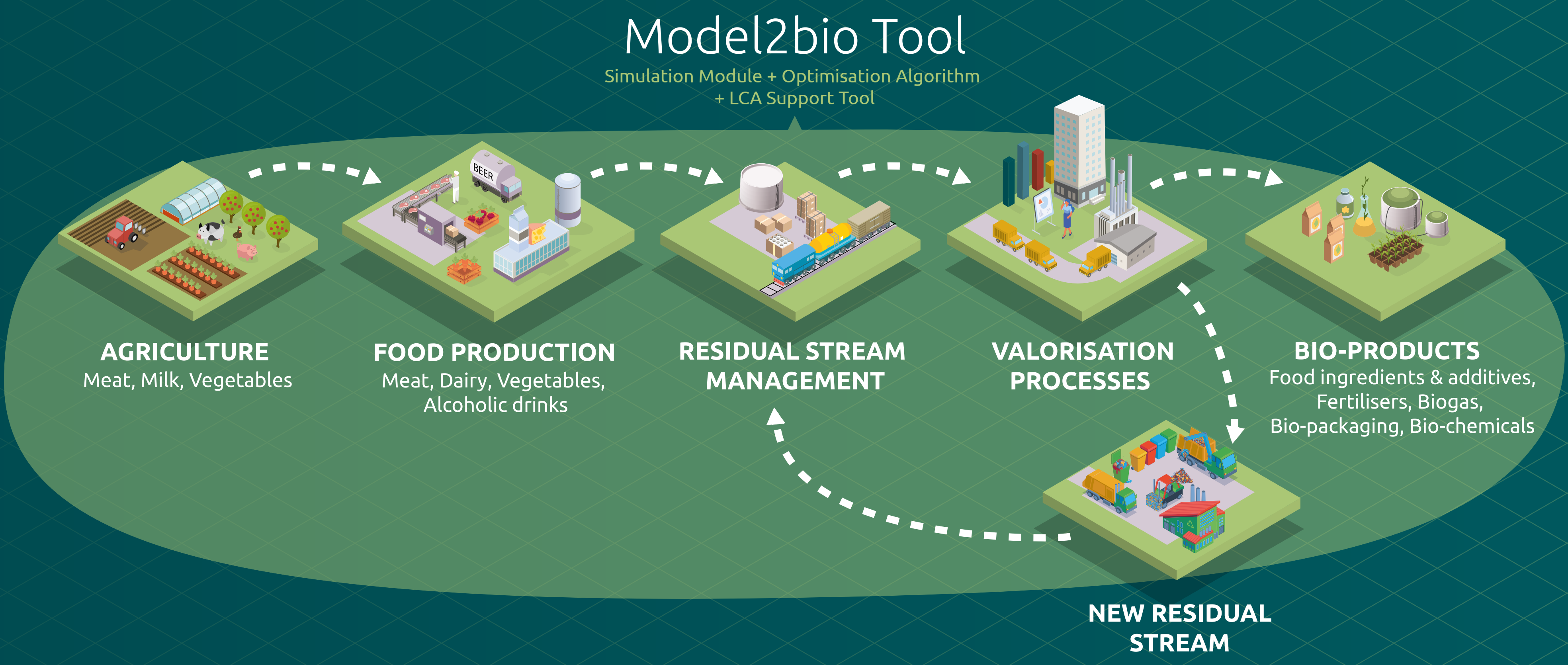
model2bio
waste-to-feedstock

DO NOT MISS THE POTENTIAL OF AGRI-FOOD RESIDUES!

How to make the most of our food resources?

Best practice tips for food producers, bio-industries, scientists and policymakers



Model2Bio
Modelling tool for giving value to agri-food residual streams in bio-based industries
Deliverable 8.4 Best Practise Flipbook
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From waste to feedstock

What if there was a tool to help agri-food producers identify by-products with a high potential for becoming new bio-based products? What if this tool could also identify the best way to reuse these agri-food by-products and simulate new valorisation scenarios?

In May 2020, scientists, technology developers and food clusters from across Europe started their mission to develop such software:

The Model2Bio Decision-Support System.

