiently), composting waste biomass to generate soil enhancing products and biomass left on field for soil conditioning (country report 2018 report).

[18] http://www.cleanenergyregulator.gov.au/csf/Pages/at-a-glance.aspx
[19] https://www.snowyhydro.com.au/snowy-20/about/
[20] https://renewablesnow.com/news/tasmanias-2nd-interconnector-to-be-fast-tracked-702867/
[21] https://apo.org.au/sites/default/files/resource-files/2019-02/apo-nid221706.pdf
[22] https://arena.gov.au/assets/2020/04/bioenergy-roadmap-faq.pdf

Regarding energy production, in Australia around 72% of the electricity was produced from fossil sources (data from 2020) with a 5% contribution of bioenergy.

Summary of biorefineries, demonstration and pilot plants

Table 5. Operating biorefineries in Australia (commercial, demonstration and pilot scale).

Facility	Description	Feedstock	Products
Manildra – Nowra. Commercial	Biochemical conversion of starch sugars to ethanol	Waste starch	Ethanol for food, pharmaceuticals, personal care
Sarina – Mackay. Commercial	Biochemical conversion of sugar cane molasses to ethanol sugar	Sugar cane molasse	Ethanol for fuel market and liquid fertiliser
Ecotech Biodiesel- Brisbane. Commercial	Two stage base catalysed esterification process; German licence	Cooking oil, tallow	Biodiesel, glycerine
Barnawartha BDI Biodiesel[23] - Victoria. Commercial	Biodiesel produced using a batch process; Most product is exported to the EU and California	Vegetable oil, tallow and used cooking oils	Biodiesel
Licella -CAT-HTR[24] Somersby. Pilot plant	Uses Hydrothermal upgrading platform, Cat-HTR™	Residues, waste and non-edible biomass.	Bio-fuels (bio-crude oil) and chemicals
Northern Oil Advanced Biofuels[25]- Yarwun Queensland. Pilot Plant	The pilot plant has multiple technologies: pyrolysis, hydrothermal liquefaction (HTL) and gasification	Sugar cane bagasse and prickly acacia. In the future: sawmill waste, tyres, plastics, food waste, biosolids	Biofuels (bio-crude)
Ethtec, Hunter Pilot Biorefinery (HPB) [26] Muswellbrook, New South Wales. Pilot Plant	Multistage Biochemical process to convert sugars to ethanol; lignin is used as fuel and the acid recovered and recycle	Lignocellulosic material (sugar cane bagasse, crop stubbles and forest material).	Ethanol and xylitol

Major innovation, RD&I activities and funding

MicroBioGen

An important innovation step by Australian stakeholders is related to the use of optimised organisms (MicroBioGen) to produce advance renewables biofuels. This development could allow Australia to produce enough ethanol to replace nearly 10% of petrol by converting its sugar cane bagasse to and replace nearly 140,000 tonnes of currently imported protein feed. It is the first technology development where the one micro-organism can be utilised for the efficient production of both bioethanol and high protein feed.

[23] https://justbiodiesel.com.au/
[24] https://www.licella.com.au/what-we-do/
[25] https://www.sor.com.au/wp-content/uploads/2020/03/009_NOR-A4-Biofuels-factsheet_091116.pdf
[26] https://www.ethtec.com.au/introduction

The project 'Biocatalyst optimisation for efficient production of biofuels from non-food biomass and deployment through a global partner corporation' was partially financed by ARENA (A$8M project spend in total) and the project outcome estimates:

- an 25% effective reduction in operating costs;
- more biofuels manufactured;
- more high-value protein produced.

A peer reviewed Life Cycle Analysis made for this project shows a: 29% reduction in CO_2, 11% decline in fossil energy use, and 240% decrease in land use compared to the commercial yeast compared to commercial Gen II biocatalyst.

Licella

Licella is an Australian company that has developed Cat-HTR technology that is a catalytic hydrothermal reactor capable of converting various carbon rich substrates into a renewable biocrude oil.

According to the company "Licella's patented Catalytic Hydrothermal Reactor (Cat-HTR™) platform is a truly disruptive technology set to revolutionise how we approach a zero-waste economy and transition to sustainable renewable fuels and chemicals. The Cat-HTR™ is also offering a new stream of revenue to industries looking to diversify, creating valuable new products from waste and residues."

Using water at near or supercritical temperatures, the Cat-HTR™ converts a wide variety of low-cost, waste feedstocks and residues into high-value products. The Cat-HTR™ platform has been extensively tested, and conservatively scaled up, over the past ten years to its current commercial-ready module, located on the NSW Central Coast, Australia.

The company is collaborating with a range of international players including Mitsubishi Chemical, Mura, KBR, Shell amongst others.

3.3 AUSTRIA

Introduction

For the Austrian government, the use of regional and renewable raw material, as well as the setting of a bioeconomy strategy will open new opportunities to Austria as a business location. With a targeted development towards the bioeconomy Austria expects to reduce dependency on fossil fuels and energy sources while adding value for chemical products, composite materials, fuels or energy in the region[27]. In this context, Austria is already well-positioned to build on existing strong (bioeconomic) value chains.

Major Stakeholders

The Austrian Bioeconomy Strategy, is based on a broad involvement of stakeholders, including the government, scientific and technological communities and industry.

[27] Bioeconomy A strategy for Austria, Vienna 2019.

Governmental entities:

- The Federal Ministry of Agriculture, Regions and Tourism (BMLRT)
- The Federal Ministry for Climate Actions, Environment, Energy, Mobility, Innovation and Technology (BMK)
- The Federal Minister for Education, Science and Research

Universities and Research Institutes:

- Technical University Vienna
- Vienna University Resources and Life Science
- University of Graz
- Graz University of Technology
- University of Innsbruck
- University of Applied Sciences Upper Austria
- Energy Institute at the Johannes Keppler University Linz
- BEST - Bioenergy and Sustainable Technologies GmbH,
- Wood K plus,
- Austrian Institute of Technology
- AAE Intect
- AEA - Austrian Energy Agency
- Joanneum Research
- International Institute for Applied Systems Analysis (IIASA)
- Karl Franzens University Graz

Industrial partners, including large companies and innovative small and medium-sized enterprises (SME):

- Siemens
- Andritz
- AustroCel Hallein
- Lenzing
- Mondi
- Heinzel
- Sappi
- Agrana
- Wien Energie
- OMV
- Anniki
- Austropapier
- Münzer Bioindustrie – Division Biodiesel
- BDI – Bioenergy
- EVN
- PPM-Energie aus nachwachsenden Rohstoffen
- New Energy Capital Investment

Relevant Policies and policy implementation

In 2018, several Austrian Federal Ministries presented a working document on the bioeconomy and the respective roles and fields of research[28]. In the same year, the Integrated Climate and Energy Strategy[29] (Mission 2030) was described by the Austrian Federal Government. Austrian relevant policies consider that to emerge bioeconomy further a stimulus is needed in bioenergy, efficiency measures, biorefining of materials from agriculture and forestry and circular economy.

In March 2019, the Austrian Bioeconomy Strategy[30] was passed by the Council of Ministers. This economic approach seeks to replace fossil resources (raw materials and fuels) with renewable raw materials in as many areas and applications as possible. The Austrian Bioeconomy Strategy has set the following target areas for the further establishment of the bioeconomy:

[28] https://nachhaltigwirtschaften.at/resources/nw_pdf/biooekonomie-fti-strategie-ag2-2018.pdf
[29] https://mission2030.info/
[30]https://www.bmvit.gv.at/innovation/publikationen/energieumwelttechnologie/biooekonomiestrategie.html

- reach the climate goals;
- reduce dependency on non-renewable raw materials;
- promote innovation;
- promote economic development;
- protect and create jobs;
- promote sustainable societal transformation.

In this strategy biorefining is attributed as key enabling technology to achieve the mentioned targets and is further supported by the national research, technology and innovation strategy for implementation[31].

General use of biomass

Austrian largest biomass potential is seen in woody feedstocks. Nevertheless, waste and residues are also an important feedstock for bioenergy technology. The total primary energy supply (TPES) of Austria in 2018 was 32.8 Mtoe and around 64% of the TPES was imported[32]. The national energy production is only 11.7 Mtoe from which 51.5% comes from biofuels and waste.

The woody biomass used for non-energetic purposes is designated mainly to the production of wood-based materials such as: sawn wood, compressed wood products, particle board industry, pulp and paper industry and innovative materials. The agricultural feedstocks are mainly used for food and feed and chemicals.

Summary of biorefineries, demonstration and pilot plants

Table 6. Operating biorefineries in Austria (commercial, demonstration and pilot scale).

Facility	Description	Feedstock	Products
AustroCel Biorefinery - Hallein. Commercial	Lignocellulosic biorefinery. 160,000 tons of pulp/a	Cellulose waste	Bioethanol
Sappi-Gratkorn Mill. Commercial	Lignocellulosic biorefinery	Residues from forest	Paper and chlorine free pulp, Heat
Goss(er)-Leoben. Commercial	Conversion of 16.5 kton biogenic waste	Biogenic waste	Biomethane and fertilizer
Lenzing AG - wood-based fibres. Commercial	Lignocellulosic biorefinery. 300,000 tons of pulp/a	Lignocellulose form agriculture or forest	Pulp, bioenergy, Acetic acid, Furfural, Magnesium Lignosulphonate, Soda Ash, Sodium Sulphate, Xylose.
AGRANA Biorefinery (Pischelsdorf). Commercial	Processing of agrarian raw material (600,000 tons/a) to bioethanol (250,000 m^3/a)	Wheat, maize	Bioethanol, animal feed, wheat starch and wheat gluten, high-purity CO_2.

[31] FTI-strategie 2030 - strategie der bundesregierung für forschung, technologie und innovation. https://www.bundeskanzleramt.gv.at/themen/forschungskoordination_fti.html
[32] Source: World Energy Balances, World Energy Statistics © IEA 2020

Zellstoff-Pols. Commercial	Lignocellulosic biorefinery	Wood forestry	Pulp, paper, black liquor as fuel. Power generation and heating.
Ecoduna AG/ eparella GmbH - Bruck/Leitha, Lower. Demonstration	Microalgae production from nutrients, CO_2 and sunlight	Carbon dioxide	Microalgae for food and cosmetic applications
Lignozellulose - Biorefinery (LCF Biorefinery) - Vienna. Pilot t	Lignocellulosic biorefinery	Cereal residues, forest biomass and residues, paper, cellulosic, MSW	Nanolignin, bioactives, organic acids, erythritol, fibres
Lignovations - TU Wien Vienna. Pilot t	Lignocellulosic biorefinery	Woody residual biomass and agricultural by-products	Colloidal lignin particles (applications as UV booster, antioxidant, biocide, emulsifier, drug carrier)

Major innovation activities, RD&I activities and funding

For Austria, research and innovation related to bioenergy and biorefinery is the basis for a structural change from fossil energy. RD&I activities are linked to industry collaboration to try to stimulate new research ideas, encourage technology transfer, and strengthen the innovative capacity of companies to make Austria an important research business location. Important initiatives to reach these goals include the following programs:

The Austrian Competence Centre for Excellent Technologies (COMET) program supports collaborative research between universities and companies. Various industries in the bio-based product sector and innovative SME's are currently exploring and have been implementing integrated biorefining pathways.

There is also a regional initiative with strong focus on biorefining activities lead by the Austrian Biorefinery Centre (ABCT) at the University of Natural Resources and Life Sciences in Vienna, that bundles fundamental and applied research in the fields of biorefineries, chemistry of renewable resources, biomaterials, and analysis of biorefinery streams.

Main funding programs for bioenergy and biorefinery projects are managed by the Austrian Research Promotion Agency (FFG), the Federal Ministry for Climate Action, Environment, Energy Mobility, Innovation und Technology (BMK), the Austrian Climate and Energy Fund and the Kommunalkredit Public Consulting.

3.4 DENMARK

Introduction

The Danish landscape is dominated by agriculture. In 2016 62% of the land area was classified as agricultural land; 15% as forest; 14% as urban areas, infrastructure, and other artificial surfaces; and 9% as open nature. At the same time Denmark has formed comparatively ambitious policies for a transition to renewable energy, including bioenergy.[33]

Demark does not have a dedicated bioeconomy strategy yet. The government commitment to bioeconomy was framed at the beginning by the 'Growth Plan for Foods' and the 'Growth Plan for Water, Bio and Environmental Solution' (2013). Both plans were designed to contribute to increasing economic growth, employment, and exports. The latter growth plan was the appointment of the National Bioeconomy Panel (NBP) which has been the advisory body to provide recommendations for the government regarding the country's bioeconomy development.

The NBP's definition of bioeconomy refers to 'the use of basic building blocks used to produce energy, chemicals and materials originated from renewable biological resources including plants and animals'. The NBP identifies opportunities to lower the dependence on the fossil fuels, to increase resource efficiency, to promote exports of technology, to enhance value creation and to complement food production.[34]

Major Stakeholders

The NBP has the objective to facilitate bioeconomy governance-implementing and/or ensuring an integrated and cross-policy approach. The panel is composed of researchers, NGOs, leading companies, key organisations and authorities.

Governmental entities:

- The Ministry of energy, Utilities and Climate (EFKM)
- The Ministry of Environment and Food of Denmark (MFVM)
- The Danish Energy Agency
- Danish Ministry of Higher Education and Science
- Innovation Fund Denmark

Non-Governmental Organizations:

- Algecenter Danmark
- The Danish Biogas Association
- Danish Biotech
- Danish Energy
- Danish Environmental Technology Association
- Danish Forest Owners Associations
- Danish Fuel Industry Association
- Innovation network for biomass (INBIOM)
- The Danish Agriculture and Food Council

[33] Bentsen NS, Nilsson D, Larsen S (2018) Agricultural residues for energy – a case study on the influence of resource availability, economy and policy on the use of straw for energy in Denmark and Sweden. Biomass Bioenergy 108:278–288.
[34] Fund C., El Chichakli B., Patermann C. Bioeconomy Policy (Part II) Synopsis of National Strategies around the World. A report from the German Bioeconomy Council, 2015.

Universities and Research Institutes:

- Danish Technological Institute
- Technical University of Denmark
- University of Copenhagen
- University of Southern Denmark
- Aarhus University
- Aalborg University

Industrial partners, including large companies and innovative small and medium-sized enterprises (SME):

- Aarla
- Bigadan
- Biogasclean
- Daka Ecomotion
- DLG group
- Emmelev Mølle
- Haldor Topsøe
- Hamlet Protein
- KMC
- Novozymes
- SEGES
- Steeper Energy
- Terranol
- Ørsted

Relevant Policies and policy implementation

As mentioned before Denmark does not have a national biorefinery strategy, however, the government established the National Bioeconomy Panel (NBP). The first NBP was setup in 2013 and evaluated in 2016. In 2014 the first report with four recommendations on how to promote the development of bioeconomy in the near to long term perspective was published followed by reports focused on 'green', 'yellow' and 'blue' biomass.[35]

There are also two regional initiatives with strong focus on biorefining activities:

- Green Growth in Central Denmark Region.[36]
- Bioeconomic Growth Center Guldborgsund.[37]

In 2017 the National Bioeconomy Panel was re-launched by the Minister of Environment and Food. The panel consists of 15 members from industry, universities, and organizations. In 2018 the report 'Proteins for the future' was published, focusing on protein from e.g. green biomass. In 2016 the government established an Advisory Board for Circular Economy and in June 2017 the advisory board published their recommendations. Based on this the Government has in in June 2018 launched their strategy for circular economy which also contains parts related to biorefining.[38]

General use of biomass

In Denmark, the biomass used for energy production (heat and power) is wood and straw, while rape seed is used to produce for biodiesel. Due to a large animal production a large amount of grain (almost 80% of total harvest) and grass forage is used for feed. Denmark does not have a pulp and paper production and all non-energy use of wood is for construction, furniture etc.

The non-energy use of straw is e.g. for bedding, the non-energy use of grain is for industrial use and the non-energy use of potatoes is for industrial processing for starch and protein (potentially for food/feed).

[35] https://mfvm.dk/miljoe/anbefalingerom-biooekonomi/ (Danish)
[36] https://www.rm.dk/omos/english/regional-development/energyhub/bio-economy/
[37] http://www.bioguldborgsund.dk/
[38] https://mfvm.dk/miljoe/strategi-for-cirkulaer-oekonomi/ (Danish)

Summary of biorefineries, demonstration and pilot plants

Table 7. Operating biorefineries in Denmark (commercial, demonstration and pilot scale).

Facility	Description	Feedstock	Products
Emmelev Commercial	Commercial production of Biodiesel (150 kton/y)	Rapeseed	Biodiesel
Daka Ecomotion Commercial	Second generation biodiesel Capacity 100 kton/y	Residues from slaughterhouses and primary agriculture residues.	Biodiesel
Billund Biorefinery Demostration	Technology provider Kruger: thermal hydrolysis and feedstock provided by Veolia.	Manure & organic agricultural waste.	Biogas and organic fertilizer
Renescience by Orsted. Demonstration	Enzymatic separation of unsorted waste streams into useful organic fractions. Process 144,000 tons of waste per year.	Municipal solid waste and other waste streams.	Organic liquids that can be converted to biogas.
Steeper Energy Pilot	Transform low-energy density into valuable by using Hydrofraction.	(wet) organic feedstocks	High energy density bio-oil.
Pilot Plant Aarhus University. Center for Circular Bioeconomy (CBIO) of biomass to biooil. Pilot	Biogas from green biomass (hydrothermal conversion)	Green biomass: Grass	Protein and Bio-oil
Danish Technological Institute (DTI). Pilot	Facilities include: Mills, wet mills, chemical and enzymatic reactors, pasteurization, ultrafiltration, chromatography and drying	Diverse biomasses	Diverse Products
Technical University of Denmark. Pilot	Thermal processes: gasification and pyrolysis Fermentation, distillation, filtration, spray drying.	Diverse biomasses	Diverse Products

Major innovation activities, RD&I activities and funding

In Denmark there are no funding programs directly targeted biorefining, but there are funding programs funding related research, development and demonstration.

Some relevant public funding programs:

- EUDP: Funding of energy development and demonstration projects, including bioenergy.
- GUDP: Funding development and demonstration projects mainly in agriculture and food/feed industry.
- MUDP: Funding of environmental development and demonstration projects, e.g. waste recycling, reduced emissions and circular economy.
- Innovation Fund Denmark: Different funding programs, largest being “Grand Solutions” that have thematic calls, e.g., bioresources and energy.
- Independent Research Fund Denmark: Open calls within the area of basic research within technology and production sciences.

Some relevant private funds:

- Novo Nordisk Foundation.
- Biotechnology-based synthesis and production research: Funding biorefinery projects involving biotechnology aspects, e.g., fermentation or enzymes.
- The Velux Foundation – Open calls within technical and natural sciences.

The development of the Danish Biogas Network is also an example of innovation and RD&I activities. The Danish biogas production increased 40-45% between 2016-2017. By March 2017 a total of 166 biogas plant were in operation in Denmark using different feedstocks e.g., sewage sludge, industrial waste, landfills, farming and agricultural waste.

Additionally, European funding such as the Horizon 2020 program is supporting projects related to the development of biorefinery process to convert microalgae and municipal solid waste to value-added products.

3.5 GERMANY

Introduction

The government of the Federal Republic of Germany defines the bioeconomy as the production, exploitation and use of biological resources, processes, and systems to provide products, processes and services across all economic sectors within the framework of a future-oriented economy.[39]

The bioeconomy strategy of the German Government assumes its global responsibility in the interconnected international bioeconomy. The German perspective includes a holistic bioeconomy development that integrates and combines interdisciplinary research and systemic solutions. The implementation of the strategy has been formulated in the context of research funding, the pertinent framework conditions and cross-cutting instruments.

Major Stakeholders

Governmental entities:

- Federal Minister of Food and Agriculture (BMEL)
- Federal Ministry of Education and Research (BMBF)
- Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)
- Agency for Renewable Resources (FNR)
- Federal Office for Agriculture and Food (BLE)
- German Environment Agency (UBA)
- In addition, a bioeconomy council has been installed. This Bioeconomy council is an independent advisory body to the German government. It develops recommendations for action to implement the national bioeconomy strategy.

[39] https://www.ptj.de/en/project-funding/bioeconomy

Non-Governmental Organizations:

- Worldwide Fund for Nature (WWF)
- Nature and Biodiversity Conservation Union (NABU)
- Welthungerhilfe Foundation: foundation against global hunger and for sustainable food security.
- Brot für die Welt (Bread for the World)

Universities and Research Institutes:

- Thuenen Institute: Research for the development of sustainable uses of the German natural resources.
- Nova-Institute: Research institute on the transition of the chemical and material industry to renewable carbon.
- UMSICHT Fraunhofer: Institute for Environmental, Safety, and Energy Technology
- German Biomass Research Centre (DBFZ)
- CBP Fraunhofer: Center for Chemical-Biotechnological Processes
- Research University in the Helmholtz Association (KIT)
- Institute for Energy and Environmental Research (IFEU)
- Several Universities, e.g. Aachen, Göttingen, Bayreuth, etc.

Industrial partners/Companies:

- BASF
- Beiersdorf
- Evonik
- Fuchs Europe
- Henkel
- Nordzucker
- Suedzucker
- Linde Engineering
- Cargill
- And many more

Federations and Networks:

- DECHEMA: Expert network for chemical engineering and biotechnology.
- Staerkeverband (VGMZ): Verband der Getreide, Mühlen und Stärkewirtschaft
- Ovidverband (OVID): Der Verband der ölsaatenverarbei-tenden Industrie in Deutschland
- German Chemicals Industry Association (VCI)
- Industrielle Biotechnologie Bayern Netzwerk (IBB)
- Association of German Engineers (VDI)
- Science and industry cluster of the Rhine-Main-Neckar region (BioRN)
- Union for the Promotion of Oil and Protein Plants (UFOP)
- Etc.

Relevant Policies and policy implementation

The New German Bioeconomy Strategy (January 2020) provides the conditions to develop the full potential to strengthen Germany as a bioeconomy leader, and to create the technology and jobs of tomorrow. Two guidelines support the objectives set out in the New German Bioeconomy Strategy:[40]

- The first guideline highlights how biological knowledge and advanced technology are the pillars of a future-oriented, sustainable and climate-neutral economy.

[40] Summary -National Bioeconomy Strategy. January 2020. https://www.ptj.de/en/project-funding/bioeconomy

- The second guideline relates to the use of biogenic raw materials by industry. Today there is also an increasing focus on bio-based residues and waste materials.

The Federal Government's strategy on the bioeconomy has objectives at different levels of the society and across all economic sectors. This can be summarised in six common strategic goals:

1. Develop bioeconomy solutions for the sustainability agenda
2. Recognise and harness the potential of the bioeconomy within ecological boundaries
3. Enhance and apply biological knowledge
4. Provide a sustainable raw material base for industry
5. Promote Germany as the leading location for innovation in the bioeconomy
6. Involve society in the bioeconomy and intensify national and international collaboration

General use of biomass

In 2018, the total primary energy consumption in Germany was 12,963 PJ. Of this 14% was produced from renewables (1,809 PJ). In 2050, it is expected that domestic biomass (from agriculture, from wood and from waste) will contribute substantially to the energy supply in Germany. It is expected that up to 26 % of the need for heat, electricity and fuels and energy production can be produced from biomass.[41] The non-energetic uses of biomass include feed, food and chemicals and materials production (produced from industrial crops). According to the national bioeconomy strategy, biogenic resources can replace much more than just fossil raw materials, they can open the door for completely new products, such as nutritional supplements for improved food, new composite materials for building houses or car bodies, or optimized crops that are more robust and productive.