This system simulates the entire value chain and helps agri-food producers and manufacturers of bio-based products select and reuse organic residues in the most economic and sustainable way.
It consists of three elements:

- **Simulation Module**
  This module estimates the composition, quantity and seasonality of residual streams. It also predicts the potential of the residues for reuse. The module is based on mathematical models and data libraries on production, intermediate treatment, bio-processes, and logistics.
- **Optimisation Algorithm**
  This algorithm calculates the most technically and economically feasible routes for the management, treatment and reuse of agri-food by-products.
- **Life Cycle Assessment Module**
  This module evaluates the economic, environmental, and social impacts of the routes identified by the optimisation algorithm.

To feed the tool, we acquired information on the composition, volume and logistics of agri-food residual streams. Data for established technologies such as anaerobic digestion or composting were taken from literature. For novel technologies, we performed experiments to determine efficient recipes for extracting compounds from residues or fermenting them to generate new molecules.

In this booklet, we show the unique potential of agri-food by-products and share tips for their reuse, future research, and policy implementations. We hope that you will take inspiration from our results and experiences.

The team behind the Model2Bio project

Check out the video, graphics and articles about food loss and the Model2Bio project in our info pack.

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The impact of food loss

About one third of all food produced globally is discarded.

Several tens of millions of tonnes are thrown away every year in the European Union (EU) alone; 58.5 million according to the European Commission[1].

About two thirds of this amount is wasted by consumers and 17 % is lost in the agri-food industry during production and processing. The rest is disposed by food services and retail[2].

With increasing population and resource scarcity food loss has serious consequences:

- **Social consequences**
  More than 30 million people struggle for regular and decent meals even though the food produced would be enough to feed ten billion people.

- **Climatic consequences**
  Millions of tonnes of CO_2 are emitted to produce food that ultimately gets lost, thus adding to our environmental footprint. Organic waste rotting in landfills emits methane, a greenhouse gas 84 times more potent than CO_2 over a 20-year period.

- **Environmental consequences**
  Food loss depletes the environment of limited natural resources and wastes billions of cubic meters of fresh water. It increases soil erosion, biodiversity loss and eutrophication of water sources.

- **Economic consequences**
  Lost food is lost profit. The value of lost food is estimated at €132bn, not taking into account the money spent on the management of discarded food.

Taking agri-food residues as resources for bio-based industries will reduce food loss and:

- create new job opportunities supporting rural areas in their development,
- decrease greenhouse gas emissions as less residues are incinerated or landfilled,
- reduce environmental impacts on water and soil due to more efficient usage of resources,
- increase profits and business opportunities for agri-food producers and bio-industries.

Food waste is food that is thrown away by retailers, food service providers and consumers.

Food loss is any food, and inedible parts of food, removed from the food supply chain.

1 European Commission (2023) Reducing food waste factsheet

2 EU Platform on Food Losses and Food Waste. (n.d.). Food Safety. https://food.ec.europa.eu/safety/food-waste/eu-actions-against-food-waste/eu-platform-food-losses-and-food-waste_en

Agri-food residues are not waste – they are a resource!

Agri-food residues have the potential to substitute fossil resources, palm oil and sugar, for instance. In the circular economy, the value of agri-food residues is recognised, and they serve as a resource to generate energy, chemicals or components for food, feed and materials.

Despite this potential, the EU still landfills or incinerates agri-food residues at different rates per country. When by-products are reused to extract compounds, only part of their potential is retrieved. This loss is due to inefficient management and can be reduced if technologies and processes are improved.

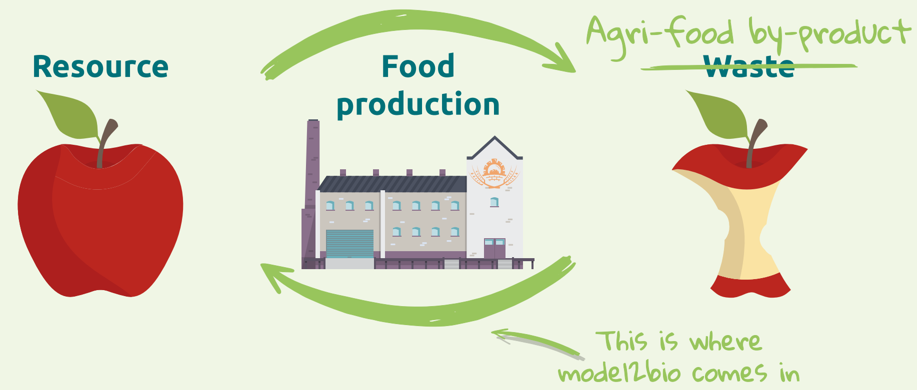
Holistic management that maximises the valorisation of agri-food residues should take a biorefinery approach and integrate several processes. This generates as many products as possible from a single residual stream.