Summary of biorefineries, demonstration and pilot plants[42]

Table 8. Selected biorefineries in Germany (commercial, demonstration and pilot scale).

Facility	Description	Feedstock	Products
Zeitz Commercial	Biorefinery for the production of energy and material products from and starch	Sugar beet, grain	Energy and bioethanol
Krefeld Commercial	A starch biorefinery for the production of material and chemicals (food starch, paper starch, protein, keto-gluonic acid, sorbitol, etc.)	Maize	Materials and chemical products.
Schwedt Commercial	A sugars or starch biorefinery for the production of energy and 1st generation bioethanol, biogas and organic fertiliser	Sugar beet, grain	Energy and materials
UPM Leuna Commercial	Use of lignocellulosic biomass (hard wood, SRC wood) chemicals such as glycol	Wood	Material and chemical products.

[41] Bioenergy in Germany Facts and Figures 2020. FNR.
https://www.fnr.de/fileadmin/allgemein/pdf/broschueren/broschuere_basisdaten_bioenergie_2020_engl_web.pdf

[42] There is no "correct" list of German biorefineries. There is a huge number of biomass processing facilities for various products, e.g. using plant oil for detergents and/or cosmetics, starch for additive of construction materials, herbs for pharmaceutics, and many more. Those companies operate for decades, thus long before the term biorefinery was defined by IEA Task 42. It is impossible or would be arbitrary to make a clear cut between the new bioeconomy and the old (mingled) economy. Therefore just few examples are shown in Table 8.

Brensbach/Biowert Commercial and demo	A biorefinery that uses grasses and silage to produce energy, materials and chemicals (biogas, reinforced composites, insulation material and organic fertiliser)	Grass and Silage	Energy, material, and chemical products.
Sunliquid® Straubig Pilot	A biorefinery to produce energy products from sugars and lignin (such as 2nd generation bioethanol, biogas and lignin)	Straw	Energy products
Selbelang Pilot	A biorefinery for the production of materials and chemicals (lactic acid, amino acids and animal feed) from grasses	Grasses	Material and chemical products
BIOWERT Commercial	A biorefinery producing bioplastics, insulation materials, fertilizer and electricity from grass silage and food residues	Grasses	Material and fertiliser

Major innovation activities, RD&I activities and funding

The new bioeconomy strategy sets the framework for the successful expansion of the bioeconomy future research funding and focuses on:

- expanding biological knowledge and the use of biological processes and systems;
- increasing availability of biogenic raw materials to the industry via cycle-oriented concepts;
- integrating the bioeconomy strategy within the German economy;
- scale up current and future cross-border cooperation.

Additionally, securing the global food supply is a central aim of the National Research Strategy BioEconomy 2030. The Federal Research Ministry (BMBF) launched the funding initiative to support the following action areas regarding sustainable food production and high-output agriculture[43]:

- producing Healthy and Safe Foods;
- securing the Global Food Supply;
- ensuring Sustainable Agricultural Production.

Through the ‘Research for Sustainability’ (FONA) Strategy, the BMBF will double the amount of funding it provides for research on climate protection and more sustainability over the next five years to four billion euros.[44]

3.6 IRELAND

Introduction

The Irish Government has affirmed the importance of the bioeconomy and the vision for Ireland to become a global leader in this area through a co-ordinated approach that harnesses Ireland’s natural resources and competitive advantage. In 2018, Ireland published the National Policy

[43] https://www.healthydietforhealthylife.eu/index.php/partners-prova-layout/96-participating-members/559-germany?jjj=1629972998434
[44] https://biooekonomie.de/en/news/bmbf-supports-research-sustainability

Statement on the Bioeconomy (2018). The key actions to expand the bioeconomy set out in the National Policy Statement, include:

- promoting greater coherence between the many sectors of the bioeconomy;
- strengthening the development of promising bio-based products and growing the relevant markets for them;
- accessing funding available at EU level as well as leveraging private investment.

The Bioeconomy Statement has concentrated on developing the key major pillars of the bioeconomy and ensuring consistent attention of Government as Ireland moves towards the objective of a decarbonised economy by 2050 and to support and rural employment and development.[45]

Major Stakeholders

The actions set in the National Policy Statement on Bioeconomy can only progress by cooperation and collaboration between the public service, industry and the research institutes.

Governmental entities:

- Department of Communications, Energy and Natural Resources
- Department of Agriculture, Food, and the Marine
- Department of Jobs, Enterprise, and Innovation
- Department of the Environment, Community, and Local Government
- Environmental Protection Agency (EPA)
- Commission for Energy Regulation (CER)

Universities and Research Institutes:

- NUI Galway, Ryan Institute for Environment
- Marine and Energy Research
- University College Cork (UCC),
- Sustainable Energy Research Group
- University College Dublin (UCD)
- Energy Research Group
- Dundalk IT, Centre for Renewable Energy
- Institute of Technology Carlow
- Galway Mayo Institute of Technology
- Teagasc: Agriculture and Food Development Authority.
- MaREI Marine and Renewable Energy Research Centre co-ordinated by UCC
- Dairy Processing Technology Centre (DPTC) co-ordinated by UL
- Shannon ABC (Applied Biotechnology Centre)
- BEACON research centre, co-ordinated by UCD
- Marine Institute

Associations:

- Irish Bioenergy Association (IrBEA)
- The Composting and Anaerobic Digestion Association of Ireland (Cré)
- Irish BioIndustry Association (IBIA)
- Renewable Gas Forum Ireland (RGFI)
- Irish Bioeconomy Foundation
- Irish Bioenergy Association (IrBEA)
- Irish Farmers Association (IFA)
- Irish Forestry and Forest Products Association (IFFPA)
- Irish Cattles-Sheep Farmers Association (ICSA).
- BioConnect
- Knowledge Transfer Ireland (KTI)

[45] National Policy Statement on the Bioeconomy. Department of the Taoiseach. Government of Ireland. February 2018.

Industrial partners, spinouts and SME:

- Dairygold
- CMP
- Glanbia
- Monaghan Bioscience
- Bord na Mona
- Gas Network Ireland
- Calor Ireland

Relevant Policies and policy implementation

- National Policy Statement on the Bioeconomy (2018)
- Project Ireland 2040 (national plan) – National Strategic Outcome 8: Transition to a LowCarbon and Climate Resilient Society (2018)
- Ervia-commissioned report by KPMG Ireland on de-carbonising domestic heating in Ireland (AD biomethane) (2018)
- Bioenergy Supply in Ireland 2015-2035 (2017)
- Economic Assessment of Biogas and Biomethane in Ireland (2017)
- Draft Bioenergy Plan (2014)
- Irelands National Renewable Energy Action Plan (NREAP) (2010)
- BioÉire project results, e.g. The Irish Bioeconomy: Definition, Structure and Situational Analysis (2017)
- The Economic Impact of the Irish Bioeconomy – The Bio-Economy Input Output Model: Development and Uses (2015)

The Climate Action and Low Carbon Development Act 2015 provides for the establishment of a national framework with the aim of achieving a low carbon, climate resilient, and environmentally sustainable economy by 2050.

The current primary support mechanism for renewable electricity in Ireland is the Renewable Energy Feed-In Tariff (REFIT) scheme. The Support scheme for renewable heat is expected to be operational in 2018. It provides operating aid for 15 years to renewable heat from biomass.

General use of biomass

The agri-food sector is a key industry in Ireland’s future bioeconomy. Many agricultural bodies are active in the bioeconomy, including dairy co-operatives and other food and food ingredients co-operatives which are developing a state-of-the-art biorefinery turning by-products into high value bio-based products.

Ireland recently set-up arguably the first biorefinery in Ireland, producing marine-based protein, lipids and calcium. Many global pharma and biotech companies have production and research facilities in Ireland and provide expertise and materials as biological waste streams to the bioeconomy.

In the bioenergy sector, harvesting and burning peat has been relevant but now it is transitioning to biomass procurement. Gas Networks Ireland (part of Ervia group) and EU-funded Causeway operate the gas grid and the injection biomethane for the first time into Ireland’s gas network.

Summary of biorefineries, demonstration and pilot plants

Table 9. Operating biorefineries in Ireland (commercial, demonstration and pilot scale).

Facility	Description	Feedstock	Products
Cellulac Ltd. Commercial	Production of100,000 ton of chemicals and fuels from 2nd generation feedstocks. Technologies like fermentation non-MGO bacteria are used	Lignocellulosic materials	High enantiopurity lactic acid and ethyl acetate.
Biorefinery Grass Demonstration[46]	Conversion of fresh grass into multiple products	Grass	Protein for animal feed, protein concentrate for other uses, fertilizer and biogas

Major innovation activities, RD&I activities and funding

The Government has provided through Science Foundation Ireland funding of €14.2 million for a Bioeconomy Research Centre (Beacon) which will explore how to convert marine resources and the residues produced during food production into higher value products.

The Government is also providing €4.6 million in financial support through Enterprise Ireland's Regional Economic Development Fund for the establishment of a Bioeconomy innovation and piloting facility to scale technologies that convert Ireland's natural resources (including residues) to products of high value for use as food ingredients, feed ingredients, pharmaceuticals, natural chemicals, biodegradable plastics and more.

The Department of Agriculture, Food and the Marine has funded a number of collaborative academic- bioeconomy related research projects including the Bio-Éire research project, led by Teagasc, focused on identifying and prioritising interlinking cross-sectoral value chains in the bioeconomy. The Bio-Éire project identified the need in the short/medium term to focus on agricultural, marine and forestry resources through the valorisation of waste and side streams and the production of bio-based materials, bio-based chemicals, and bioenergy.

Other significant developments include the establishment of the Irish Bioeconomy Foundation to bring together relevant stakeholders with an interest in establishing a National Bioeconomy Hub.

3.7 ITALY

Introduction

Bioeconomy in Italy has an important role. Italy uses biological resources, from land and sea, as the input to produce food and animal feed, and different industrial goods such as, materials and energy. The Italian strategy is looking at the synergy between primary production and industry. Bioeconomy is seen as a possibility to effectively contribute to revitalize territories

[46] https://biorefineryglas.eu/

starting from quality and low impact agriculture, and by leveraging on relational capital of rural communities.[47]

After the time frame of the COVID-19 pandemic, the Italian Bioeconomy turned out to be one of the most resilient ones in Europe. In 2020 the Bioeconomy in Italy, intended as a system that uses biological resources, including waste, to produce goods and energy, generated an output of 317 billion euros, registering an employment rate of approximately 2 million people.

Major Stakeholders

Governmental entities:

- Presidency of the Council of Ministers
- Ministry of Economic Development
- Ministry of Education, University and Research
- Ministry of Agricultural, Food and Forestry Policies
- Ministry of the Environment and Protection of Land and Sea
- Committee of the Italian Region
- Agency for Territorial Cohesion
- Italian Technology Clusters: Green chemistry, Agrifood, Bluegrowth

Non-governmental entities:

- Italian Biomass Association (ITABIA)
- Consorzio Italbiotec
- Chimica Verde Bionet
- Renewable Energy Consortium for Research and Demonstration (RE-CORD)
- Consorzio Italiano Biogas e Gassificazione
- ITP plants for the future
- Assobioplastiche
- Federchimica

Universities and Research Institutes:

- University of Aquila (UNIVAQ)
- University of Bari (UNIBA)
- University of Bologna (UNIBO)
- University of Messina (UNIME)
- University of Milano Bicoca (UNIMIBO)
- University of Padova (UNIPD)
- University of Torino (UNITO)
- Italian National Agency for New technologies, Energy and Sustainable Economic Development (ENEA)
- National Research Council (CNR)
- Council for Agricultural Research and Analysis of Agrarian Economics (CREA)
- Centro Ricerche Produzioni Animali
- Centro di Ricerca Interuniversitario sulle Biomasse da Energia (CRIBE)
- University of Tuscia (UNITUS)

[47]The Italian Bioeconomy Strategy Bit II. Implementation Action Plan (2020-2025).

Industrial partners and SMEs:

- Novamont
- ENI Versalis
- Fater S.p.A
- ASTER Cons
- Biosphere S.R.L
- Biotec Sys S.R.L
- Faci S.p.A.
- Beaulieu Fibres-International Terni s.r.l.
- Spiga Nord S.p.A.
- Ticass s.c.r.l.
- BASF Italia S.p.A.
- GFBiochemicals Italy s.r.l
- Versalis S.p.A.
- Biochemtex S.p.A
- Matrica S.p.A.
- Mater-Biotech S.p.A.

Relevant Policies and policy implementation

In May 2019 a New Bioeconomy Strategy for Sustainable Italy (BITII) was presented to the Presidency of the Council of Ministers. The objective of the new BIT is to increase the turnover and employment of the Italian Bioeconomy (317 billion euros and 2 million employees in 2020) by 15% by 2030, while increasing the level of circularity of the economy.

In January 2020, the Integrated Plan for energy and Climate (PNIEC) was sent to the European Commission. Its goal is to cover 30% of gross final energy consumption by 2030 with renewable sources, in line with European objectives, The PNIEC sets out biomethane from agricultural waste and the fraction organic solid waste (FORSU) from separate collection. In 2030 the release of 1.1 billion Sm3 is expected, which corresponds to the entire volume of natural gas used in Italy in public and private transport in 2018, this known as the new biogas-centred strategy.

The relevance of the Bioeconomy in the Italian production system is destined to grow significantly in the immediate future thanks to the integrated strategy for the relaunch of Italy outlined in the National Plan for Recovery and Resilience (PNRR) which provides huge investments for the "Green Revolution and ecological transition", whose goal of making the country system more sustainable must be achieved by leveraging agriculture, renewable energy sources, industrial supply chains and mobility.

General use of biomass

Agricultural and forest residues are produced in large quantities in Italy. Current initiatives and policies consider production of bio-based products from non-food biomass in marginal lands and from bio-residues of agri-food, forestry and maritime activities, a good opportunity for rural and coastal areas of the country. The Italian agri-food value chains could be increased through processing by-products and wastes to valuable bioactive ingredients like phytochemicals, bioactive peptides, prebiotics, dietary fibre, minerals, polyunsaturated fatty acids, carotenoids, etc.[48]

The forest sector also plays a strategic role in providing Italy with biomass, ecosystem services and carbon emissions fixation. The recovery and recycling of wood products along with the replacement of energy intensive industrial materials with long lasting wood-based products to reduce carbon dioxide emissions.

[48] http://cnbbsv.palazzochigi.it/media/2079/iap_2332021.pdf

In Italy, biomass plays a key role in the sustainable energy transition. Alongside its thermal and electrical use, it is used in the production of biofuels (to replace petrol, diesel and methane) and as a source of green chemical intermediates for the production of plastics.

Between 2005 and 2018, the Italian production of energy from renewable sources doubled, going from 10.7 to 21.6 Mtoe and covering approximately 17.8% of the National Gross Final Consumption (higher than the target of 17 % set for 2020 by Directive 2009/28 /EC, a unicum among all the EU Countries). Bioenergy was the sector that provided the greatest contribution (10.6 Mtoe), mainly used to produce thermal energy (72.7% of the total), electricity and biofuels for transport (15.5% and 11.8%, respectively).

Despite the important industrial advances in the sector, the critical aspect remains the availability of the raw biomass material. The latest European Directive on Renewable Energy (RED 2) indicates the maximum contribution of biofuels produced from crops food 7%, with a progressive reduction to zero for those based on the use of raw materials with a high ILUC (Indirect Land Use Change). In addition, in Italy the scarcity of land available for dedicated crops and the advance of desertification phenomena pose various challenges. Among these, the optimized use of available resources combined with increasing attention to soil problems, whose fertility will also be guaranteed through the development of biorefining schemes that provide for the replenishment of carbon and nutrients (biofertilizers).

Residues and waste will therefore play an important role as renewable raw materials not only for energy, but also for the chemical industry. Currently, in fact, about 90% of the raw materials of the EU chemical industry for non-energy uses come from fossil resources and only 10% from renewable carbon sources. 6% of all fossil resources is devoted to plastic production alone. Growing concerns about climate change and the accumulation of plastics in the environment will favour the production of new bio-based materials that are biodegradable and compostable, in line with the general goal of reaching 30% of raw materials for industry chemicals by 2030. Within the bio-based industry, new models of biorefineries that are capable of transforming various renewable biomasses rather than petroleum into fuels and synthetic intermediates for the chemical industry will be developed.

Summary of biorefineries, demonstration and pilot plants

Table 10. Operating biorefineries in Sweden (commercial, demonstration and pilot scale).

Facility	Description	Feedstock	Products
Mater Biopymer -Praica, Frosione. Commercial	The plant has been built to manufacture PET. Capacity of 100 kton/year	Primary biomass oil crops: shea, palm, coconut, rapeseed and sunflower, soy.	Biodegradable polyesters (Origo-Bi)
Novamont-Terni, Commercial	Capacity 20 kton/year compounding and 60 kton/year polyesters	Local agricultural crops.	Bio-lubricant and bioplastics
ENI-Biorefinery di Gela, Sicily. Commercial	Ecofining technology 600 ktons/year HVO productions.	Biomass with no food chain competition. e.g. vegetable oil, frying oil, fats, fats from fish and meat industry and waste by-products	Fuels, Hydrotreated Vegetable Oil (HVO)
Matrica-Porto Torres, Sassari Commercial	Capacity 350 kton/year	Agricultural feedstock	Biolubricants, bioadditives, Azealic acid, Pelargolic acid

ENI-Porto Maghera, Venice. Commercial	Capacity 420 kton/year	Residues: food production waste, such as waste oils, animal fats.	HVO biofuels (Hydrotreated Vegetable Oil), green diesel, green naphtha
Biochemtex-Crescentino, Vercelli Demonstration	Capacity 40 kton/year Enzymatic hydrolysis technology	Lignocellulosic biomass	Bioethanol
Mater-Biotech-Bottrighe, Rovigo. Pilot	Capacity 30 kton/years Fermentation technology	Starch crop sugars, lignocellulosic biomass	Chemicals: 1,4 bio-butanediol
Reverdia-Cassano Spindola, Alessandria. Pilot	Capacity 10 kton/year	Starch and starch derivatives	Succinic acid
Versalis Biorefinery - Crescentino (Italy) Pilot	Capacity 40 kton/year	Hardwood (poplar), Agricultural residuals	Bioethanol, Lignin, Green electricity, Disinfectants

Major innovation, RD&I activities and funding

The Italian strategic RD&I program is the National Operational Program (PON), which contributes to the improvement of the quality of higher education and to the strengthening of research, technological development, and innovation. The program is strongly related to the development of green chemistry and it is aligned with the main objectives of HORIZON 2020 program.

The Italian 'Hydrogen Valley' is a project that aims to set the first Italian technological incubator for the development of a hydrogen supply chain (including production, transport storage and use of hydrogen), in collaboration with universities, research institutes, associations and companies, to boost the energy transition and decarbonisation. The project is led by ENEA and had an initial investment of 14 million euros.

At the European level, the Italian participation in R&D projects on biorefineries funded by H2020 is significant. More than 60 projects see the Italian participation, both as project leader and as project partner, 30 of which are Bio-based Industries Joint Undertaking (BBI JU) initiatives.

At the National level, Italy is involved in many projects on biorefineries in the framework of the National Operational Program on Research and Innovation. Novamont in collaboration with ENEA is leading a national project, the COMETA project, on the development of value chains for green chemistry.

ENEA has started, in collaboration with ENI Versalis, at the Trisaia Research Centre, the procedures for setting up a hydro-treatment pilot plant catalytic for the refining of bio-oils and the production of 15 kg/h of high viscosity bio-lubricant. The plant it will be used in the future for the refining of different bio-oils origin including lignocellulosic biomass pyrolysis oils (a complex mixture which is difficult to treat in current refineries), using renewable hydrogen, thus allowing experimentation and optimization on a pilot scale, with particular interest to the catalytic aspects.

3.8 THE NETHERLANDS

Introduction

For the Netherlands, biomass plays an important role in food supply and in the transition towards a bio-based and circular economy. The main objectives of these transitions are to reduce the dependence on fossil energy and fossil resources, to have an optimal use of raw materials and to achieve the necessary associated reduction in CO_2.

For the Dutch government the following eight pillars are vital in the development of bioeconomy policy:

- using resources within the planetary boundaries;
- reducing climate change;
- production for people;
- sustainable resource management;
- a stable and predictable legal framework;
- collaboration in the value chain;
- long-term research and innovation agenda;
- regional strategy and rural development.

Major Stakeholders

Governmental entities:

- Ministry of Economic Affairs and Climate Policy (EZK)
- Ministry of Agriculture, Nature and Food Quality (LNV)
- Netherlands Enterprise Agency (RVO)
- TKI Agri & Food
- TKI Biobased Economy (TKI.BBE)
- Topsector Energy
- Holland Chemistry (Topsector Chemistry)

Non-Governmental entities:

- Greenpeace
- Natuur & Milieu
- Natuurmonumenten (NM)
- State Forestry Service (SBB)

Universities and Research Institutes:

- Dutch Organisation for Scientific Research (NWO)
- Radboud University (RU)
- TU Delft (TU)
- University of Groningen (RUG)
- University of Twente (UT)
- Utrecht University (UU)
- Wageningen University (WU)
- Netherlands Institute for Catalysis Research (NIOK)
- Wageningen Research (WR)
- National centre for applied research on renewable energy and green resources (ACRRES)
- Netherlands Organisation for Applied Scientific Research (TNO)

Industrial partners and SME:

- AEB
- Avantium
- Albemarle Catalyst
- Alco Energy Rotterdam
- Biodiesel Amsterdam
- Biomass Technology Group (BTG)
- BioMCN
- Bumega
- Cargill
- Clean Energy for Me
- Corbion
- Cosun biobased products
- Croda
- DSM
- DS Smith Packaging
- Duynie
- Ecoson
- Eska Graphic Board
- Feyecon
- Grassa
- Harvestagg
- HyGear
- Hooglans Marrum
- Indugras
- Millvision
- Neste
- NewFoss
- OrgaWorld
- Photanol
- Port of Amsterdam
- Port of Rotterdam
- Rotie
- Smurfit Kappa
- VION
- VPK Packing Group

Relevant Policies and policy implementation

Currently, the Netherlands has an integrated approach for the Bioeconomy – Biobased Economy – Bioenergy.[49] At the beginning the main driver towards bioeconomy was set by the national targets on renewable energy which are set in the Renewable Energy Directive (EU-RED, 2009/28/EC). The Dutch energy policy aims to secure energy supply for the future and reduce emissions from the energy sector by increasing the share of renewable energy of final energy consumption at 14% share by 2020, 19% by 2023 and 25% by 2030.[50]

Since 2016, when "The Biomass 2030 – Strategic vision for implementation of biomass" appeared, the Dutch bio-based economy is going towards a broader vision for the creation of sustainable value from biomass to produce food, feed, chemicals, materials and energy.

And in 2019, the Dutch National Climate Agreement (Het Klimaatakkoord) was published. The main goal of the agreement is to achieve a 49% reduction in national greenhouse gas emissions by 2030 compared to 1990 levels. The aims are: to start consultations on how to achieve this target within five different sector platforms, to facilitate the debate on measures and to provide clear direction, each sector platform was assigned a sector-specific target regarding the reduction on emissions by 2030.

General use of biomass

It is considered that biomass for chemicals and materials in the Netherlands can significantly contribute towards the replacement of fossil resources and the concurrent reduction of CO_2 emissions.[51] In the Netherlands in 2015 the use of biomass for materials was 6.8 million tonnes dry matter for wood & paper and 0.2 for oils & fats million tonnes. The total use of biomass including bioenergy and biofuels 13.3 million tonnes.

[49] Presentation. "The Bioeconomy in the Netherlands opportunities for collaboration" Ir. Kees W. Kwant (2018). http://news.nost.jp/wordpress_en_3.4.1/wp-content/uploads/2018/11/1.1-Kees-Kwant-Netherlands-Enterprise-Agency-RVO.pdf

[50] Netherlands Climate and Energy Outlook 2020 - Summary © PBL Netherlands Environmental Assessment Agency The Hague, 2020 PBL publication number: 4299

[51] Strategic Biomass Vision for the Netherlands towards 2030. Ministry of Economy Affairs.

Summary of biorefineries, demonstration and pilot plants

Table 11. Operating biorefineries in the Netherlands (commercial, demonstration and pilot scale).

Facility	Description	Feedstock	Products
Alco Energy Rotterdam Biorefinery Commercial	Partnership Alco group (an ethanol production, distribution and trading group)-Vanden Avenne Commodities (trade, distribution and storage of grain and derivatives)	Cereals (grains)	Electricity, ethanol, animal feed
Bio-BTX Groningen Pilot	Uses a ICCP (Integrated Cascading Catalytic Pyrolysis) technology for the cost competitive production of drop-in aromatic chemical	Diverse feedstocks	Chemicals
Bio-MEG plant Demonstration	Avantium operates a bio-MEG -bio-MPG demonstration plant in the Netherlands since 2019	Sugars	Mono-ethylene glycol and mono-propylene glycol
Empyro Bioliquids Biorefinery Twente Commercial	Production of 20 million litres of pyrolysis oil per year that can be used for production of chemicals	Woody biomass	Pyrolysis oil
Zambezi process Pilot	Partnership Avantium, AkzoNobel, Chemport Europe, RWE and Staatsbosbeheer	Wood (Non-food biomass)	Chemicals: high-purity glucose and lignin
ACRRES Research Centre Lelystad. Pilot	National centre for applied research on renewable energy and green resources. Multi-purpose biorefining facilities	Digestible and fermentable residues	Diverse bio-based products
BBPIP Bio-based Products Innovation Plant Wageningen Pilot	R&D facility by Wageningen Food & Biobased Research (WFBR). To develop innovative processes to convert green raw materials (biomass) into bio-based products	Diverse feedstocks	Diverse bio-based products
Grassa Pilot	A mobile, small scale modular process installation. It has a capacity 1-5 tonnes fresh material per hours	Grasses and agro-residues	Protein for feed and fibres for based products
BioMCN Commercial	Production capacity 250 million liters biomethanol for transport	Bio-methanol from waste digestion plants	Biomethanol
Musim Mas glycerine refinery Farmsum Commercial	A 200,000 Mt refining capacity	By-product glycerine	High quality glycerine for personal care, home care, food & pharmaceutical
Neste Biorefinery Rotterdam Commercial	The production capacity of the refinery is 1 million tons per year	Waste and residues	Fuels and chemicals
Photanol B.V. Corbion Nouryon Pilot	Photosynthesis, cyanobacteria capture CO_2, keep the carbon (C) and return oxygen (O_2) as a by-product.	CO_2	Chemicals
Avantium YXY® Technology -Geleen Pilot	Catalytical conversion of plant-based sugar into FDCA a building block for a wide range of plant-based chemicals and plastics	Fructose	Polyethylene furanoate (PEF)

Major innovation activities, RD&I activities and funding [52]

In the short term, for the Netherlands it is very important to make efforts to develop biorefining technology for the cascaded use of biomass in order to enhance financial gains and reduce the use of fossil fuels e.g. in the chemical sector.

In the long term, there is a need for alternative protein production to strongly reduce the amount of land required for fodder. Innovation relating to CO_2 as a raw material and bioenergy carbon utilisation or storage (BECCUS) is essential for this purpose.

The major innovation activities can be summarized in the following projects:

- Bioasphalt made of lignin (Chaplin)
- Biobased Performance Materials (BPM)
- DEI+ programme
- MOOI programme
- Scaling up lignin crude
- Small-scale biorefining
- TKI BBE Biorefinery Projects

Funding programs like the 'Stimuleringsregeling Duurzame Energieproductie' (SDE+), the Incentive Scheme for Sustainable Energy Production initiated a system of feed-in premium allocation subsidising renewable energy in the electricity, heat and gas sectors.

The Topsector Energy (TSE) funding is the driving force behind innovations that are necessary for the transition to an affordable, reliable, and sustainable energy system.

In 2015, a new Research Agenda for the Bio-based Economy was produced by the Top Consortium for Knowledge and Innovation named TKI-BBE. The TKI-BBE operates within the Top sector Chemistry and Energy and stimulates the development of this bio-cascading

The Funding for small and medium enterprises is also important and it was created to connect to the innovation agendas of the Topsectors. Subsidies given for: Advisory projects, feasibility projects, R&D-cooperation projects.

3.9 SWEDEN

Introduction

The production and refining of biomass contribute significantly to the Swedish economy. Sweden's natural resources include important forestry areas and agricultural lands, while marine resources (including fisheries, microalgae and macroalgae) are relatively less utilized, although with growing interest. Sweden has good conditions to facilitate a conversion to a bio-based economy. Industry has retained its competitiveness through increased production and harvesting of the biomass through genetic breeding programmes, more efficient production and harvest methods and processing.[53] Compared to its population, Sweden holds both large areal land for forestry and agriculture as well as a rather broad industrial setting and thus the interest in biorefining of side streams and residues from forestry as well as from agriculture hold a large interest for a broad range of applications in incumbent industry, e.g. refinery industry, chemical process industry, iron and steam industry, food and feed industry etc.

[52] National Policy Statement on the Bioeconomy. Department of the Taoiseach. Government of Ireland. February 2018.
[53] Swedish Research and Innovation Strategy for a Biobased Economy Report: R3:2012 ISBN 978-91-540-6068-9

Major Stakeholders

Viewing the bioeconomy as something which cuts across all industry and society, Sweden has encouraged different stakeholders to work together to build the Sweden bioeconomy.

Important governmental entities (non-exhaustive):

- Swedish Energy Agency
- VINNOVA (Sweden's innovation agency)
- FORMAS
- The Swedish Ministry of the Environment
- The Swedish Ministry of Infrastructure
- The Swedish Forest Agency
- The Swedish Board of Agriculture
- Swedish Enivronmental Protection Agency

Non-governmental entities (non-exhaustive):

- BioInnovation
- Swedish Bioenergy Association
- Energiforsk
- Innovation and Chemical Industries in Sweden (IKEM)
- The Federation of Swedish Farmers (LRF)
- Drivkraft Sverige (former SPBI)
- Swedenergy- Energiföretagen i Sverige

Universities and Research Institutes with significant research in the field:

- Luleå University of Technology
- SLU - The Swedish University of Agriculture
- Umeå University of Technology
- Chalmers University of Technology
- KTH Royal Institute of Technology
- Lund University
- Mid Sweden University
- Linköping University of Technology
- Karlstad University
- RISE- Research Institutes of Sweden
- IVL Swedish Environmental Research Institute

Examples of industrial actors and SMEs (non-exhaustive):

- Adesso Bioproducts
- BILLERUDKORSNÄS
- Colabitoil
- Energifabriken
- Foodhills
- Metso
- HOLMEN
- Indienz
- Kraton Chemical
- Lantmännen Agroethanol
- Liquid Wind
- MoRe Research
- Norra Skogsägarna
- Nouryon
- Organo Fuels Sweden
- Perstorp
- Piteå Science Park/Bothnia Bioindustries Cluster Skellefteå Kraft
- PREEM
- Pyrocell
- Renfuel
- SCA
- SEKAB
- Setra
- Skellefteå Kraft
- SmurfitKappa
- St1
- Stora Enso
- SunCarbon
- Sunpine
- Södra
- Umeå Energi
- Valmet
- VEAB
- Votion Biorefineries
- Wargön Innovation
- Övik Energi

Relevant Policies and policy implementation

Since 1970, Sweden has been implementing policies to promote the use of biomass mainly through the implementation of tax programs and certificates schemes to provide an incentive to the production and use of renewable energy and the reduction of GHG emissions.

The main drivers for the development of Sweden bioenergy and bioeconomy related policies include[54]:

- contribution/implementation of the EU strategy on Bioeconomy;
- independence from fossil resources/security of supply;
- development of new bioeconomy sectors (bioenergy, industrial bio-based products);
- new business, increased employment;
- mitigation of climate change/adaptation to climate change;
- resource efficient economy (reduction of waste, use of residues) (JCR, SCAR, 2014).

Since 2011 the Government commissioned FORMAS, VINNOVA and the Swedish Energy Agency to submit a proposal for a national strategy for the development of a bio-based economy (bioeconomy). In 2019, the Swedish parliament instructed to start the National bioeconomy strategy, where the government together with the green sectors will look for increased access to biomass and employment and create environmental and climate benefits.[55] The strategy is still being elaborate.

The Climate Act and the Climate Policy Framework, from 1 January 2018, establishes that the transport sector's climate impact will decrease by 70% by 2030 compared with 2010. The reduction quota means that the authorities will require an increasing proportion of renewable fuels such as biofuels to be mixed in fossil fuels. The share of biofuels should then be at least 40%. The reduction quota system is being updated at specific control stations; one such being negotiated during 2021 where the specific reduction levels are to be specified for the coming years. In 2022, as a response to rapidly increasing prices for transport fuels, the Swedish Government suggested a pause for the reduction quota system. This suggestion freezes the reduction quota for 2023 on the same level as the one for 2022.

General use of biomass

The main biomass resources in Sweden come from forests and agriculture. In the last 5 years, the use of biomass has increased significantly in the transport sector (biofuels), while the use in other sectors remains rather constant. According to the 2019 data, the main three sources of energy supply in Sweden included: nuclear fuels (33%), biofuels (26.5%) and fossil fuels (20.8%).[56]

The larges use of biofuels in Sweden is in the industry sector, e.g., in the pulp and paper industry (~35%), other main users are district heating generation, the transport sector, residential etc. and for electricity generation. Although it should be noted that most of the biomass uses for energetic purposes are side streams and residues from forestry and agriculture. Thus, it is the biomass for non-energetic purpose, such as the production systems for wood products (construction etc.) and production of pulp and paper and the systems around food and

[54] Development of the Nordic Bioeconomy, NCM reporting: Test centers for green energy solutions – Biorefineries and business needs. Nordic Council of Ministers 2015.
[55] Presentation. The Swedish bioeconomy strategy – work in progress Hans Nilsagård Senior advisor Ministry of Enterprise and Innovation KSLA, 9 June 2021
[56] Swedish Energy Agency.Energy in Sweden 2021 - An overview, ISBN (pdf) 978-91-7993-020-2. July 2021.

feed products in the agricultural sector which facilitates large parts of the use of biomass for energetic purposes in Sweden.

Summary of biorefineries, demonstration and pilot plants

Table 12. Operating biorefineries in Sweden (commercial, demonstration and pilot scale).

Facility	Description	Feedstock	Products
AAK-Dalby. Commercial	Processing of Swedish-grown rapeseed and a large number of different imported vegetable fats	Primary biomass oil crops: shea, palm, coconut, rapeseed and sunflower, soy	Vegetal specialty fats for food and cosmetic industry
Domsjö Fabriker Commercial	With production capacity: 230,000 tonnes cellulose, 120,000 tonnes lignin and 20,000 tonnes bioethanol	Forestry raw material: wood	Cellulose, lignin, bioethanol and Biogas
Ecobränsle, Karlshamn Commercial	Production capacity 55,000 ton biodiesel (RME)	Rapeseed and biomethanol	Biodiesel
Kraton Chemical AB Refinery, Sandarne Commercial	Distillation technology with a capacity of 170,000 ton of tall oil per year	Crude tall oil	Chemicals and polymers
Lantmännen Agroetanol Commercial	The capacity today is about 230,000 m^3 of ethanol and 200,000 tons of protein feed (DDGS)	Grains, waste and residues from the food industry, agriculture, and forestry	Ethanol and protein feed
Adesso RME plant Bioproducts, Stenugsund Commercial	Perstorp produce180,000 m^3 biodiesel (RME) per year	Rapeseed	Biodiesel and glycerol
Preem Commercial	Production of hydrotreated vegetable oil (HVO); Technologies: hydrocracking or hydrogenation	Residual raw tall oil. derived from black liquor in pulp mills	Biodiesel HVO
Pyrocell Commercial	Pyrolysis plant jointly owned by Setra and Preem	Residues: Sawdust	Bio-oil (for coprocessing)
ST1 Gothenburg, Ethanol (Etanolix)Plant (NEOT) Commercial	The annual production capacity of 5,000 m3 of advanced bioethanol	Residues: biowaste and process residue from local bakeries and bread from shops	Bioethanol, animal feed and biogas
Sunpine-Piteå Commercial	Production capacity of 100 million litres of tall diesel per year	Crude tall oil	Biodiesel, rosin, bio-oil, sulphate turpentine and district heating.
Södra Mönsterås Liquid Forest™ Commercial	A new extraction process, allows the production of commercial grade methanol	Wood chip	Biomethanol
Södra Mörrum Commercial	Capacity of 20 tonnes of used textile	Used textiles: cotton-polyester blends.	Materials cotton fibres
RISE Processum Biorefinery Örnsköldsvik Demonstration	Capacity of 2 tonnes of feedstock per 24 hours. Hydrothermal reactions	Residual products from forestry and agriculture	Carbohydrates, lignin, proteins, enzymes, chemicals, material and ethanol

Lignoboost- Domsjö Bäckhammar Demostration	Capacity of 8 000 tons of lignin per year. Extraction process	Residual black liquor	High purity lignin.
Gobigas-Gothenburg (mothballed demonstration	Biomass gasification and biomethane synthesis	Forestry residues, such as tops and branches	Biogas
Indienz AB, Anneberg-Skåne Pilot	Fermentation process	Residual products from agriculture and forestry	Biohydrogen and recombinant protein
Colabitoil- Norrsundet Pilot	Producing Hydrotreated Vegetable Oil (HVO)	Residues: used cooking oil	New bio-based petrol and aviation fuel products
LTU Green Fuel-Piteå Pilot (mothballed demonstration)	Gasification	forest industry residues	synthesis gas and green fuels
RenFuel-Bäckhammar. Pilot	Catalytic process	residual black liquor	lignin oil (Lignol)
SCA Obbola-Umeå (under construction) Pilot	Future capacity of up to 300,000 tonnes of biofuels	Black liquor	liquid biofuels and chemicals

Major innovation, RD&I activities, and funding

Achieving a bio-based economy requires, in addition to research and development, demonstration projects. The major innovation and RD&I activities are related to the development of new bioenergy technologies and biorefinery conversion processes for the co-production of biofuels, biochemicals and new materials using forest and agricultural residues as well as the development of bioenergy with carbon capture and storage and utilization.

Diverse governmental and non-governmental organisations provide the funding to conduct these initiatives and programs, some of them are described in more detail in the following section.

- BioInnovation: a joint industry initiative with focus on materials, construction and design and chemicals and energy. The initiative was funded by VINNOVA, the Swedish Energy Agency and FORMAS.

- Bio4Energy: a program to create links and collaboration between the academic clusters and the industrial actors regarding the biorefinery of forest raw materials and organic waste, collaboration between Umeå University, Luleå University of Technology and SLU - The Swedish University of Agriculture. Funding provided by the Swedish Government (directed strategic governmental funding).

- Chalmers Energy Initiative (CEI): focuses on the development of biomass-based energy combine, thermochemical conversion of biomass, chemical and biochemical conversion of biomass and process integration to partly transform chemical pulp mills into energy combines for production of fuels and products. Funding provided by the Swedish Government (directed strategic governmental funding).

- The biofuels program and the new Bio+ programme: funded by the Swedish Energy Agency with the objective to develop technologies needed to broader the market of biofuels produced from lignocellulose or residual products, to develop biofuels for aviation, to demonstrate and promote the use of ethanol and biogas for heavy transport. From 2021 these programmes and other biomass related efforts have been replaced by a large programme (+100 MSEK/yr) at the Swedish Energy Agency gathering all biomass activities in one programme, this is called Bio+ and the first call was closed in June 2021. The Swedish Energy Agency also hosts an active Pilot and Demonstration Programme, this is not exclusive for bio-applications but has funded several projects supporting biorefinery development.

- F3-Swedish knowledge centre for renewable transports: f3 activities are focused on increasing the knowledge about future transport systems with renewable and sustainable fuels. F3 is financed jointly by the centre partners, the Swedish Energy Agency, and the region of Västra Götaland. As of 2022 f3 is run as an innovation cluster.

- SET4Bio and SET-Plan: The SET4Bio project aims to build-up a cost-competitive bioenergy and renewable fuels market in Europe via the Integrated Strategic Energy Technology (SET) Plan endorsed by EU Member States. The project brings together private and public stakeholders to mobilize the resources and to stimulate the investments for the deployment of bioenergy and renewable fuels at large scale in Europe. Funding was provided by the European Union’s Horizon 2020 research and innovation programme.

For commercial installations and first of a kind plants also other instruments could be used such as investment support programmes. In Sweden there are two major examples supporting amongst other sustainable investments also investments related to the bioeconomy, these are the Climate Leap Program (Klimatklivet, hosted by the Swedish Environmental Agency) and the Industry Leap Program (Industriklivet, hosted by the Swedish Energy Agency). These initiatives provide and have contributed to the investment and construction of several biogas facilities as well as other biofuel initiatives.

3.10 KEY EXAMPLES OF BIOREFINERIES IN THE TASK 42 COUNTRIES

Several key examples of biorefineries in the eight IEA Bioenergy Task 42 countries have been listed in Appendix 1. These key examples were chosen by the representatives of each country. For each key example the following topics are described:

- state-of the art;
- type of biorefinery;
- location;
- owner;
- feedstocks;
- conversion processes;
- outputs/products;
- description;
- contact details.

What defines the success of a key example is not that straightforward of course. This depends on many factors like the goals that were set for the biorefinery and the assessment of the results and the impact that was achieved. Each country was free to decide on the specific success stories for their own key examples, since this largely depends on the national situation.

So no common criteria were used that apply for all the countries. In the case of Austria[57] success stories of biorefineries related e.g. to the contribution of the biorefinery to:

- reaching the climate goals;
- reducing dependency of non-renewable raw materials;
- promoting innovation;
- promoting economic development;
- protecting and creating jobs;
- promoting sustainable societal transformation.

Appendix 1. contains the following key examples of biorefineries in the Task 42 countries:

- Sarina Biorefinery MacKay, Queensland (Australia)
- Manildra Nowra Biorefinery (Australia)
- Lenzing AG Biorefinery (Austria)
- AGRANA Biorefinery Pischelsdorf (Austria)
- Billund Biorefinery (Denmark)
- BIOWERT (Germany)
- Cellulac (Ireland)
- Versalis Biorefinery - Crescentino (Italy)
- Biorefinery di Gela (Italy)
- Empyro Bioliquids Biorefinery (The Netherlands)
- Avantium YXY® Technology (The Netherlands)
- Södra Mönsterås Liquid Forest™ (Sweden)
- Lantmännen Agroethanol (Sweden)

3.11 GENERAL CONCLUSIONS

For most of the countries, the biorefinery concept is implicit in the national bioeconomy strategies plans. Bioeconomy is seen as a mean to minimize their dependency on fossil-based raw materials, specially from fossil-based energy. Bioeconomy is highly driven by the country's commitments to reach the climate goals and agreements.

The biorefinery concept is frequently seen as an opportunity to make more efficient the use of the natural resources and a good opportunity to stimulate the rural and regional economic development and social transformation. For countries with a relevant agri-food sector it is also an opportunity to strength the link between primary production and industry and to valorise residual-waste streams and promote innovation.

In the case of European countries there is interest to develop expertise and to reach a leadership position in sustainable bioeconomy, which is seen as the future economy.

[57]https://www.bmvit.gv.at/innovation/publikationen/energieumwelttechnologie/biooekonomiestrategie.html

4. Analysis of the global deployment status of biorefineries

This chapter describes the analysis of the deployment status of biorefineries in different areas of the world based on the content of two databases.

4.1 IEA BIOENERGY TASK 42 DATABASE & BIOREFINERY PLANT PORTAL

For this analysis first of all the newly developed Task 42 Biorefinery Atlas Portal was used, which gives an overview of the world-wide biorefinery deployment status of biorefineries. The opening page of the Biorefinery Plant Portal (https://task42.ieabioenergy.com/databases/) contains a map of the world with all biorefineries that are known by Task 42 (Figure 4). In this general overview there is an option to zoom in on a certain region. Furthermore, one can narrow down the selection of biorefinery plants that are shown by selecting specific features from the navigation column on the left. In that column one can choose to display features for feedstock, production capacity, TRL refining technology and product, and to download self-selected data subsets. Finally details of a specific biorefinery record that was chosen on the map can be shown in a pop-up window. The Task 42 biorefinery database that is the basis of the Task 42 Biorefinery Atlas Portal can be updated continuously. Therefore, stakeholders are invited to provide extra data on biorefineries in case these data are missing at the moment.

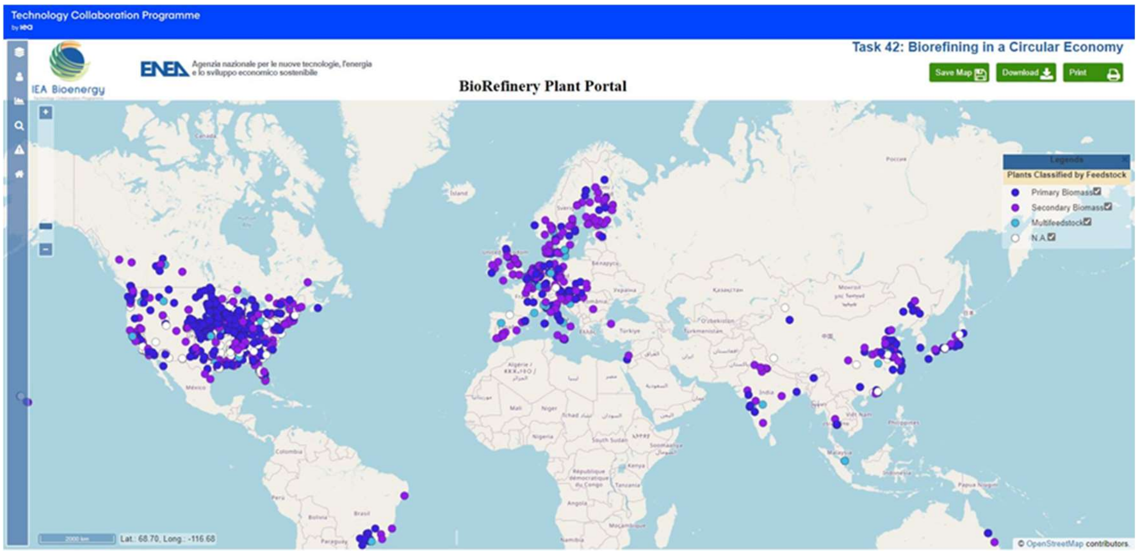


Figure 4. Biorefinery Atlas Portal (https://task42.ieabioenergy.com/databases/).