Based on their volume and the economic potential of their valorisation, promising residual streams were identified for the countries studied (Greece, Belgium, the Netherlands and Spain). These include:

- **Potato steam peels**
- **Cheese whey**
- **Brewers spent grain**
- **Grape seeds & peels**

Within the framework of the Model2Bio project, two to three potential value chains were identified for each residual stream and are presented on the following pages.

It is difficult to apply these value chains simultaneously in the same biorefinery. The decision of which value chain to use depends on investments for necessary equipment, how advanced a technology is and legal restrictions.



Agri-food by-products are generated as side products during an agricultural process or industrial production of food and beverages. They are often used as feed or for anaerobic digestion. In the circular economy, they are considered a resource. Synonyms: **Residual stream** and **residue**.

Valorisation increases the economic value of residues by converting them into useful products such as new materials or energy. In doing so, the economic value of the converted product is higher than the cost of its conversion.

Don't miss the potential!

By-products matter!

Pomace

Brewer's spent grain

Erythritol

The yeast *Moliniella* can transform the glucose and fructose in grape seeds and peels into erythritol. This **low-calorie sweetener** is also a safe sugar substitute for people suffering from diabetes.

Flavonoids

Grape seeds and peels contain a significant number of flavonoids. These flavonoids can be extracted and utilized as a **food supplement**, adding nutritional value to various products.

Protein

Cheese whey and brewer`s spent grain are rich sources of protein. They can be extracted and used to increase the protein content of **meat substitutes** and other alternatives to animal products.

Polyphenols

Artichoke bracts and potato peels possess compounds with antioxidant activity. These natural compounds can be used as **active cosmetics ingredients** in skin care creams for instance, or added to preserve them.

Glycoalkaloids

These potent compounds are naturally present in potato peels. Glycoalkaloids can be added to pesticides as active component that **acts against pests**.

Organic acids

Acetic acid and other organic acids can be used in the production of cosmetics or as building blocks for the generation of **bioplastics**. Producing organic acids from cheese whey or potato peels could be a sustainable alternative to the traditional fossil-based production.

Oil

When proteins are extracted from cheese whey, a sugar-rich residue remains. It can be used to grow yeast that produces fats with **qualities similar to palm oil.**

Artichoke bracts

Potato peel

Cheese whey

Potato steam peels

What about it?

Potatoes are one of the main crops globally. They are consumed fresh or as French fries, chips, and other processed foods. Per tonne of processed potatoes, about 0.16 tonnes of potato peels are generated.

The main components of potato peels are water and carbohydrates, but they also contain proteins, polyphenols and glycoalkaloids. Their relative quantity in the peels varies according to the potato variety, its maturation state and the peeling method used during processing.

If not discarded, this residue is mostly used in animal feed, composting and biogas production. Products of higher added-value than these can be generated from potato steam peel.

What's to gain?

Three potential value chains were identified. With a maximum of three steps per process and only up to three processes per value chain, each generates two to three products:

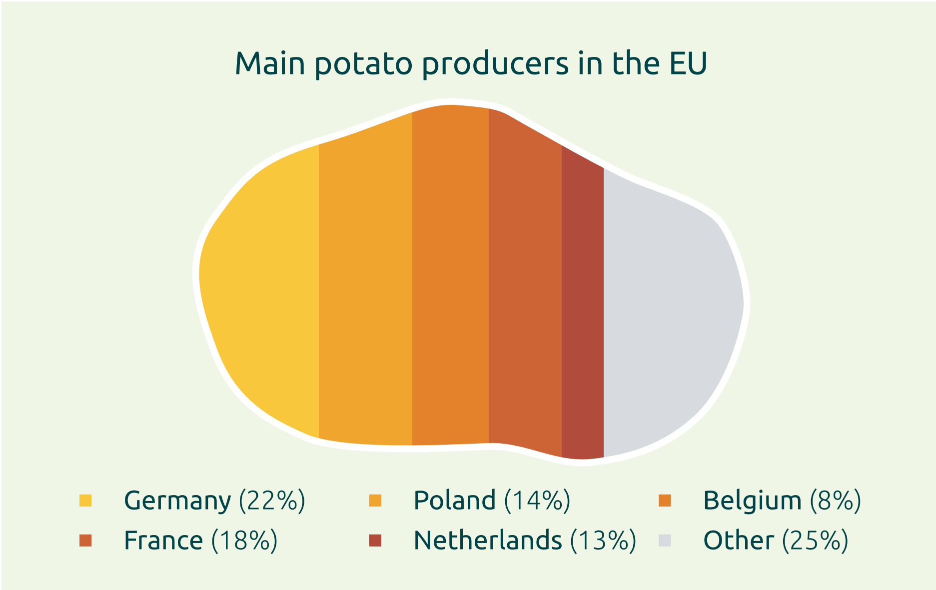
- Glycoalkaloids as active ingredient in pesticides
- Fungal protein for human consumption
- Organic acids as building blocks for the production of bio-plastics or flavours
- Biogas or compost

How much are we talking?

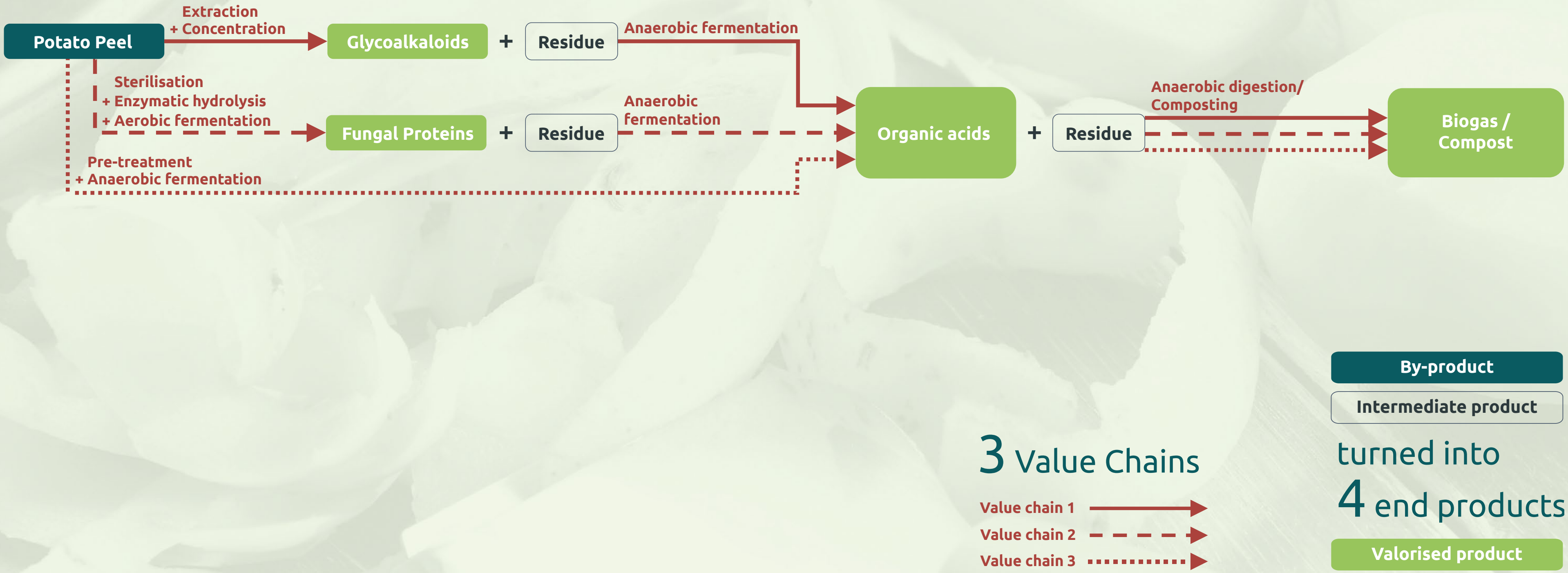
Per kilogram of raw potato peel, 0.75 grams of enriched extract containing 8 percent of glyocalkaloid is obtained. Although this is a low amount, the extract is highly concentrated and glycoalkaloids generally are of high-added value. Not only could they be used to produce bio-pesticides, but they are also promising compounds for cancer treatment.