4.2 BIOREFINERY OUTLOOK PROJECT DATABASE

Unfortunately, the records of the Biorefinery Outlook database have not yet been included in the Task 42 Biorefinery Atlas Portal. However, they could be used for the analysis that will be described in the following sections. Therefore, IEA Bioenergy Task 42 wants to acknowledge and thank the colleagues from BTG and JRC for providing the Biorefinery Outlook database for our analysis. The Biorefinery Outlook database was based on an existing JRC bioeconomy database and was expanded based on the updated biorefineries classification work (see Section 2.2), and on further research of running and planned projects (including input from stakeholders).

The focus in the Biorefinery Outlook database is on chemical/material driven biorefineries (including also use of effluent gases, such as CO_2 and CO for biochemicals etc.) producing bio-chemical and bio-materials as their main products, including the production of innovative high value bio-based products. Traditional bio-based products such as pulp and paper and wood products and biomass as an energy source were not focused upon in this database. Furthermore, the Biorefinery Outlook database only shows the commercial biorefineries. Special care was taken to ensure not only focus on large installations. Besides the European countries the Biorefinery Outlook database also includes 10 non-EU countries: Norway, Switzerland, United Kingdom, USA, Canada, Australia, New Zealand, Japan, Brazil, China, India and Thailand.

4.3 COMBINED ANALYSIS OF THE TWO BIOREFINERY DATABASES

The analysis of the deployment status in this report made a combined use of the IEA Bioenergy Task 42 database and the Biorefinery Outlook database. So, the total number of operational biorefineries (1,312 records) in the analysis originates from two databases:

- Task 42 Biorefinery Atlas Portal (915 records);
- Biorefineries Outlook database (397 records).

Data sources used in the Task 42 Biorefinery Atlas Portal were diverse with more focus on energy-driven biorefineries:

- BBI-JU (7 records);
- Biofuel Digest (82 records);
- BioRefineries Blog (6 records);
- ENEA (1 record);
- IEA Bioenergy installations database (191 records);
- IEA Task 42 publications (53 records);
- Joint Bioeconomy survey JRC-SCAR-BBI-IEA 2019 (53 records);
- Power4Bio project (8 records);
- U.S. Department of Energy (514 records).

The Biorefineries Outlook database had a special focus on chemicals and material-driven biorefineries. The analysis excluded the biorefineries in the Task 42 Biorefinery Atlas Portal that were idle (52 records), cancelled (22 records), stopped construction (12 records) or shut down (21 records). Our analysis gave insight in several biorefinery characteristics that will be described in the next sections:

- geography;
- feedstock types;
- process and platform;
- product types.

4.4 GEOGRAPHY

As mentioned the total number of biorefineries in the analysis was 1,312 excluding the cancelled biorefineries (Figure 5). A total of 637 biorefineries were found in the United States. This large number of biorefineries in the US has been excluded from Figure 6 to avoid distortion of the bar chart, so that it is easier to see the numbers in the rest of the world:

- More than 40 biorefineries were found in the countries China, Finland, France, Germany, The Netherlands, Sweden and the United States.
- Between 10 and 40 biorefineries were found in Australia, Austria, Belgium, Brazil, Canada, Denmark, India, Italy, Japan, Spain and the United Kingdom.
- All other countries had less than 10 biorefineries.

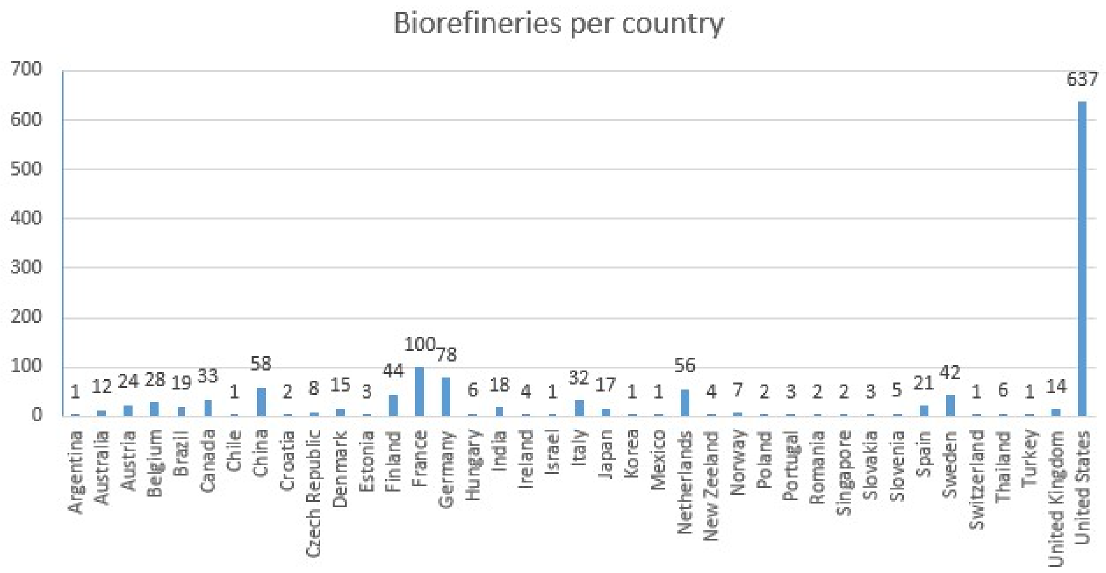


Figure 5. Biorefineries per country (excluding cancelled).

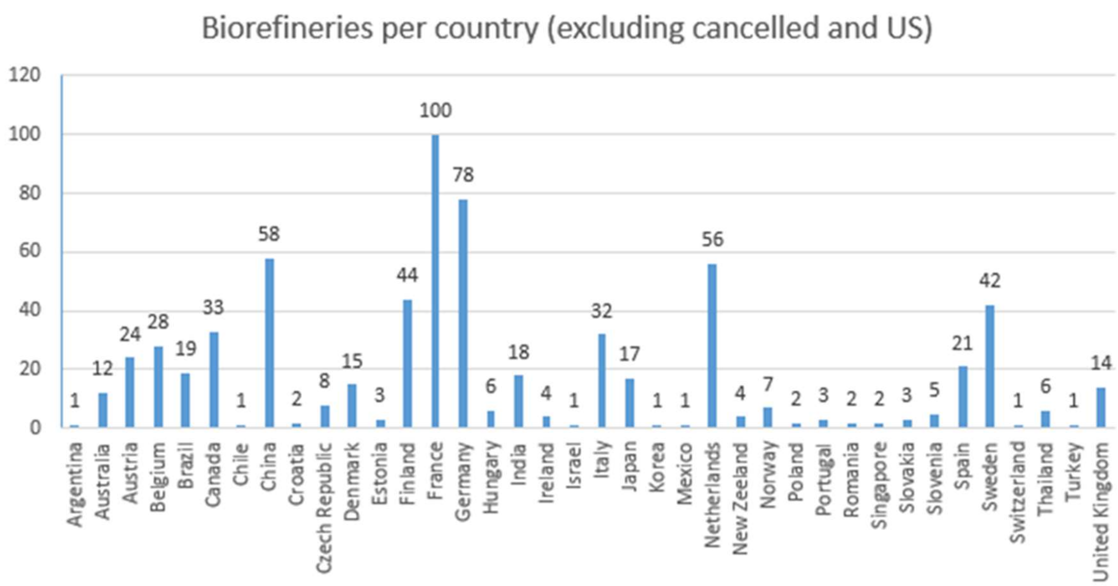


Figure 6. Biorefineries per country (excluding cancelled and US).

4.5 FEEDSTOCK TYPES

The main feedstock type of the biorefineries in the databases is primary biomass. However, secondary biomass is also an important feedstock for biorefineries (Figure 7). The main primary biomass feedstocks are starch crops and oil crops (Figure 8). Sugar crops, lignocellulosic biomass from crop lands/grass lands and lignocellulosic biomass from forestry are also important primary biomass feedstocks. The main secondary biomass feedstock is other organic residues followed by residues from agriculture and residues from forestry. Figure 9 shows the location of the biorefineries in the Task 42 Portal of Biorefineries based on the main feedstock type used. It can be seen that primary biomass based biorefineries (in blue) dominate the map, although there are also many secondary biomass based biorefineries. Please keep in mind that the 397 biorefineries of the Biorefinery Outlook database have not yet been included on this map.

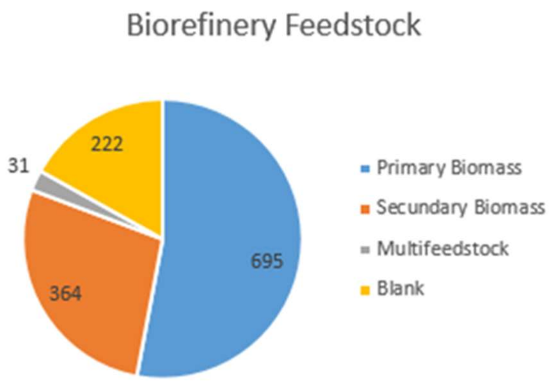


Figure 7. Main biorefinery feedstock types.

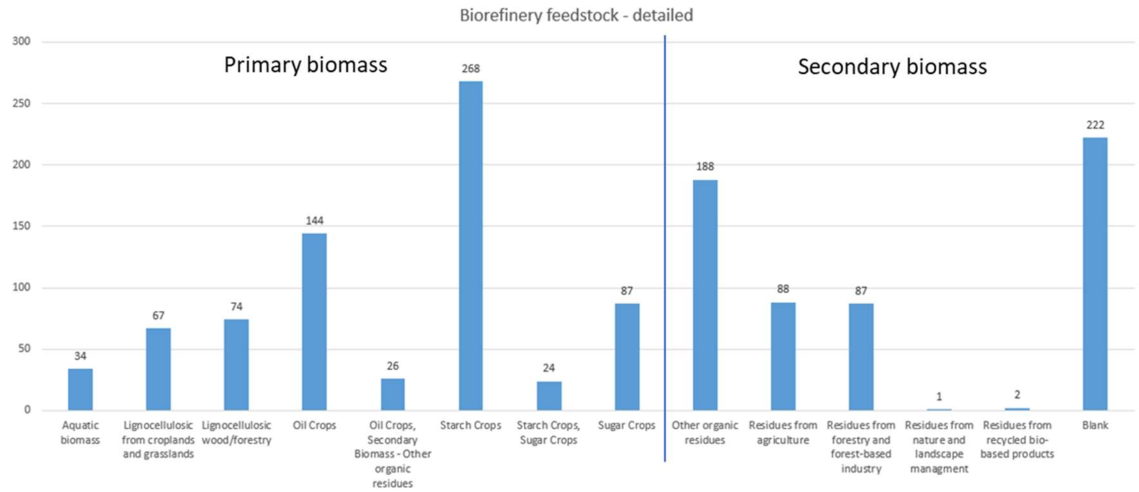


Figure 8. Main biorefinery feedstock types within primary and secondary biomass.

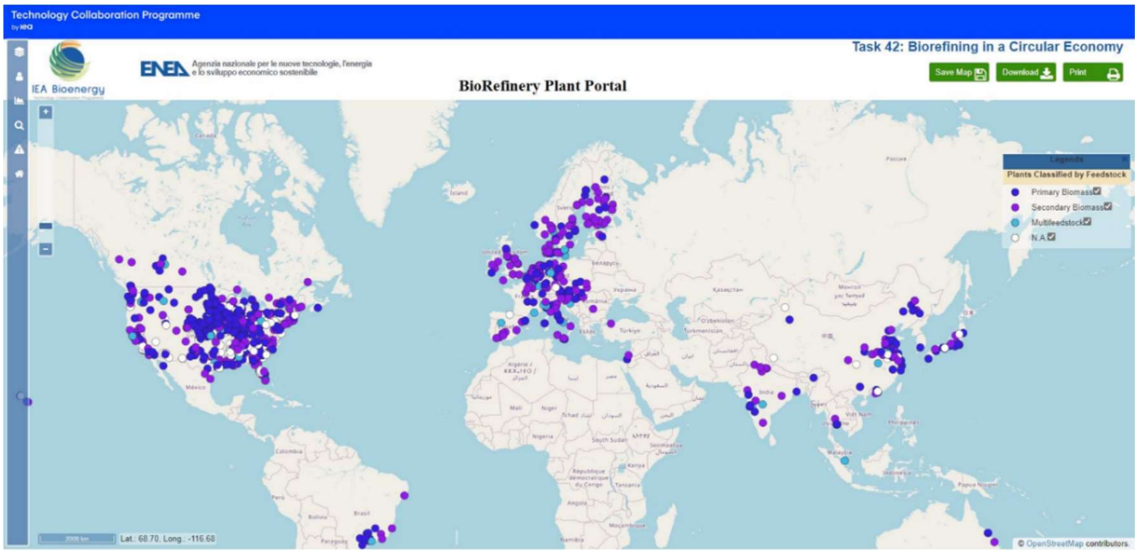


Figure 9. Representation of biorefineries in portal based on feedstock type.

4.6 PROCESS AND PLATFORM

Unfortunately, a large number of blanks (602 in total) had to be excluded from these process and platform results. Biochemical conversion is most commonly used in biorefineries and within that category fermentation sticks out (Figure 10 and 11). Chemical conversion is second in line with catalytic conversion, esterification and hydrogenation as specific technologies. Finally, mechanical and thermo-chemical conversion is often used with extraction, separation, gasification and pyrolysis as specific technologies.

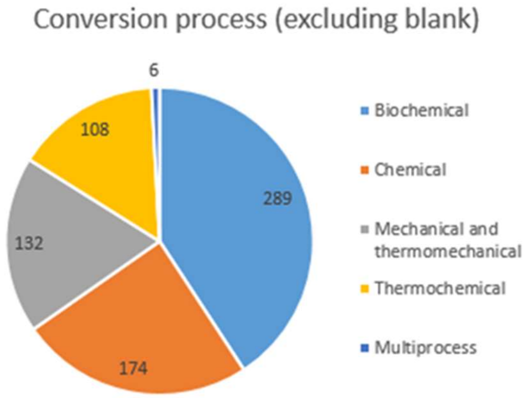


Figure 10. Main conversion processes.

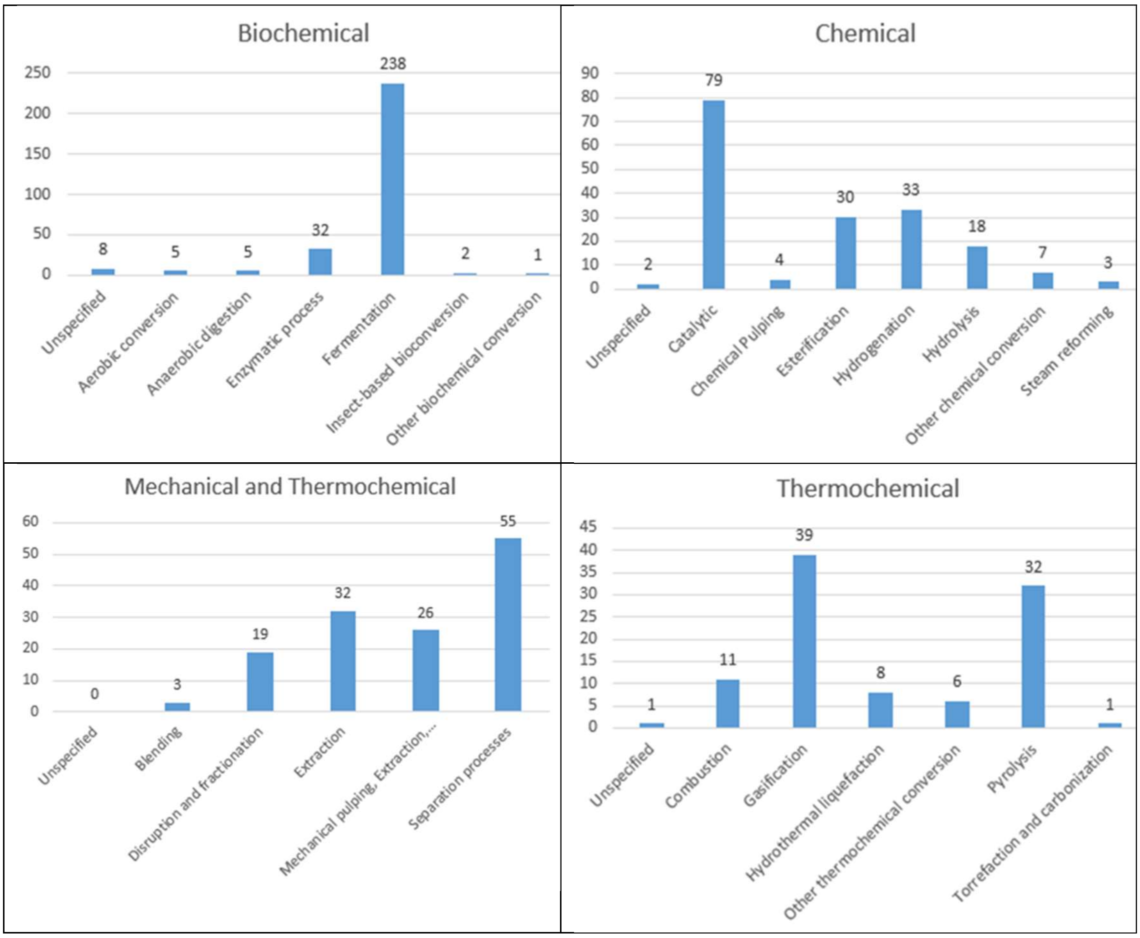


Figure 11. *Specific technologies within biochemical, chemical, mechanical & thermochemical and thermochemical conversion processes.*

Figure 12 shows the representation in the Portal of the biorefineries based on the main conversion process used. For the large number of blank dots for the US we can probably assume 'esterification' for biodiesel and 'fermentation' for bioethanol producing biorefineries. Fortunately, the attributes in the database can be updated easily and this can then be visualized in the Portal after each update again.

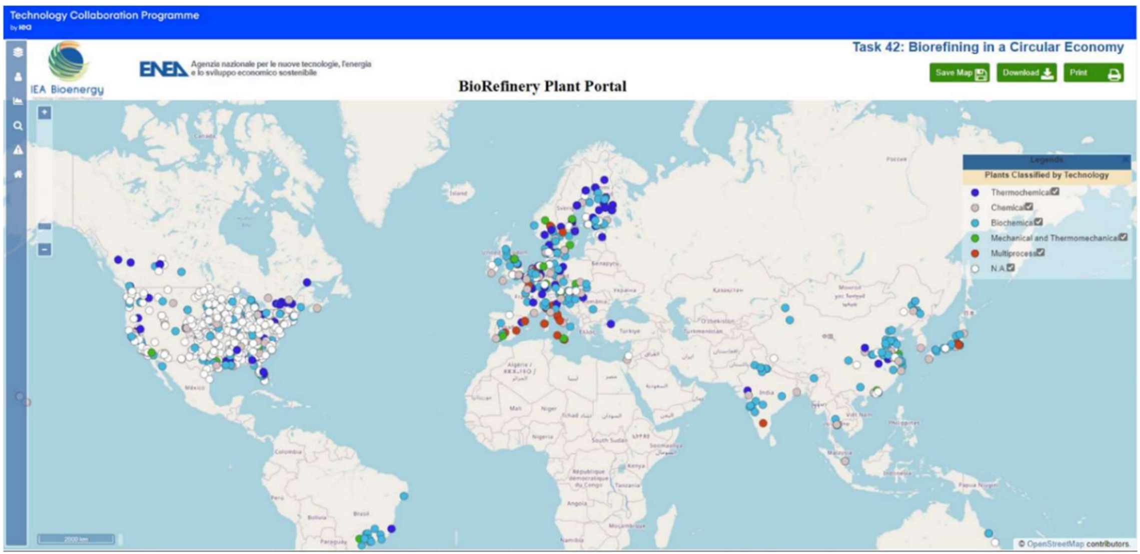


Figure 12. Representation of biorefineries in portal based on conversion process.

4.7 PRODUCT TYPES

The main biorefinery product group is still energy and especially the fuels type (Figure 13 and 14). Chemicals, although produced in a much smaller number of biorefineries, are also an important product group, with building blocks as the largest type, followed by pharmaceuticals and neutraceuticals. Materials is the smallest product group that still matters, with polymers and fibres as the main types. Figure 15 shows the representation of the Biorefineries based on the main products. It can be seen that the green colour of energy is dominating the map.

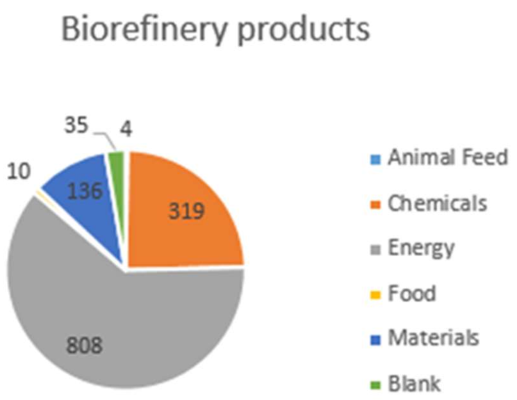


Figure 13. Main biorefinery product types.

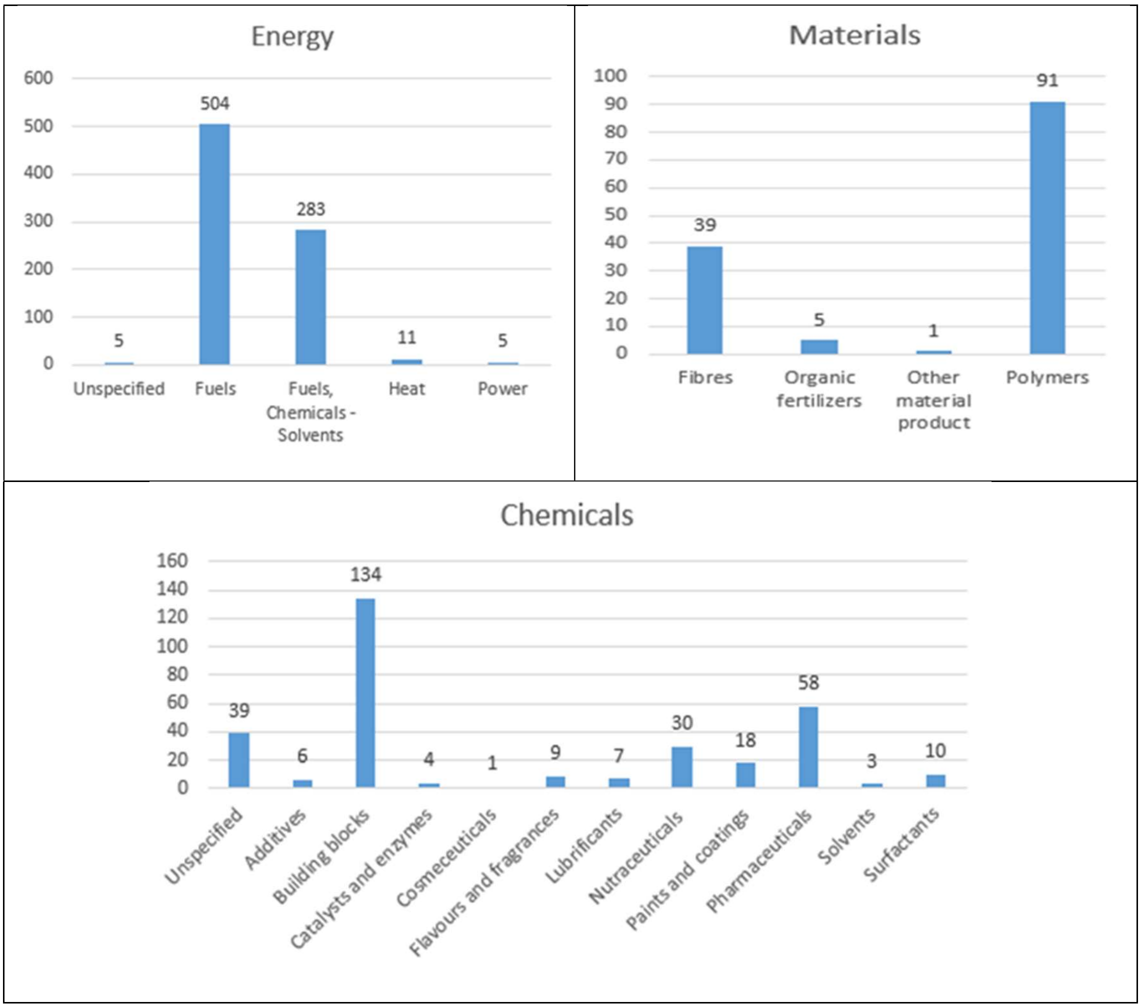


Figure 14. Product types within energy, materials and chemicals.

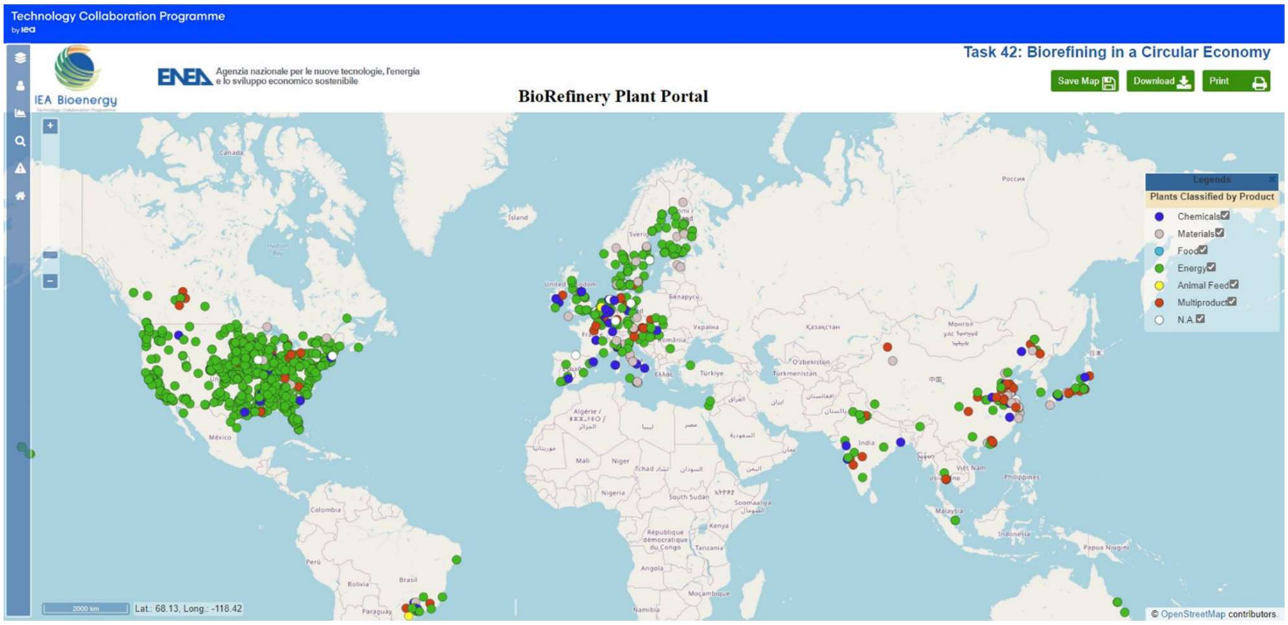


Figure 15. Representation of biorefineries in portal based on product types.

5. Major technical and non-technical biorefinery deployment barriers & potential solutions

5.1 TECHNICAL DEPLOYMENT BARRIERS AND POTENTIAL SOLUTIONS

General technical deployment barriers for the introduction of biorefineries have been described below for the four elements of the recently adopted classification system (see Section 2.2), viz feedstock, platform, conversion process and product.

Feedstock - In general the availability of sustainable biomass is considered to be an important barrier for the feedstock supply. Biorefinery Outlook (2021) recommends to design integrated feedstock supply systems in order to provide feedstock in a sustainable way at reasonable cost. Technical feedstock barriers mainly relate to the complex composition of biomass, which requires different pre-treatment and valorisation processes. Furthermore, the infrastructure for feedstock harvesting, collection and storage is not always well developed yet, and still needs to be improved to increase sustainable biomass availability. An overview of feedstock related technical barriers and potential solutions is given in Table 13, which is based on Biorefinery Outlook (2021).

Table 13. Feedstock related barriers and potential solutions (modified from Biorefinery Outlook, 2021).

Technical Barrier	Potential solutions
Limited biomass cultivation due to restricted land availability for non-food uses	• Develop efficient and sustainable biomass production • Support and exploit the bioeconomy potential of rural areas • Use marginal land
Limited biomass cultivation due to climate changes that lead to drier circumstances	• Consider the use of resilient species and look for species that can grow on marginal land with lower input needs
Inefficient biomass harvesting methods	• Adopt harvesting technologies to access difficult terrains • Use ICT to decide on optimal time for harvesting
Degradation and loss of biomass quality due to storage problems	• Improve storage management and technology
Complex nature of the biomass feedstocks is leading to problems	• Implement the use of multiple and more advance pre-treatments and conversion processes • Produce biocommodities with standardised properties, e.g. pyrolysis oil, pellets
Unstable biomass supply due to seasonality, poor infrastructure, low quality and cost	• Implement systems for continuous supply • Use ICT to provide relevant knowledge regarding biomass in the entire supply chain

Poorly developed supply chain for the use of residues and recycling (collection, transport and processing)	• Develop a strong and sustainable residues management network • Enhance data availability for the identification, tracking and current uses residual biomass streams
Uncertainty regarding the guarantee of lower environmental impact (not only GHG)	• Promote the evaluation and development of integrated pathways to increase overall efficiency and lower environmental impact
Uncertainty regarding real cost of processing secondary feedstocks (residues and recycled bio-based materials)	• Evaluate the real (extra) cost of collecting, sorting, cleaning and processing of secondary biomass

Conversion process – The biorefinery conversion processes include the following steps: pre-treatment, primary refining, secondary refinery, purification, product conditioning and recovery and re-use of by-product streams. These biorefinery conversion processes are not yet optimal in many cases and sometimes still in an early stage of development. This leads to cost and productivity barriers that need to be overcome by various optimization steps that are described in Table 14.

Table 14. Conversion process related barriers and potential solutions (modified from Biorefinery Outlook, 2021).

Technical Barrier	Potential solutions
Constricted pre-treatment and conversion processes exclusive to produce a single product, reducing the possibility of other outlets	• Focus on improving the pre-treatment and primary conversion processes to extract a larger amount of usable material fractions toward diverse products • Establish decentralised pre-treatment processes (close to the biomass production) suitable for multiple biorefineries
Limited development of catalyst for thermochemical processes towards biomass upgrading	• Develop suitable R&D strategies for catalysts to increase feedstock flexibility in the conversion processes
Biochemical processes with low product concentration and multiple side products production leading to energy intensive and expensive downstream processes (recovery and purification steps)	• Develop and enhance the use of biotechnology to improve enzymatic pathways (biocatalyst) in biochemical processes
Limited development of out the box biotechnology for simultaneous biodegradation and biotransformation of biomass	• Promote R&D towards hybrid processes that look for integrated conversion (biodegradation–biotransformation)
Bottlenecks towards scale-up of new technology such as:	• Enhance R&D investments for research and engineering

• validation of technologies at demonstration and precommercial scale is expensive; • research teams with limited engineering know-how for scale-up; • limited biomass quality and availability for the scale-up.	• Collect reliable information or data from pilot scale biorefineries • Make available enough public money for co-financing pilot/demonstration plants • Continue with flagship initiatives for public-private partnerships projects
Economically unfavourable thermochemical processes to convert secondary biomass (residues) to added value products	• Integrate thermochemical processing with other conversion technologies (i.e., biochemical), and evaluate more economic alternatives
Limited integration of primary and secondary conversion processing to exploit advantages of process integration	• Consider the integration of conversion processes in existing industrial facilities or industrial complexes

Platform & Product - The technical barriers and solutions for Platforms (intermediate products) and Products are discussed here together in Table 15. Assuring the real environmental benefits (e.g. a reduction of GHG emissions) of the use of bio-based products can be a technical barrier. So technical developments need to focus on generating new knowledge to continuously improve product performance. A more detailed description of technical barriers and solutions for the specific pathways (see Section 2.3) is given in Biorefinery Outlook (2021).

Table 15. Platform (intermediate product) and product related barriers and potential solutions (modified from Biorefinery Outlook, 2021).

Technical Barrier	Potential solutions
Relative low diversification of intermediate products into new products due to loss of functionalities or properties during the processing	• Improve separation and extraction processes for valuable ingredients • Find milder operational conditions during pre-treatment and primary conversion processes
Bio-based products sometimes have a lower quality and lower performance compared to conventional alternatives (mostly fossil based)	• Perform (mechanical or chemical) modifications to improve product properties and broaden the applications to other markets • Modification of conversion processes to prevent excessive biomass damage (e.g. proteins denaturalisation)
Lack of cost competitiveness when providing the same functionally	• Optimisation and integration of the conversion processes and upgrade of biomass side-streams to high value products
Difficulties to demonstrate the bio-based product performance or new functionalities	• Involve external partners downstream in the value chain at an early stage of the product development

	• Implement matchmaking programmes to match companies in different parts of the value chain with each other
Lack of recognition of bio-based content in products	• Certification and standardisation for bio-based products including the measure of the bio-based content in products
Lack of information and recognition of environmental benefits	• Development of instruments to communicate about the benefits of bio-based products to public procurers and consumer

The Biorefinery Outlook (2021) report identifies specific Research, Development and Innovations (RD&I) needs to overcome technical barriers looking at specific product examples in ten different product groups. The main RD&I recommendations mentioned are:

- Financial support is necessary over the full RD&I-trajectory (fundamental research, applied research and piloting, demonstration and market support for 1st of a kind commercial applications) to raise the TRL level of enabling innovative biorefining technologies.
- Robust, feedstock flexible, biorefining technologies and logistical systems (transport, storage) should be developed to be able to process the full available biomass potential, which is very diverse, being able to meet a varying feedstock market demand (volumes over time and place, right quality).
- Primary biorefinery (pre-treatment) technologies should be developed converting various and low-quality biomass feedstocks in higher quality biocommodities that meet the processing requirements of a variety of biorefining technologies for widescale use.
- Secondary biorefinery processes (fermentation, gasification, incl. DSP) should become more energy efficient and product selective to increase market competitiveness.
- Develop a more clear and understandable assessment approach of the overall sustainability (incl. end-of-life strategies) of the bio-based products, linked to an efficient communication strategy. This will enhance market acceptance and consumer awareness, supporting market deployment

5.2 NON-TECHNICAL DEPLOYMENT DRIVERS AND BARRIERS

General non-technical deployment drivers and barriers were defined by the Biorefinery Outlook (2021) in the following categories: business, innovation, economic, access to feedstock, environmental, societal and policy. A modified overview of these drivers and barriers is given in Table 16. They were prioritised by stakeholders for the European situation. The forthcoming European legislation (e.g. Green Deal) is seen as the main driver for biorefinery deployment, followed by government support for R&D and scale-up, the need to reduce fossil dependence, functional benefits of bio-based products and the growing awareness of impacts of using fossil resources.

Table 16. General non-technical drivers and barriers (modified from Biorefinery Outlook, 2021).

Category	Drivers	Barriers
Business	• Functional benefits of bio-based products • Green premium prices • Lower cost over product lifecycle • Corporate social responsibility policies • Favourable purchase policies • Rising demand • Promotional benefits • Increasing number of bio-based applications • Flexibility through wider range of products	• Lower quality compared to fossil-based equivalents • High production costs • Low willingness of consumers to pay more for bio-based products • Multiple products divide focus of biorefineries • Better properties or functionalities are required to justify higher price • Difficult to enter existing markets
Innovation	• Willingness to investment in green innovations is high • Widespread support for R&D activities	• Lack of investments • Difficult to finance scale-ups
Economy	• Volatile oil & petrochemical prices • Opportunity to grow and protect jobs • Stimulating for development of rural farming communities • Availability of skilled workforce • Willingness to investment in bio-based production • Distributed and decentralised bio-economy models build resilience in supply chains	• Volatile oil & petrochemical prices • High cost levels in certain regions
Access to feedstock	• Flexibility in supply chain through diverse feedstocks • Crops on marginal lands • Forests have many other functions besides feedstock supply • Growing availability of source-separated bio-waste	• Increased land use • Perceived biomass availability too low • High, fluctuating or increasing biomass prices • Perceived competition with food & feed for land
Climate change and environment	• Bioeconomy at centre of sustainable development strategies • Need to reduce fossil dependence • Environmental benefits of bio-based products	• Less exclusive focus on using bio-based materials • Assessing environmental sustainability with LCA is expensive • Sustainability requirements for bio-based products stricter than for fossil-based products • Recycling issues
Societal (citizen and society)	• Growing consumer preference for green products • Growing awareness impact fossil products • Positive attitude towards bio-based products	• Bio-based is a poor marketing term • Low public awareness of biorefinery products • Confusing terminology (e.g. bio-based and biodegradable) • Perception of lower quality or higher price related to bio-based

	• Increase in personal and occupational health and safety • Preference for natural fibres • Promotional benefits	• Bio-based no longer convincing sale argument • Doubt on the use of biomass and cutting trees
Policy and regulation	• New dedicated legislation is expected to boost biorefinery products • For some bio-based products standards and eco-labels exits	• No or less financial support for chemicals and materials from biorefineries compared to support for bioenergy and biofuels • Lack of level playing field • For many bio-based products relevant product standards and eco-labels are still missing • Existing general legislation contain aspects that could hinder biorefinery products • Lack of stable, long-term regulations proving certainty for investors

High (production) costs are considered to be the main barrier for biorefinery deployment, although the consumer's willingness to pay more for bio-based products and the complex nature of biomass feedstocks received an almost equally high score. The lack of evidence on sustainability and the perceived competition with food were also considered important.

5.3 INSIGHTS FROM AN IMPORTANCE-PERFORMANCE ANALYSIS OF THREE BIOREFINERY CONCEPTS

The previous Section 5.1 technical barriers and Section 5.2 non-technical barriers to commercialization of biorefineries along the biorefinery value chain (feedstock, platform, conversion process and product) showed that technical barriers are associated to the existing market environment. It comprises and is shaped for instance by competitors, customers, societal expectations and policy, whereby the direction of the driving force is vague (push/pull). In light of various biorefinery concepts, their target markets and their differing technological maturity, we can assume that barriers to commercialization differ. This is the reason for investigating three specific biorefinery concepts contrary to biorefinery in general. It is advantageous to develop specific knowledge about market environment to be able to develop strategies on how to bridge the so-called valley(s) of death, the gap between lab and market. This gap might have evolved, because R&D activities prior to market introduction strongly focussed on technological development and other interdisciplinary aspects (i.e. market demand, environmental aspects and societal acceptance) that shape innovation diffusion were underrepresented.

To gain insights on special concerns in a broader commercialization, an Importance-Performance Analysis (IPA) was conducted for three biorefinery concepts valorising lignocellulosic, green, and algal biomass. The IPA methodology was originally developed in the field of marketing to identify which product attributes customers perceive as important, and how they rate the level of performance. For the conducted study a mismatch of importance and performance ratings signals barriers to commercialization, which were specified in a survey among 70 international experts in the field of lignocellulosic, green, and algal biorefinery research. The experts were asked how important they rate (from 1 very unimportant to 5 very important) the factors feedstock supply, processing/conversion, applicability of raffinates and co-substances, demand for bioproducts, and dimensions of policy, economics, society and environment for a broad commercialisation of the lignocellulosic/green/algal biorefineries. They were additionally asked to rate the current performance (from 1 very poor to 5 very good) of these factors related to commercial scale lignocellulosic, green and algal biorefineries. Furthermore, they were asked to explain the most relevant specific commercialization barriers in terms of policy, economics, society and environment along the value chain.

5.3.1 Lignocellulosic Biorefineries

Lignocellulosic biorefinery - as it builds on pulping refinery - can be characterized as the most mature biorefinery concept, in the scope of this investigation. The analysis reveals the general tendency of high importance ratings with relatively lower performance. The perceived level of performance is however is generally good (see Figure 16). Resources should be invested to improve the current policy and economic performance of commercial scale biorefineries, which was rated lower than its importance. Low performance of policies addressing the feedstock supply, demand for bioproducts, economics and society and environment were stated such as need for more specific forest management regulations, ecologically driven tax systems or CO_2 pricing schemes for fossil-based products targeting to foster the demand for bioproducts. Low economic performance linked to:

- feedstock supply due to volatile feedstock prices;
- processing/conversion due to inefficient technology;
- and demand for bioproducts due to low willingness to pay more for bioproducts were stated.

The dependency of the factors becomes very clear and highlights the necessity to align measures implemented.

5.3.2 Green Biorefinery

The analysis of green biorefinery reveals similar mean performance and importance values compared to the lignocellulosic biorefinery. However, we see a tendency of lower performance ratings of policy and economic factors with higher importance at the same time (see Figure 17). Economic issues of concern were linked to an inefficient conversion processes, and therefore immature, complicated technology and no willingness to invest. The specification of the economic dimension to the bioproduct demand can be explained with reported low economic values of products from green biorefineries and cheap imported feed products like soybean feed, which were suppressing the competitiveness of green biorefinery products. Especially considering feedstock supply, the survey reveals the demand for policies to improve support for sustainable feedstocks and agriculture, and draws a link of policies to the societal and environmental dimension.

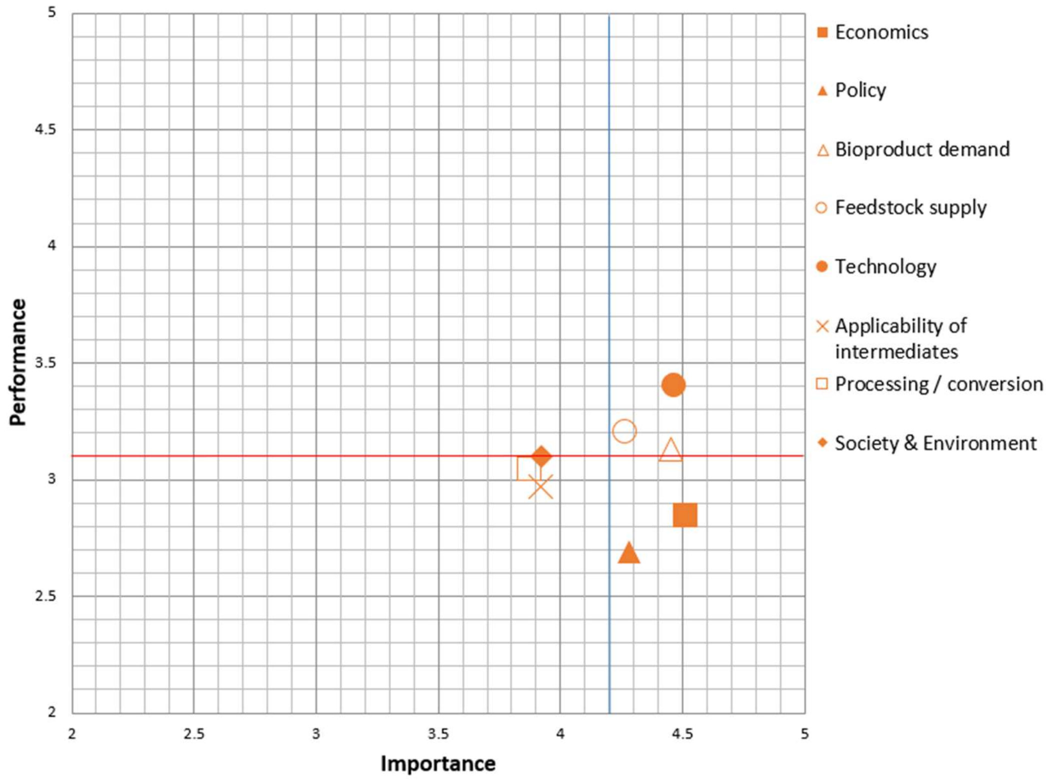


Figure 16. Importance-Performance-Matrix referring to data for lignocellulosic biorefineries. Red line: mean performance value, Blue line: mean importance value (source: modified from Hilz, 2021).