To make this process economically feasible it is important to also valorise the residues generated therein. These are rich in sugars and yield approximately the same organic acids as direct fermentation of potato peel.

A scale-up of this process is needed to bring this biorefinery closer to industrial requirements.



A second life for potato peels



Cheese whey

What about it?

During cheese making, about 90 % of the volume of milk used remains as cheese whey. More than 10 million tonnes of this liquid by-product were generated in the EU in 2021[1].

Cheese whey is mostly disposed of in wastewater systems, which requires prior treatment. A small share is reused for animal feed or to produce proteins. But the potential of cheese whey goes beyond that.

It is generated all year round, does not need any pre-treatment and mainly consists of water and sugars in the form of lactose. The composition may vary according to the animal origin of the milk and the curdling process used during cheese production, but about 75 % of cheese whey is lactose (w/w on a dry basis)[2]. It also contains proteins that can be used for biofilm production for food packaging.

What's to gain?

Three potential value chains were identified. With a maximum of two steps per process and only up to three processes per value chain, each generates two to three products:

- Proteins for bio-film production
- Microbial oil to substitute palm oil
- Organic acids as building blocks for the production of bio-plastics
- Biogas or compost

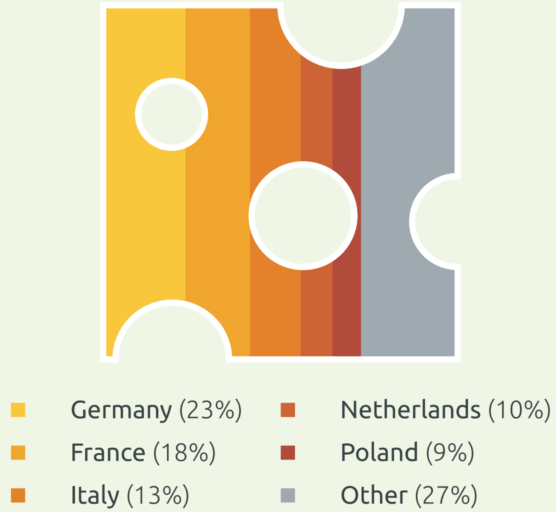
How much are we talking?

More than 70 % of the protein present in the residue is recovered.

About ten grams of lipids per litre of sterilised whey with 50 g/L lactose can be produced within 2 days using the yeast *Candida oleaginosus*. This is similar to or higher than without the filtration step. The combination of filtration to extract proteins and aerobic fermentation to produce lipids is thus feasible. Harvest of the microbial biomass needs further improvement to increase the yield of biogas or compost.

About 26 grams of organic acids per 100 grams cheese whey are generated: 65 % butyric acid, 11 % acetic acid and 24 % lactic acid. The high level of purity allows for cheaper downstream processing. Producing organic acids from cheese whey could be a sustainable alternative to the traditional fossil-based production.