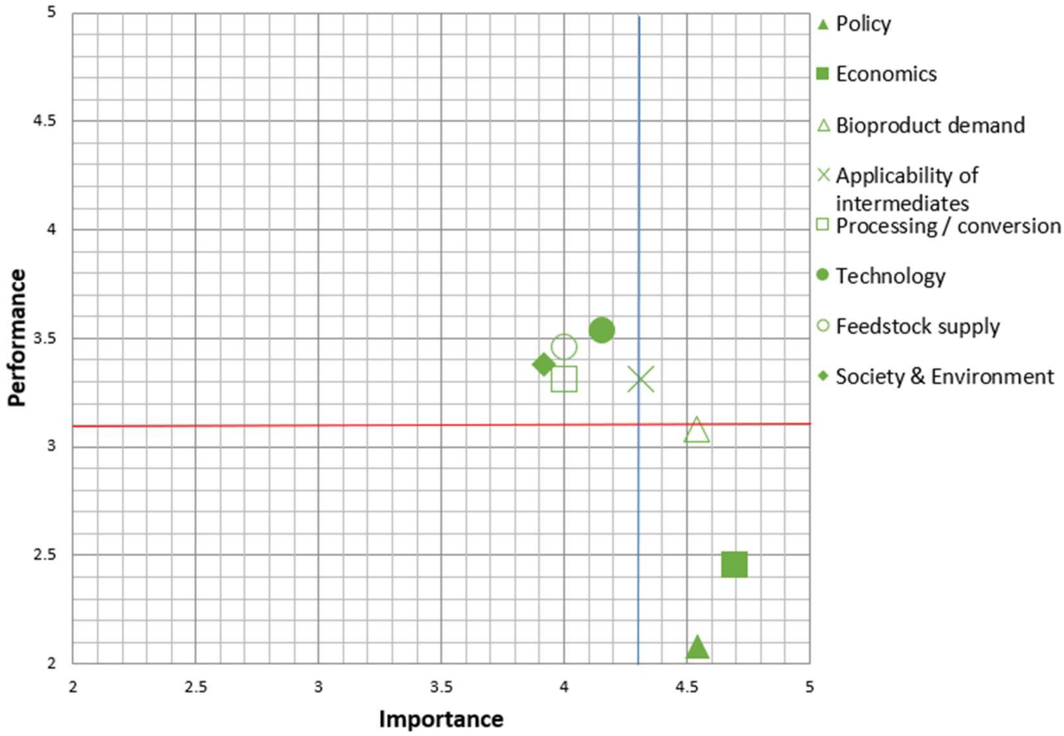


Figure 17. Importance-Performance-Matrix referring to data for green biorefineries. Red line: mean performance value, Blue line: mean importance value (source: modified from Hilz, 2021).

5.3.3 Algal Biorefinery

Algal biorefineries can be characterized the newest biorefinery concept in the scope of this investigation. We see higher mean importance ratings, but lower mean performance ratings compared to the two previously discussed biorefinery concepts. Also, here, the economic factors for commercialization show the biggest gap between perceived importance and performance. Especially the high investment costs and costs for feedstock cultivation were stated as issues in the economic dimension. Regarding societal and environmental issues, concerns about the sustainability of cultivation technologies were highlighted. Furthermore, the availability of suitable technologies was reported to be a commercialization barrier. Policies were most often mentioned as specific commercialisation barriers to the other factors, even though the category "Policy" was rated rather less important for a broad commercialisation, compared to other factors (see Figure 18).

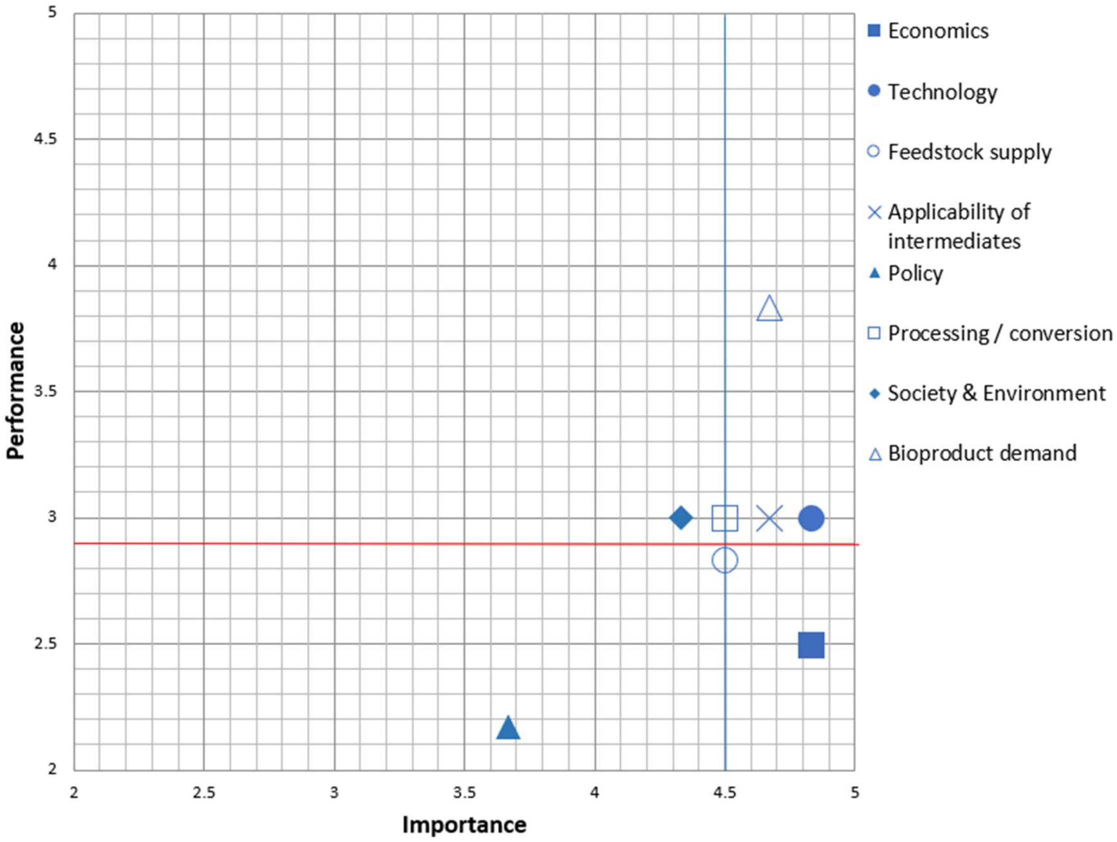


Figure 18. Importance-Performance-Matrix referring to data for algae biorefineries. Red line: mean performance value, Blue line: mean importance value (source: modified from Hilz, 2021).

5.3.4 Conclusion

Analysing the relation of importance and performance of different factors of commercialization can serve as a guide to policy development and investment strategies. The measurement of importance and performance and the calculated Importance-Performance gap revealed the current perception in the research environment related to the prevalence of specific impact areas affecting the commercialisation process of biorefineries. Because all factors generally were assigned as rather important, factors assigned relatively low importance and high performance should not be wrongly interpreted as exclusion criterium for further developments.

Independent of the biorefinery concepts analysed, this investigation suggests that there is a need for policies to transform the market environment which then levers the different economic aspects. The competitive advantage of oil refineries due to decades of promotion, efficiency increase, scaling, market formation etc. builds on market distortion because the environmental damage associated to this oil refinery technology is not paid for by the polluter. Unless the market environment is not equalized by e.g. representing the external costs related to environmental damage of using fossil resources and emitting CO_2, no matter which biorefinery concept will find itself struggling with this commercialization barrier.

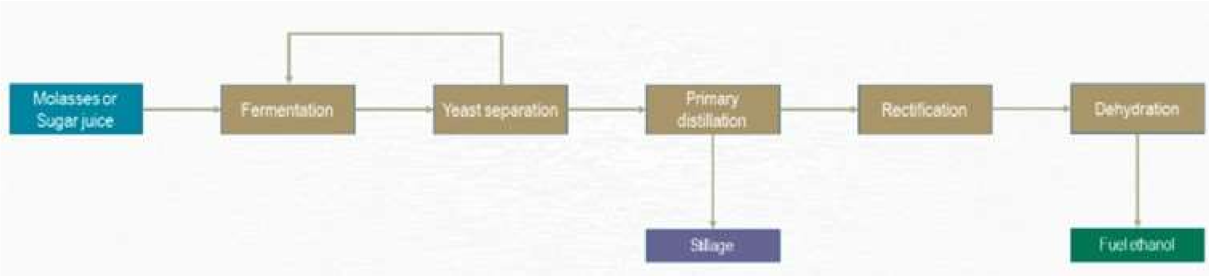
Appendix 1. Key examples of Biorefineries in Task 42 countries

Sarina Biorefinery MacKay, Queensland (Australia)

State-of the art: Commercial scale
Type of biorefinery: Single platform – C6 sugars to ethanol. This is the only facility that produces bioethanol from molasses in Australia. It has a capacity of approximately 60 million litres per year of which about two thirds is sold into the fuel market to make E10 gasoline. The molasses substrate used for ethanol production is a by-product from the manufacturing process of sugar from sugar cane.
Location: Sarina (near Mackay), Queensland, Australia
Owner: Wilmar BioEthanol
Feedstocks: Molasses
Conversion processes: Biochemical conversion of C6 sugars to ethanol using the Biostil process
Outputs/products: Bioethanol, CO_2, BioDunder (liquid fertilizer)

Description: Sarina is Australia's largest manufacturer of sugar-based ethanol. Approximately 60 million litres of bioethanol is produced per year at the Distillery. About two-thirds of this ethanol is sold into the Australian market for use in E10 and E85 blends of petrol. The Sarina bioethanol is produced from molasses – a by-product of the sugar manufacturing process. All of the molasses processed at the Sarina Distillery is sourced from Queensland raw sugar mills. That means the bioethanol is derived from 100% Australian feedstock. The process used to convert the sugars to ethanol is one of the more unusual, using the Biostil process. This is where a single reactor is operated in a steady stage process and the ethanol is continuously removed. The advantages of this system include less water requirements, continuous operation and the yeast is recycled.

Contact: Wilmar BioEthanol
265 Whitehall Street, Yarraville, Victoria, 3013, Australia
General enquiries: +61 3 9235 4850
Website: https://www.wilmarsugar-anz.com



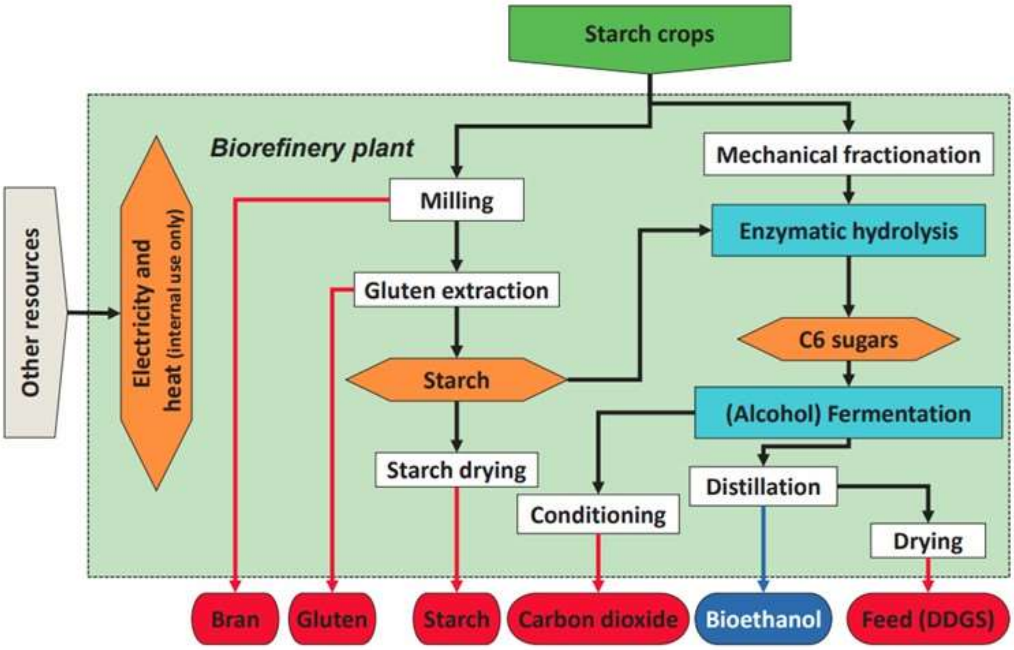
Manildra Nowra Biorefinery (Australia)

State-of the art: Commercial scale
Type of biorefinery: Single platform – C6 sugars to ethanol. This is the largest facility of its kind in South East Asia. It has a state of the art seven column distillery producing grain neutral spirits along with a range of ethanol grades for food and beverages, pharmaceuticals, personal care and industrial applications.
Location: Nowra, New South Wales, Australia
Owner: Manildra Group
Feedstocks: Primarily GMO-free wheat
Conversion processes: Biochemical conversion of C6 sugars to ethanol
Outputs/products: Bioethanol, CO_2, wheat starch, animal feed and gluten

Description: South East Asia's biggest distillery of its kind is located on the South Coast of NSW with a capacity of approximately 300 million litres of bioethanol/year. The plant is a world-class and located at the Shoalhaven Starches manufacturing facility in Nowra. The seven-column distillery creates 100 per cent pure Australian, grain-neutral spirits for fuel, craft and big brand beverages – including vodka, gin, blended whiskies and ready-to-drink packaged alcohol – from premium, GMO-free wheat. State-of-the-art technology at the flagship full-scale facility generates premium product for domestic and export markets. As industry leader for quality standards, Manildra has developed a neutral-tasting and odourless alcohol that is also ideal for use in food and flavouring, beauty and personal care, and medical and laboratory applications. The alcohol's smooth mouth feel make it a favourite among local distillers including Melbourne's Starward Whisky, who work with our premium base to blend their distinctly Australian whiskies. The company also captures hundreds to tonnes of CO_2 each week from the fermentation tanks and sells it for domestic food, beverage and hospitality markets. A by-product is a distillers grains that are used as a local livestock feed. The reason that Manildra is considered a success story is that in a country where the support for biofuels is so low, the company has been able to not just survive but thrive through innovation and taking a biorefinery approach to its manufacturing facility in Nowra. It remains the largest biofuel producer in Australia and is likely to stay that way for some time.

Contact: Manildra Group
6 Frank Street, Gladesville, NSW, 2111, Australia
General enquiries: +61 2 9879 9800
Email: customerservice@manildra.com.au
Website: https://www.manildra.com.au/manildra

Shoalhaven Starches
36 Bolong Road, Bomaderry, NSW, 2541, Australia
Phone: +61 2 4423 8200
Email: nowra@manildra.com.au



Lenzing AG Biorefinery (Austria)

State-of the art: Commercial Plant, TRL 9.
Type of biorefinery: Lignocellulosic biorefinery
Location: Lenzing, Austria
Owner: Lenzing AG
Feedstocks: Spruce, birch and beech wood from sustainable forests
Conversion processes: pulping process, Modal and Lycell process
Platforms: 40% pulp; 50% bioenergy; 10% bio-based materials: Acetic acid, Furfural, Magnesium-Lignosulphonate, Soda Ash, Sodium Sulphate, Xylose (in cooperation with DuPont)
Outputs/products: main product Viscose fibers

Description: The biorefinery in Lenzing uses the renewable raw material wood as a universal substitute for non-renewable raw materials such as crude oil 100 percent: for the production of pulp as a raw material for fibers and for a range of valuable biorefinery products such as acetic acid, xylose and furfural. The wood's remaining energy is utilized to operate the production facilities energy self-sufficient.

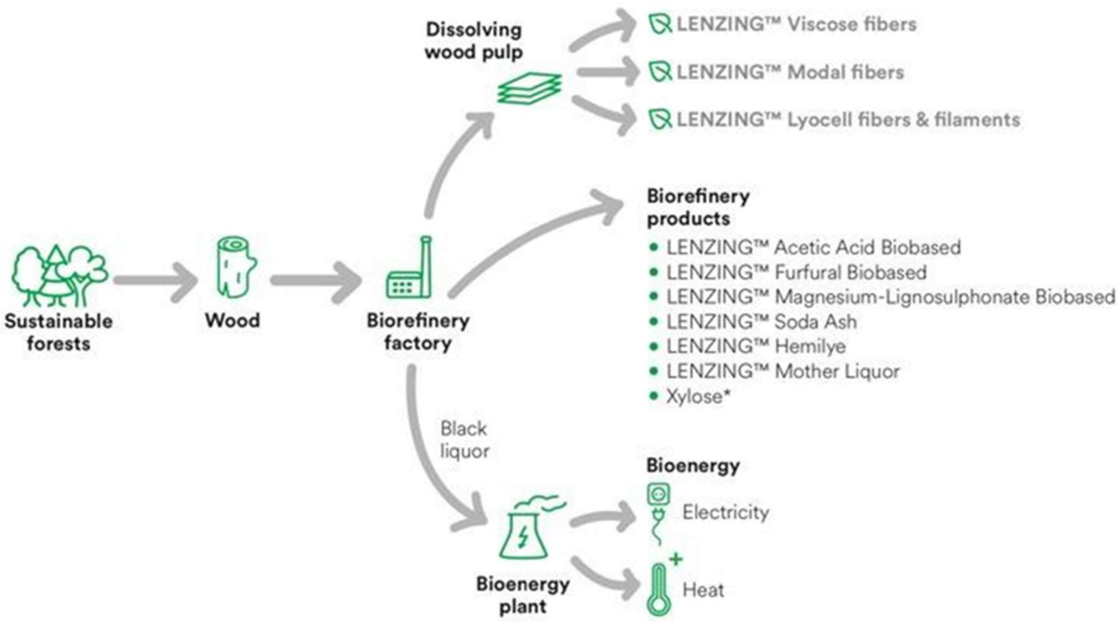
In the fiber production process the cellulose is extracted from the raw material wood. The pulp thus obtained is crushed and then mixed with N-methylmorpholine-N-oxide (NMNO), a non-toxic solvent and water in a stirred tank. In the stirred vessel, under vacuum and elevated temperature, some of the water is removed from the pulp. Once the water content has dropped to a certain level, the cellulose dissolves and forms a spinning solution, which is filtered and then forced through spinnerets. The filaments formed in this way are precipitated in a bath of aqueous NMMO solution and combined as fiber cords. Depending on the application, further treatment steps follow, such as cleaning, lubricating and drying, crimping and cutting. Compared to other cellulose regenerated fibers such as viscose, the production process is considered to have a significantly lower environmental impact due to the environmentally friendly solvent and a closed material cycle.

Biorefinery products and co-products at a glance:

- LENZING™ Acetic Acid Bio-based: food industry, pharmaceutical and cosmetics industry, chemical industry, solvents, textile industry
- LENZING™ Furfural Bio-based: primary product for furfuryl alcohol, solvent in the refining of lubrication oil, solvent for anthracene and resins, distillation of butadiene, herbicide production
- LENZING™ Magnesium-Lignosulphonate Bio-based: animal food industry, ceramics industry, production of fireproof bricks, tanning agent industry, chipboard and fiber board industry, auxiliary materials for the construction industry, fertilizer industry
- LENZING™ Soda Ash: glass industry, pulp and paper industry
- LENZING™ Sodium Sulphate: Detergent, cleaning-agent, and glass industries Xylose (wood sugar): sweetener in food and pharma industry

Contact: Lenzing Aktiengesellschaft
Christian Skilich - CEO Pulp / Board member
Mail: c.skilich@lenzing.com
4860 Lenzing, Austria
Werkstraße 2; Telefon: +43 7672 701 0
https://www.lenzing.com/

Aerial view of the Lenzing AG site in upper Austria (© Lenzing AG)



The biorefinery concept in Lenzing, Austria (© Lenzing AG)

AGRANA Biorefinery Pischelsdorf (Austria)

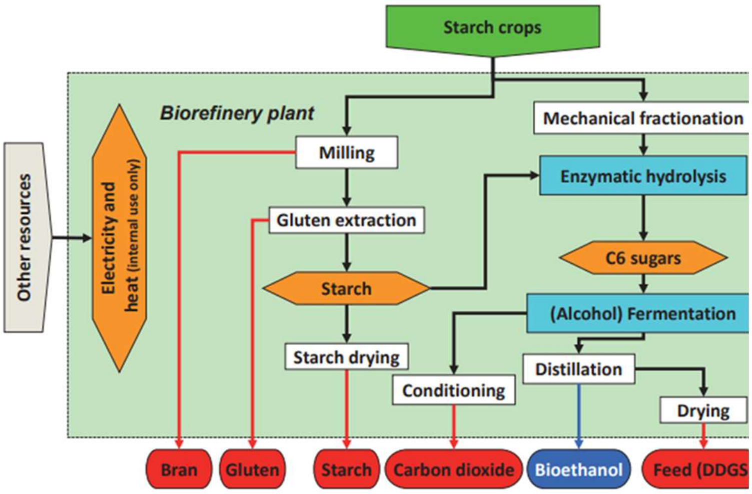
State-of the art: Commercial Scale
Type of biorefinery: Two platform (starch, C5/C6 sugars) biorefinery for the production of bioethanol, wheat starch and gluten, and CO_2 from agricultural raw materials by integration wheat starch processing into existing bioethanol facility
Location: Pischelsdorf, Austria
Owner: AGRANA Bioethanol GmbH
Feedstocks: Agricultural raw materials
Outputs/products: Bioethanol, wheat starch and gluten, CO_2

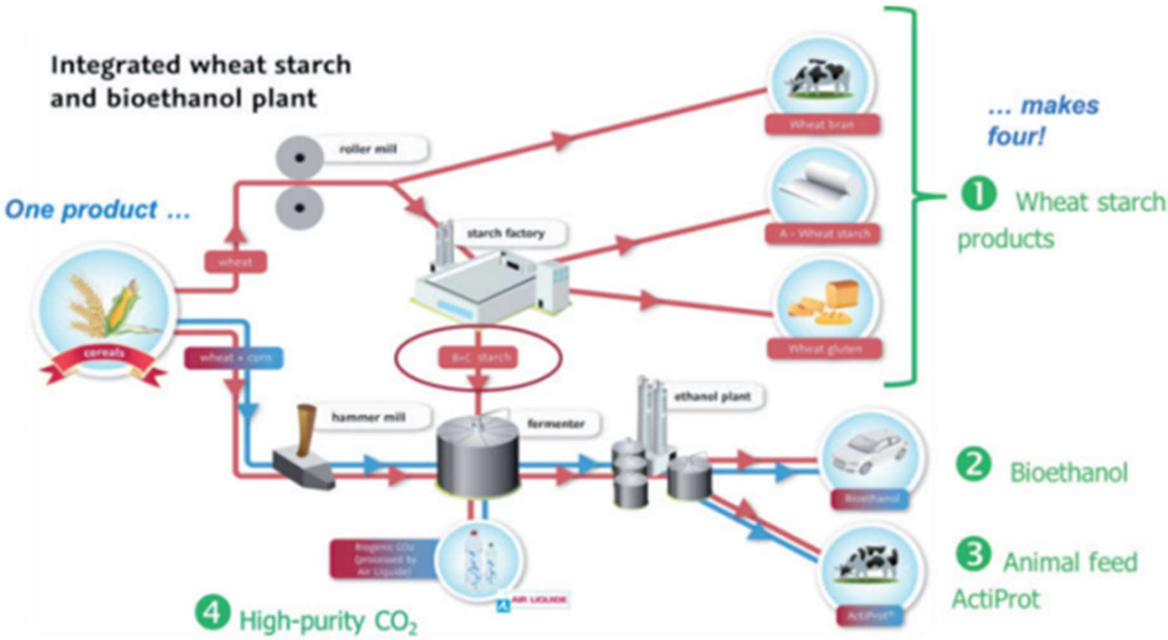
Description: The biorefinery project of the AGRANA Bioethanol GmbH in Pischelsdorf, Lower Austria, represents the holistic concept of a complete and sustainable utilisation of the used agrarian raw materials. The since 2007 existing bioethanol production plant is updated with a new wheat starch and gluten production facility that is in operation since autumn 2013. In addition, the largest and most modern CO2-recuperation plant currently in existence in Austria successfully started operating in early 2012.

Within the wheat starch facility 250,000 tonnes of wheat is processed to: 107,000 tonnes of wheat starch, 23,500 t of wheat gluten and 55,000 t of wheat bran every year. Those elements of the wheat that cannot be utilised in the first production cycle are afterwards used for bioethanol production. Those will amount to roughly 70,000 p.a. Wheat starch and gluten are essential inter-medium products that are used in the food and drinks industry as well as for technical applications i.e.: the paper industry. The used grain is certified after the ISCC-standard sustainability criteria.

In the bioethanol production segment of the biorefinery the agrarian raw material – wheat from the wheat starch production plant and additional grains – about 500,000 tonnes of grains are processed to 210,000 m^3 of bioethanol and 175,000 tonnes of high quality, GMO free protein animal feed ActiProt that reduces Austria's dependency on soy imports from abroad. To complete the holistic system of the biorefinery the CO2-recuperation plant, operated by the AGRANA partner Air Liquide, captures 100,000 tonnes of CO_2 per year. This high quality CO_2, which is a by-product of the ethanol production process (fermentation), is used in the food and drinks industry that would otherwise have to be extracted from fossil sources. The AGRANA biorefinery in Pischelsdorf makes optimal use of the agrarian raw material. First, the grain is used in the wheat starch production plant from there residuals are, with additional grains, further processed in the bioethanol production facility. The CO_2 that incurs during the fermentation process is recuperated for the food and drinks industry. In addition to bioethanol high quality, GMO free protein animal feed (DDGS) is produced. Hence, the optimal use of the raw material is warranted.

Contact: AGRANA Bioethanol GmbH
phone: +43 2277 90303 13112
web: www.agrana.com





Billund Biorefinery (Denmark)

State-of the art: Demonstration plant
Type of biorefinery: One platform (biogas) biorefinery using waste
Location: Grindsted, Denmark
Owner: Billand Vand, Krüger & Veolia
Feedstocks: Household waste, organic industrial waste, wastewater sludge, manure and other organic waste
Conversion processes: aerobic conversion, anaerobic digestion, thermal hydrolysis
Platforms: Biogas
Outputs/products: Biogas and organic fertilizer

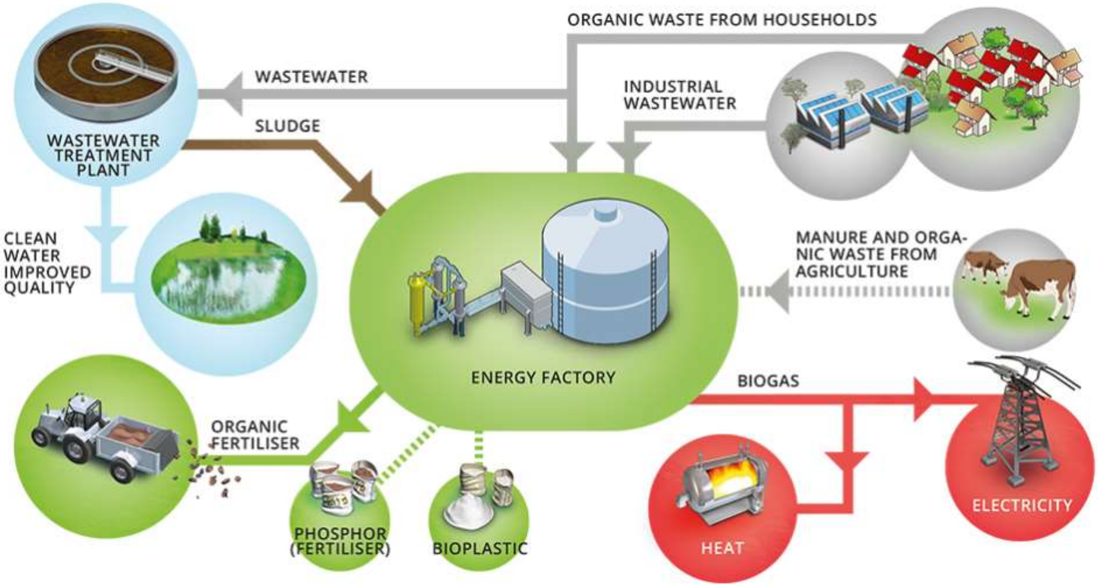
Description: Billund BioRefinery is a lighthouse project that demonstrates the possibilities for sustainable recycling and better utilization of resources. The results of the project are an even better treatment of the wastewater by utilizing the energy and nutrients in the wastewater and the organic waste.

The Wastewater Treatment Plant of the Future integrates the organic household waste into a broader context in which the waste is mixed with wastewater so that both are treated even more effectively in terms of the environment as well as energy. It all begins with a proper sorting of the waste at each individual consumer followed up by an effective treatment and gasification of the waste.

The Wastewater Treatment Plant of the Future operates above all more effectively – both in terms of improved water treatment as well as reduced energy consumption. It uses better and more intelligent control systems in relation to sewer catchments and amounts of precipitation – also through preceding control and alarm at e.g. extreme rain events. At the same time, the wastewater treatment itself is performed much more effectively and at a markedly lower consumption of energy.

The patented Exelys™-technology is a key element in Billund BioRefinery, which makes the Future Wastewater Treatment Plant an "Energy Factory". Exelys™ is the next generation of thermal hydrolysis which in brief extracts even higher energy amounts out of the biomass, and at the same time markedly reduces the sludge amount. The biogas production is increased by 50 percent while the sludge amount is reduced by 30 percent. All resources are integrated into one combined treatment of household waste, organic industrial waste, wastewater sludge as well as manure and other organic waste. In this way it is possible to achieve the optimum mix which will give the most efficient utilisation of the energy. At the same time, the farming industry benefits from an odour-free, organic fertiliser that is easy to handle and has a high nutritive value for the crops. The advanced processes at Billund BioRefinery make it even easier for the crops to absorb the nutrients so the fertilizer value is very high. Billund BioRefinery integrates all resources in one large, energetic cycle – from table to soil and back.

Contact: Thomas Kruse Madsen, CEO
Billund BioRefinery
Grindsted Landevej 40
DK-7200 Grindsted, Denmark
phone: +45 76 50 27 00
e-mail: info@billundbiorefinery.dk
web: www.billundbiorefinery.com



BIOWERT (Germany)

State-of the art: Commercial Scale, started operation in 2007
Type of biorefinery: A 4-platform (biogas, green juice, fibres, electricity & heat) biorefinery producing bioplastics, insulation materials, fertilizer and electricity from grass silage and food residues
Location: Brensbach, Germany
Owner: BIOWERT GmbH
Feedstocks: Grass
Conversion processes: mechanical separation, anaerobic digestion
Platforms: biogas, organic fibres, organic juice
Outputs/products: Grass fibre insulation (AgriCell^{BW}), natural fibre reinforced plastic (AgriPlast^{BW}) and fertiliser made from digestate (AgriFer^{BW}) and biogas

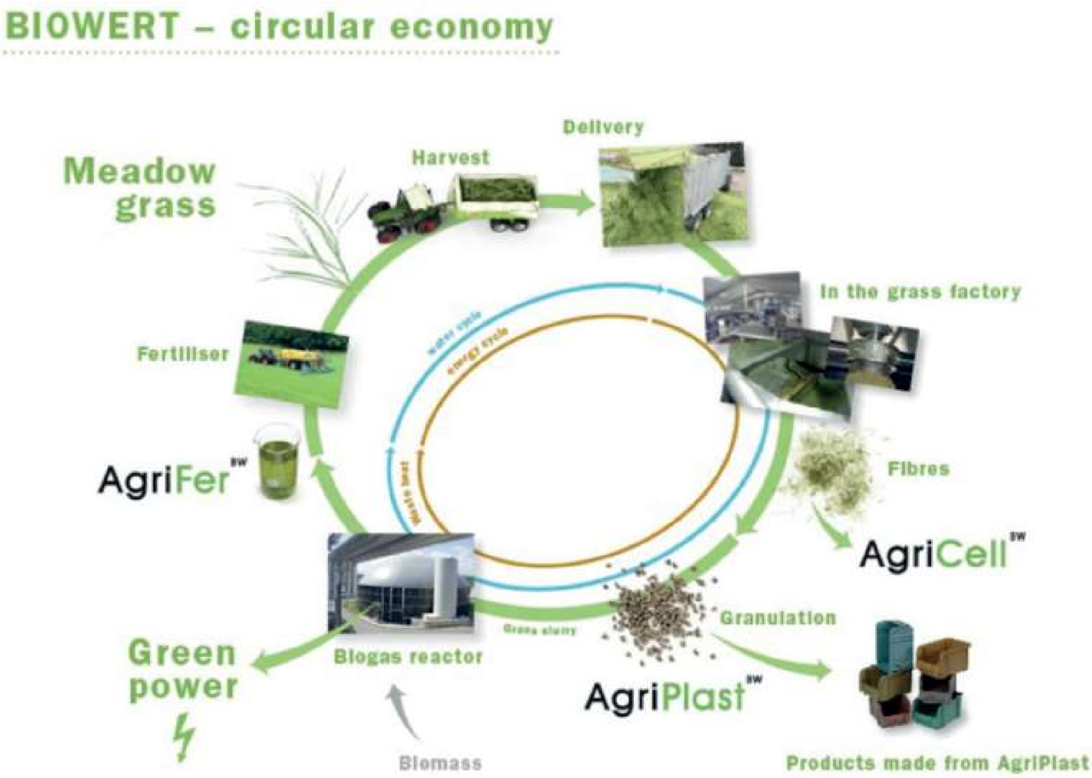
Description: The facility has an annual throughput of about 2,000 t dry matter (equivalent to 8,000 t grass per year at 25%-30% dry matter content). The BIOWERT plant is directly connected to a biogas plant that produces 1,340,000 m^3 of biogas annually which is used in combined heat and power facilities, which in 2012 produced 5.2 GWh_{el} of electricity. The heat and electricity are partly used together with the process water of the biogas plant within the BIOWERT plant and excess electricity is exported to the electricity grid.

Grass is used as regionally available feedstock. The grass silage is mixed with process water from the biogas plant and heated. The heated suspension is mechanically treated in a multi-stage process, subsequently gently dried in order to produce fibres. The specially developed two-step drying process is paramount for the production of high quality cellulosic fibres. The grass fibres are further processed into AgriCell^{BW} and AgriPlast^{BW} synthetic granules. AgriPlast^{BW} contains 30 – 50% grass fibres and 50–70% recycled polyolefine and is used for injection moulding for a range of uses.

In addition nutrients from the digestate of the biogas plant are recovered and redistributed to farmers that have grown the grass in the form of a liquid biofertilizer (AgriFer^{BW}) u . In that way a closed-loop process chain is realized that follows the leading principles of industrial ecology.

The utilisation of grass for energy and raw material production is an example of the bioeconomy connecting agriculture and industry; such models provide for future expansion and diversification in the agricultural sector. The vision for the Biowert grass biorefinery is to develop two further grass refineries within the next three to five years.

Contact: Biowert Industrie GmbH
Gewerbegebiet Ochsenwiesen
Ochsenwiesenweg 4,
64395 Brensbach/Odw.
Germany
phone: +49 6161 806630
e-mail: kontakt@biowert.com
web: www.biowert.com



Source: IEA Bioenergy Task 37, Biogas in Society, a Case study, June 2019

CELLULAC (Ireland)

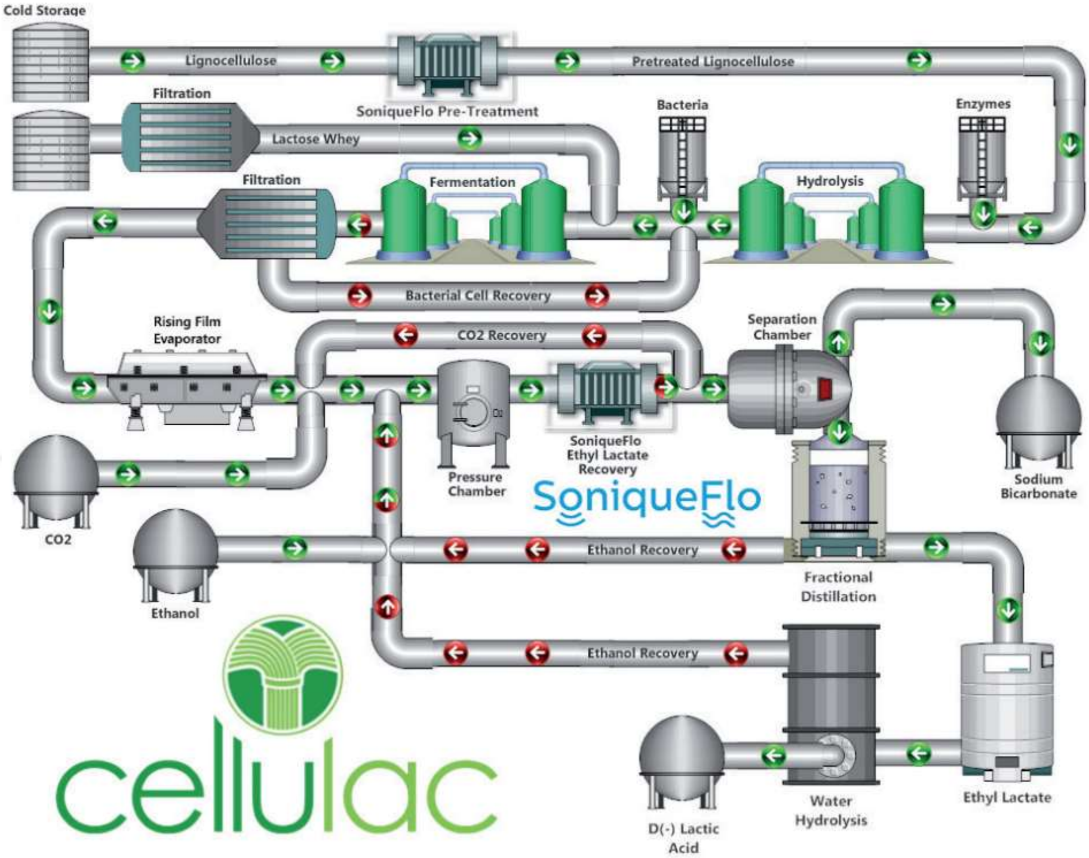
State-of the art: Commercial Scale – 100,000 Metric Tonnes
Type of biorefinery: : A 3-platform (C5, C6 sugars and lignin) for the production of chemicals and fuels from lactose whey permeate and lignocellulosic biomass
Location: Great Northern Brewery, Dundalk, Co. Louth, Ireland
Owner: Cellulac Ltd. Galway, Ireland
Feedstocks: Lactose whey permeate and lignocellulosic biomass
Conversion processes: fermentation, chemical processes
Platforms: C5, C6 sugars and lignin
Outputs/products: Chemicals (LA, Ethyl Lactate and PLA)

Description: Cellulac intends to commence production of up to 100,000 metric tonnes of high value, specialty chemicals from a wide variety of second generation (2G) feedstocks, on completion of a retrofit of the fermentation and processing facilities in the Great Northern Brewery, Dundalk, Ireland which was the second largest brewery in Ireland, to generate, at a production cost 40% below current producers, Lactic Acid and related products.

Cellulac has developed an end-to-end proprietary biochemical and process engineering platform to produce Lactic Acid, PolyLactic Acid and Ethyl Lactate, a $2.5 billion+ market currently growing at 20% pa. These products have significant established markets in (a) for use as a bio-degradable plastic ingredient; (b) the food packaging industry; (c) for medical implants; and (d) as organic solvents.

The company expects to extract net cost savings in excess of 40% versus alternative methods of production of these specialty chemicals. Central to this is (i) the flexibility to use a variety of environmentally-benign second-generation feedstocks in a bio-cascading process; (ii) the ability of the Group's complementary chemical and process technologies to extract extremely high yields of fermentable sugars from the feedstocks; and (iii) the significant energy savings achieved by the Group's technologies in the production process. These technologies, which are complementary include enzyme cocktails, fermentation protocols, non-genetically modified bacteria (non-GMO) and Hydro Dynamic Cavitation (HDC) SoniqueFlo, all of which are protected by an extensive portfolio of 140 patents (granted and pending) along with proprietary know-how.

Contact: Cellulac Ltd
Second Floor, Unit 14, Galway Technology Park
Parkmore, Galway
Ireland
web: www.cellulac.co.uk
Camillus Glover
e-mail: cglover@cellulac.co



Cold Storage
Lignocellulose
SoniqueFlo Pre-Treatment
Pretreated Lignocellulose
Filtration
Lactose Whey
Bacteria
Enzymes
Filtration
Fermentation
Hydrolysis
Bacterial Cell Recovery
Rising Film Evaporator
CO2 Recovery
Separation Chamber
Pressure Chamber
SoniqueFlo Ethyl Lactate Recovery
SoniqueFlo
Sodium Bicarbonate
CO2
Ethanol
Ethanol Recovery
Fractional Distillation
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Water Hydrolysis
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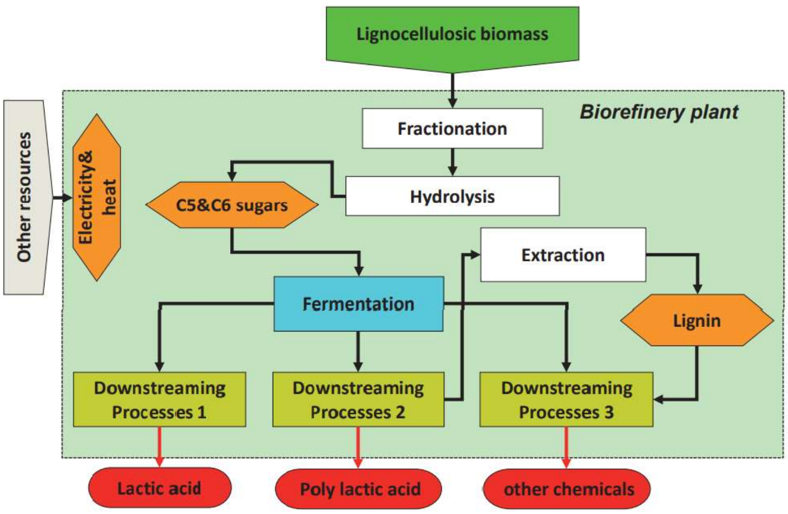


Lignocellulosic biomass
Biorefinery plant
Other resources
Electricity& heat
Fractionation
Hydrolysis
C5&C6 sugars
Extraction
Fermentation
Lignin
Downstreaming Processes 1
Downstreaming Processes 2
Downstreaming Processes 3
Lactic acid
Poly lactic acid
other chemicals

Versalis Biorefinery - Crescentino (Italy)

State-of the art: Industrial Plant, in operation since the end of 2012
Type of biorefinery: A 3-platform (C5/C6-sugars, lignin, power/heat) biorefinery for the production of bioethanol from lignocellulosic feedstock
Location: Crescentino (Piedmont Region), Italy
Owner: Versalis (Eni)
Feedstocks: Hardwood (poplar), Agricultural residuals
Conversion processes: Thermal pre-treatment followed by biochemical conversions with enzymes and yeast
Platforms: C5/C6 sugars, lignin
Outputs/products: Bioethanol, Lignin, Green electricity, Disinfectants

Description: The industrial unit located in Crescentino (Italy) represents the world's first commercial scale cellulosic ethanol plant. The plant includes a bioethanol production train, a power plant operated at 13 MWe and a biogas generation unit integrated with waste water treatment. The energy produced is used to power the plant and the excess amount is sold to the national power grid. The feedstock used so far in the plant is hardwood and agricultural residuals. Crescentino plant process is based on the PROESA® technology.

PROESA® was developed by a group of researchers at the R&D Center in Rivalta Scrivia (Italy). PROESA® is currently being commercialized for the production of bioethanol via fermentation of cellulosic sugars (2G sugars). However, another key feature of the technology is the potentially achievable high purity fermentable sugar stream. This advantage makes PROESA® suitable for both biological and chemo-catalytic technologies for the conversion of sugars to high-value bio-based chemicals and further advanced biofuels. The core of the PROESA® technology is an integrated and chemicals-free pre-treatment, followed by viscosity reduction and enzymatic hydrolysis steps that prepare 2G sugars for fermentation to bioethanol.

Biomass pre-treatment - The Versalis proprietary pre-treatment process consists of a biomass cooking step. Depending on the biomass and its cleanliness, the feed handling may include a soaking section to remove debris and impurities. The process then utilizes saturated steam to disrupt the bonds between lignin, cellulose and hemicellulose. The technology maintains the principal advantages of standard steam and water based processes (no chemical addition and high efficiency separation of cellulose and hemicellulose) while reducing the formation of inhibitors to the downstream processes. The net effect of these processes is a reduction in capital (simple materials of construction) and operating costs (low enzyme dosage).

Viscosity reduction and enzymatic hydrolysis - PROESA® uses an efficient liquefaction of the pre-treated material to ensure a constant and continuous flow of material to the fermentation section. Enzyme action coupled with a unique process design allows liquefaction with very short residence times and high dry matter contents.

Fermentation - The yeast used in the process is capable of co-fermenting C5 and C6 sugars and it is propagated at site. The current generation of yeast is able to tolerate the presence of naturally generated acetic acid. Subsequently, the ethanol is recovered by distillation plus molecular sieve dehydration. Lignin water slurry is recovered at the bottom of stripping unit and sent to lignin recovery and valorisation.

Contact: Versalis S.p.A.
Piazza Boldrini, 1
20097 San Donato Milanese (MI), Italia
tel. + 39 02 520 1
info@versalis.eni.com
www.versalis.eni.com

Biorefinery di Gela (Italy)

State-of the art: Industrial plant, in operation since 2019
Type of biorefinery: Biorefinery for the production of HVO (Hydrotreated Vegetable Oil)
Location: Gela (Caltanissetta, Sicily) Italy
Owner: Eni SpA, Raffineria di Gela SpA
Feedstocks: raw materials of biological origin, used vegetable oil, frying oil, fats, algae and waste by-products or from energy crops in desert or pre-desert soils for the production of quality biofuel food production waste such as waste oils, animal fats and other advanced by-products
Conversion processes: Eni Ecofining™ technology which, given its great flexibility, allows for different types of inputs to be treated
Platforms: Bio-oils, Hydrogen and Bio-Naphtha
Outputs/products: High quality biofuels HVO (Hydrotreated Vegetable Oil), Bio-Naphtha, bio jet fuel (in 2021)

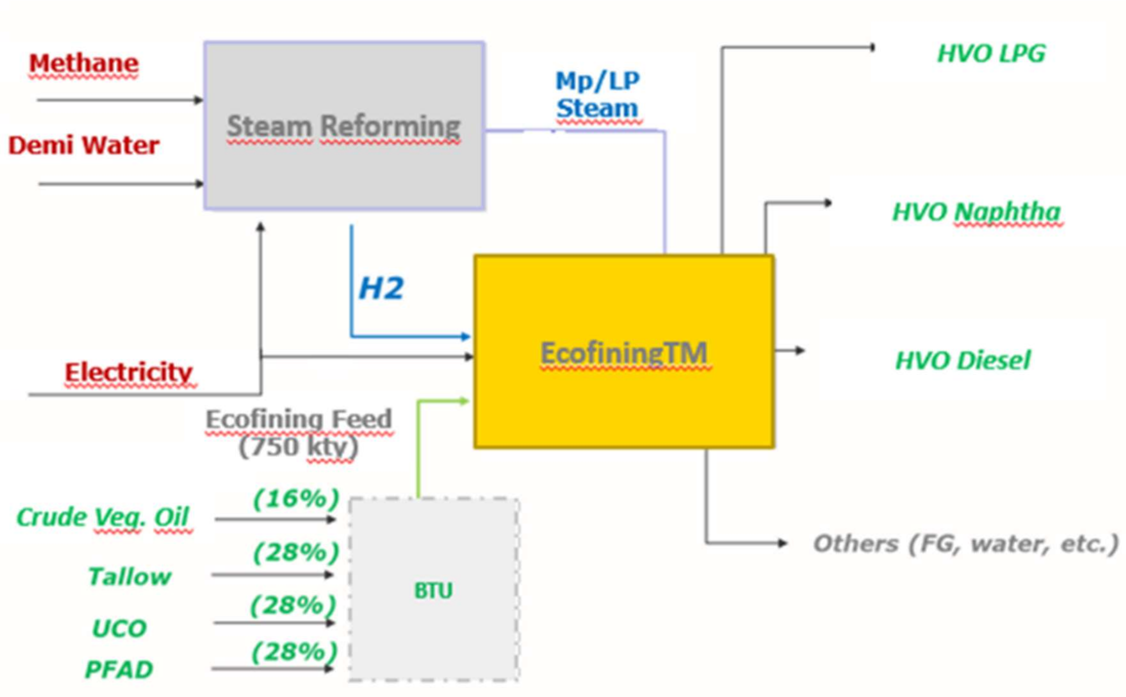
Description: Biorefineries play a central role in Eni's evolution because they contribute to the achievement of our main goal: the total decarbonization of all our products and processes by 2050. Advanced biofuels play a key role in reducing greenhouse gas emissions in the transport sector. Biorefineries, too, are the result of our constant commitment to research and technological innovation. Through the development of proprietary technologies patented by our Research Centres, we have completely redesigned the traditional refineries in Venice and Gela, where raw biomaterials are now processed: plant-based oils, animal fats, used cooking oils or algae extracts. Today we have a total processing capacity of 1.1 million tonnes per year and in the 2021-2024 Strategic Plan we have set the goal of doubling our total capacity by 2024, reaching 5-6 million tonnes by 2050. Furthermore, by 2023, our biorefineries will be palm oil free, meaning they will not use palm oil in production. Instead, alternative inputs, such as cooking and frying oils, animal fats and waste from plant-oil processing, and advanced inputs, such as algae, waste oils, lignocellulosic materials and bio-oils, will be used.

The bio-refinery of Venice, in Porto Marghera, is the first conventional refinery in the world to be converted into a bio-refinery. Since 2014, about 360,000 tonnes of raw materials of biological origin have been treated and converted here per year. As the plant will undergo further upgrades in 2024, we plan to increase processing capacity to 560,000 tonnes per year, with a larger input deriving from food production waste, such as waste oils, animal fats and other advanced by-products. At that point, the Venice biorefinery will produce 420,000 tonnes per year of HVO (Hydrotreated Vegetable Oil) biofuel. This process is made possible by our proprietary Ecofining ™ which, given its great flexibility, allows for different types of inputs to be treated.

In August 2019, after over 3 million work hours, the Gela bio-refinery also became operational. It has replaced the large petrochemical plant, on which construction began in 1962 and that has now shut down. The Gela bio-refinery can process up to 750,000 tonnes annually of used vegetable oil, frying oil, fats, algae and waste by-products or from energy crops in desert or pre-desert soils for the production of quality biofuel. Furthermore, in March 2021, the new BTU

(Biomass Treatment Unit) was launched and tested. It will enable the use of 100% of the biomass not in competition with the food chain, for example, used cooking oils and fats from fish and meat processing in Sicily. The aim is to create a zero-kilometre circular economy model for the production of biodiesel, bio-naphtha, bioLPG and bio-jet fuel. Castor oil will also be used to feed the bio-refinery, thanks to an experimental project to grow the plants on semi-desert land in Tunisia.

Contact: Raffineria di Gela SpA
Contrada Piana del Signore, 1,
93012 Gela (CL) Italy
Tel. +39 0933 841111 – email Raffineriadigela@pec.eni.com
www.eni.com - https://www.eni.com/en-IT/operations/biorefineries.html -
https://www.eni.com/en-IT/operations/italy-gela-innovative-biorefinery.html



Empyro - Bioliquids Biorefinery (The Netherlands)

State-of the art: Commercial Scale
Type of biorefinery: 1-platform (pyrolysis-oil) biorefinery for the production of chemicals, fuels, power and heat from lignocellulosic biomass
Location: Hengelo, the Netherlands
Owner: Twence
Feedstocks: Woody biomass
Conversion processes: 25 MW_{th} fast pyrolysis
Platforms: Pyrolytic liquid
Outputs/products: Pyrolysis-oil, power, heat

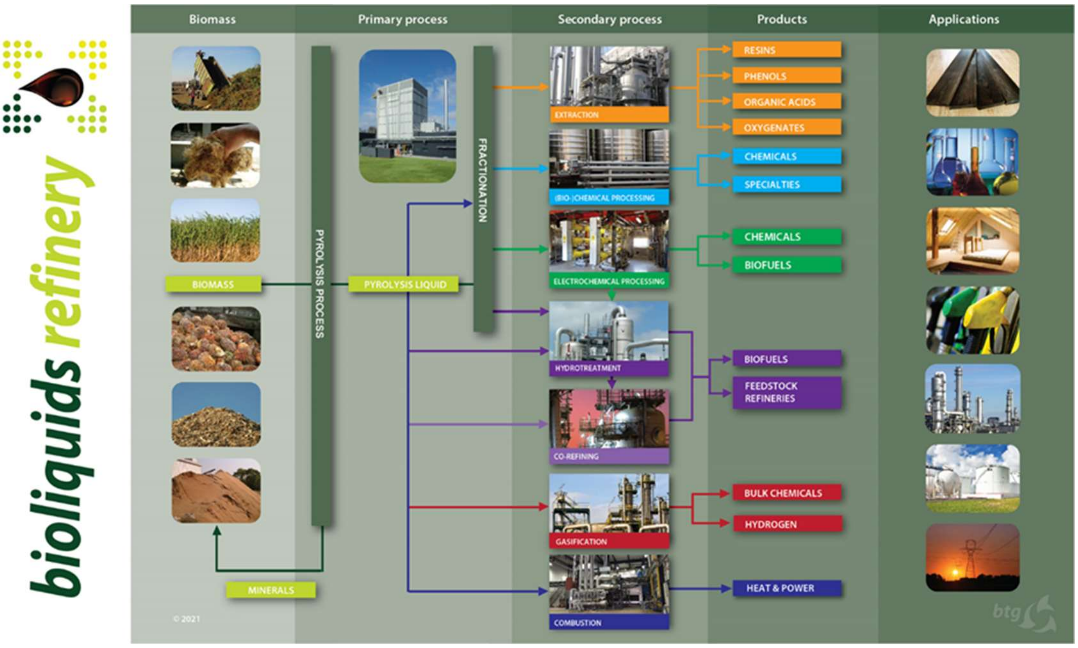
Description: Biorefining based on fast pyrolysis – heating without oxygen – of biomass is an important step in the transition towards a sustainable BioEconomy. The basis of the Bioliquids Biorefinery is the production of fast pyrolysis-oil (FPBO) from a variety of biomasses & residues. The FPBO can be directly used in different applications or further fractionated by liquid-liquid extraction. Fractionation results in a sugar syrup, a lignin fraction and an aqueous stream that can be further processed to biofuels, chemicals, and raw materials for bio-based products. Advantages of the Bioliquids Biorefinery concept are that the pyrolysis-oil can be produced at regional level where the biomass is available, closing the mineral loop, after which the high-energy oil can be cost-effectively transported to existing centralized refinery facilities for further processing.

The crucial first step of the Bioliquids Refinery is the production of the FPBO, which is demonstrated on industrial scale by Empyro in Hengelo, the Netherlands. This specific pyrolysis process was invented at the University of Twente and has been further developed in the past 25 years by BTG in Enschede, the Netherlands. Empyro was developed by BTG Bioliquids BV to demonstrate the technology on a commercial scale. At Empyro about 120 t/d biomass (e.g. pellet crumbles and/or wood chips) is mixed with hot sand and converted into 75 t/d pyrolysis-oil, char and gas (power: 6,000 MWh/year, 80 ktonnes/year steam). The first liters of oil were produced in 2015, meanwhile the cumulative production exceeds 80 kton and over 30,000 operational hours have been gained. In addition to FPBO electricity and steam are produced. Excess electricity is sent to the grid, whereas excess steam is supplied to the salt production of Nobian located next to Empyro. Long-term purchase contract has been concluded with the company FrieslandCampina, which will use the oil in its production location in Borculo to replace 10 million cubic meters of natural gas annually. In December 2018 the facility was bought by the company Twence. Fast Pyrolysis plants -identical to Empyro- have been delivered to Sweden (Pyrocell) and Finland (GFN) and taken into operation.

Fractionation of FPBO based on liquid-liquid extraction is further developed by BTG. In recent years, a fractionation pilot plant has been designed and commissioned at BTG. This pilot unit has a design capacity of 3 t/d FPBO and can fractionate FPBO into pyrolytic lignin, pyrolytic sugars, and extractives. The FPBO as well as each of the fractions are considered as raw material for the production of advanced biofuels & sustainable chemicals.

Contact: Fast Pyrolysis: BTG-Bioliquids BV
Gerhard Muggen, e-mail: gerhard.muggen@btg-bioliquids..com
web: www.btg-bioliquids.com
Bioliquids Refinery: BTG Biomass Technology Group BV
Bert van de Beld, e-mail: vandebeld@btgworld.com
web: www.btgworld.com

Empyro plant in Hengelo, the Netherlands



Avantium YXY® Technology (The Netherlands)

State-of the art: Pilot Plant (Flagship plant under construction, operational in 2024)
Type of biorefinery: 2-platform biorefinery for the production of furan-based monomer (FDCA) for polymers, fine and specialty chemicals, and fuels/resins from terrestrial biomass
Location: Amsterdam/Geleen/Delfzijl, the Netherlands
Owner: Avantium Renewable Polymers B.V.
Feedstocks: starch, sucrose (in a later stage lignocellulosic feedstocks)
Conversion processes: Chemocatalytic (Sugar dehydration, oxidation, purification, polymerization)
Platforms: Sugar platform, (lignocellulosic platform)
Outputs/products: monomer for polymers (furan dicarboxylic acid), fuels and resins (humins), solvents, flavors & fragrances (Methyl levulinate)

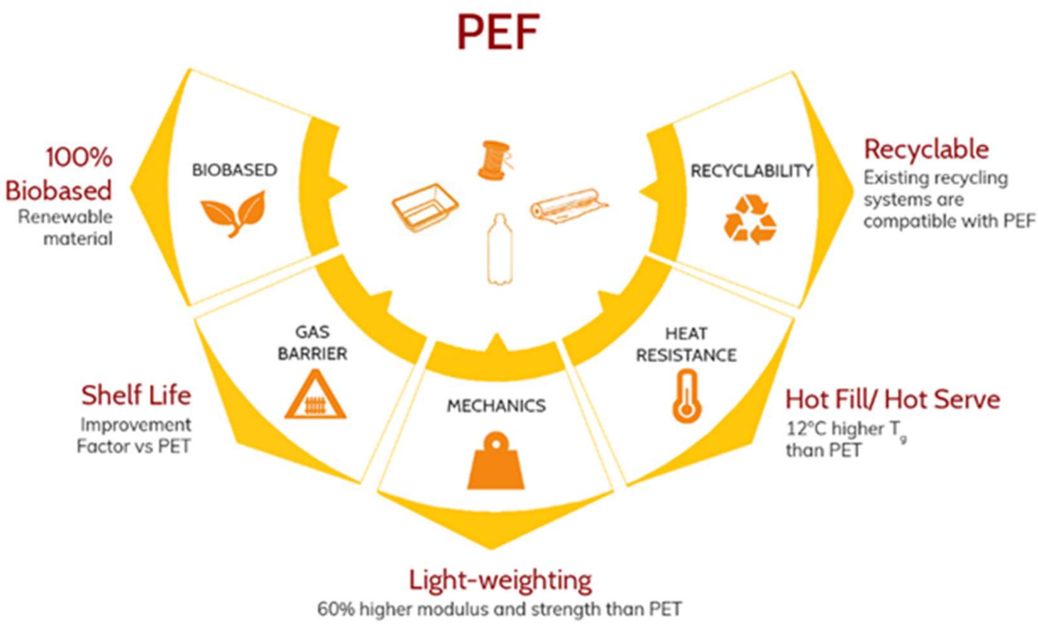
Description: The Furanics process can integrate the production of chemical building blocks, biopolymers and fine & specialty chemicals with production of biofuels, power, heat and hydrogen in a power or gasification plant. Furan derivatives, obtained by catalytic dehydration/etherification of carbohydrates, can serve as substitutes for petroleum-based building blocks used in production of plastics such as a replacement of PET and fine chemicals. Integration with a Combined Heat & Power (CHP) or gasification plant will ensure efficient use of residues, thus enabling cost-effective production of power and heat. The technology which has been demonstrated at pilot plant level, which has been operational on a 24/7 basis since the end of 2011. In December 2021, Avantium announced its positive final investment decision to construct and operate a 5,000 tonnes per annum FDCA Flagship Plant in Delfzijl, the Netherlands.

Avantium explores novel furan (YXY) chemistry, focused on efficient and, compared to enzymatic biorefinery processes, low cost conversion of C6 sugars (i.e. glucose, mannose, galactose and fructose) and C5 sugars (xylose and arabinose) into derivatives of the promising chemical key intermediate hydroxymethyl furfural (HMF). YXY's main building block, 2,5-furandicarboxylic acid (FDCA), can be used as a replacement for terephthalic acid (TA), a petroleum-based monomer that is primarily used to produce PET. Because of the enormous potential of furanics-based materials the chemical conversion of plant-based carbohydrates into FDCA has been a hot topic of intensive R&D efforts for decades. Applying Avantium's expertise in advanced catalyst development, catalytic process technology and high-throughput evaluation, Avantium is the first company to find an economically viable route to unlocking the furanics' full potential. The FDCA monomer offers exciting opportunities to create a wide range of polymers - polyesters, polyamides and polyurethanes - as well as coating resins, plasticizers and other chemical products.

Avantium's lead application PEF, used to create bottles, films and fibres, is a next-generation polyester that offers superior barrier and thermal properties, making it ideal material for the packaging of soft drinks, water, alcoholic beverages, fruit juices, food and non-food products. Therefore PEF is the 100% bio-based alternative to PET. PEF is made from plant-based sugars, which means it is renewable: The polymerization process to make PEF has already been successfully initiated at pilot plant scale. In combination with a significantly reduced carbon footprint, the added functionality, gives PEF all the attributes to become the next generation polyester. Currently, Avantium is working in collaboration with many partners to bring monolayer and multilayer PEF and PET/PEF bottles to the market.

Contact: Avantium Renewable Polymers BV
Zekeringstraat 29
1014 BV Amsterdam
The Netherlands
phone: +31 20 586 8080,
e-mail: info@avantium.com
web: www.avantium.com

YXY® Technology pilot plant in Geleen, The Netherlands consisting of an SDH unit for MMF, an oxidation unit for cFDCA and a purification unit to produce pFDCA. [Avantium]



Key features of PEF compared to fossil based alternatives such as PET. [Avantium]

Södra Mönsterås Liquid Forest™ (Sweden)

State-of the art: Commercial Scale
Type of biorefinery: Residues from forestry and forest-based industry to building blocks – Purification and upgrading of stripper methanol
Location: Mönsterås, Sweden
Owner: Södra Skogsägarna
Feedstocks: Residues from forestry and forest-based industry
Conversion processes: Purification and upgrading
Platforms: Alcohols
Outputs/products: Building blocks

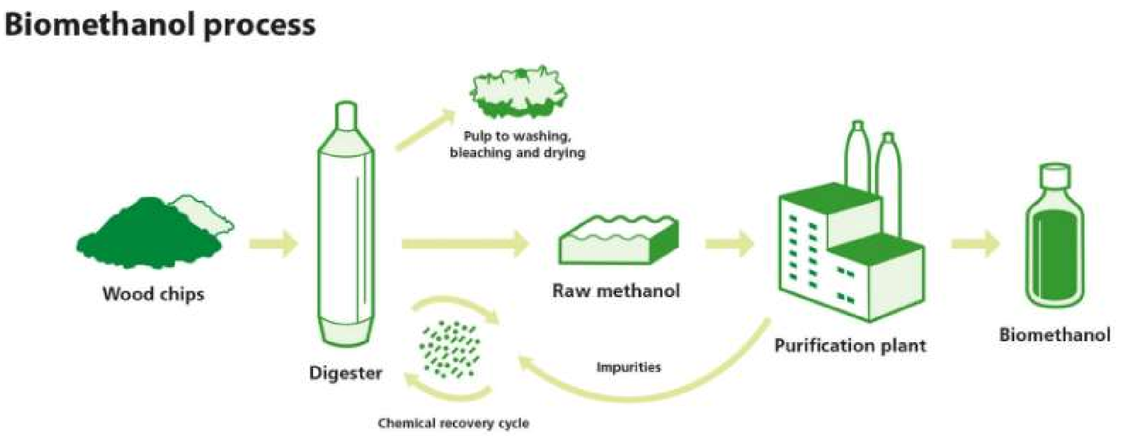
Description: The production of biomethanol is connected to the production of sulphate pulp at the Södra chemical kraft pulp mill in Mönsterås. In the pulping process wood chips are cooked with chemicals to divide the wood into its constituents, i.e., cellulose and hemicellulose, which goes to the pulp, and lignin, which ends up in the spent cooking liquor (black liquor). When the wood and chemicals react in the pulping process methanol is created. After the cooking stage, the cooking chemicals, lignin and other residues are separated from the pulp, this fraction is called black liquor. To reduce the water content of the black liquor and to recycle the cooking chemicals the black liquor is reduced by evaporation. In his process a condensate containing methanol, turpentine and sulfur compounds is obtained. When the condensate is cleaned to be reused in the mill crude methanol is created. The crude methanol is a mixture of combustible residues and is usually burned to produce heat and energy.

At the Södra mill instead a patented extraction process is used which produce a methanol product of commercial quality. It thus becomes part of the circular process that already exists at a pulp mill, where the basis is that all parts of the forest raw material are used for resource efficiency. Biomethanol is both a renewable fuel and an important platform chemical. The plant is a first of its kind commercial scale facility and was inaugurated in October 2020. In addition to the biomethanol the mill also produces e.g. pulp, electricity and power.

Initially, the methanol is sold to a Danish family-owned agricultural company, which has a large production of biodiesel from local rapeseed. The biomethanol replace the previously used fossil methanol as a raw material in the production. This makes the biodiesel completely renewable.

Regarding volumes, in general for one tonne of pulp, about 10 kg of biomethanol can be extracted. Today the production capacity of biomethanol at Mönsterås is 5,250 tonnes/year.

Contact: Södra
Skogsudden
351 89 Växjö
Sweden
Telephone: +46 470 890 00
www.sodra.com



Biomethanol production (© Södra)

Lantmännen Agroethanol (Sweden)

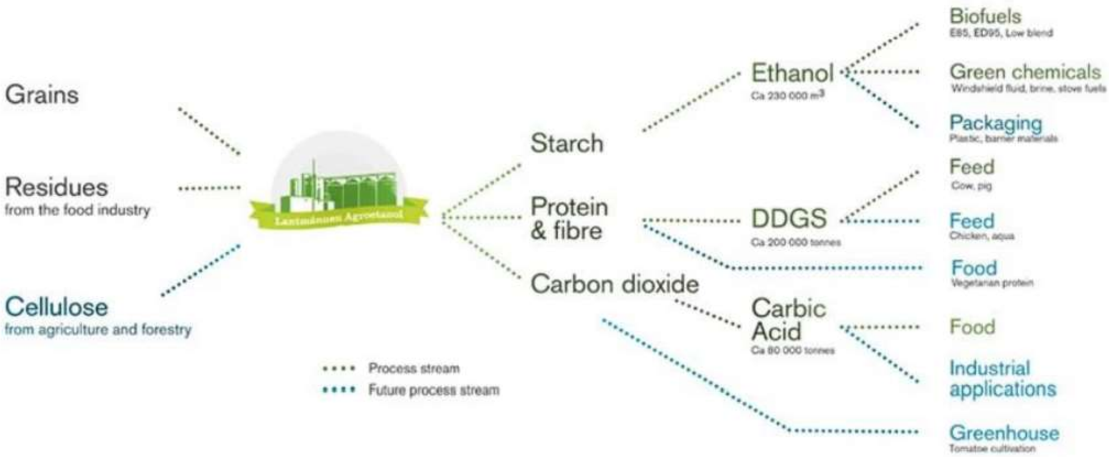
State-of the art: Commercial scale
Type of biorefinery: Starch crops and other organic residues (waste bread) for production of ethanol, feed, and carbon dioxide
Location: Norrköping, Sweden
Owner: Lantmännen
Feedstocks: Starch crops and other organic residues (waste bread)
Conversion processes: Fermentation
Platforms: Starch, alcohols, carbon dioxide
Outputs/products: Ethanol, animal feed, and carbon dioxide

Description: Lantmännen Agroetanol is the Nordic region's only large-scale producer of fuel ethanol from grain (starch). The plant is in Norrköping Sweden and was inaugurated already in 1999 but has been developed as a biorefinery continuously. In 2014 the plant was equipped to purify the carbon dioxide which is generated in the production process and in 2020 this capacity was further expanded. The carbon dioxide is used mainly in the food industry. In addition to the main production based on grain, in 2014 the plant also started processing waste from the food industry (spent bread, dough, crumbs etc.). The plant is a part of an industrial symbiosis network called Händelö eco-industrial park. During the corona pandemic, Lantmännen Agroethanol has restructured production to meet the demand for ethanol for production of alcohol-based hand sanitizer. Today, the plant can delivery capacity of over 2 million liters every month which is upgraded to a final product by a hand sanitizer producer.

When ethanol is produced from grain, a protein-rich by-product, drank, is generated. This by-product can be used as animal feed raw material. To give a rough estimate, 2.6 kg of wheat gives about 1 liter of ethanol and 0.8 kg of protein feed. Lantmännen's plant in Norrköping has the capacity to produce approximately 230,000 m3 of ethanol and 200,000 tonnes of protein feed per year, based on approximately 600,000 tonnes of grain per year. In addition, 80,000 tonnes of captured carbon dioxide is produced.

The ethanol from Lantmännen Agroethanol has just over 90% lower carbon dioxide emissions compared to fossil diesel. This is lower than conventional ethanol production from similar feedstocks and is due to both the capturing and utilization of carbon dioxide from the process and energy and resource efficient production.

Contact: Lantmännen Agroetanol
Hanholmsvägen 69
Norrköping
Sweden
Telephone: +46 10 556 01 50
https://www.lantmannenagroetanol.se/en/



Source: IEA Bioenergy, Bioenergy Success Stories, 02-2018

IEA Bioenergy

Technology Collaboration Programme