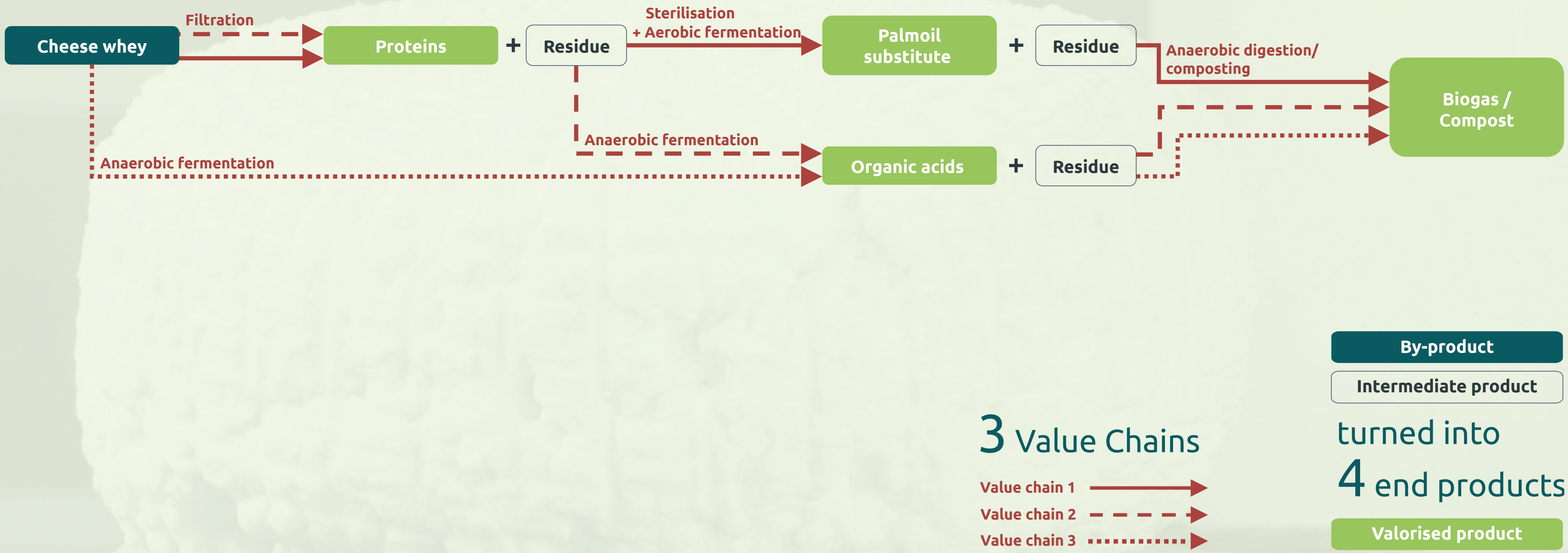
Main cheese producers in the EU



1 Eurostat 2021

2 Fernández-Gutiérrez et al., 2017

Upgrade your cheese whey



Brewer's spent grain

What about it?

The grain used during any brewing process, remains as the main residue, called brewer's spent grain. Between 10 to 20 kilograms of it are generated for every 100 litres of beer produced. During 2022, EU countries alone brewed 34.3 billion litres of beer[1].

Brewer's spent grain is mainly reused as animal feed today. Its high water content makes its transport without prior drying difficult and also causes a short shelf life of ten days maximum.

The main components of brewer's spent grain are the same regardless of the type of grain and brewing process used: proteins and fibres. Many added-value products can be obtained from brewer's spent grain all year round, as beer brewing is not seasonal.

What's to gain?

During the Model2Bio project, two potential value chains were identified. With up to two steps per process and two to three processes per value chain, they generate two or four products:

- Proteins for human consumption, or to produce protein hydrolysate and amino acids that are used in fertilizers
- Fibres as food additives
- Ethanol
- Biogas or compost

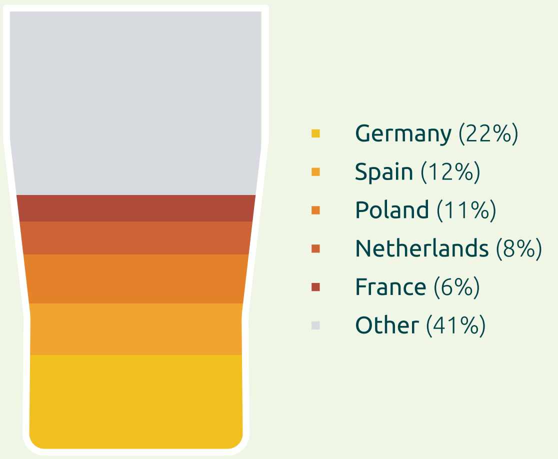
How much are we talking?

From 1 kilogram of wet brewer's spent grain, 11.5 grams with a protein content of 46 % is obtained.

The residue after protein extraction has to be neutralised to enable fermentation with fungi to produce fungal protein. This process takes between 4 and 7 days. Pre-treatment is required to make the sugars readily available for the microorganisms. More development and optimisation is needed to increase the yield and make this process feasible at industrial scale.

After sterilisation, brewer's spent grain can be directly fermented with *Pleurotus ostreatus* and *Trametes versicolor* without adjusting the pH.

Main beer producers in the EU



1 Eurostat, 2022

Repurposing brewer‘s spent grain

Grape pomace

What about it?

The European Union is the main wine producer in the world, producing around 16 billion litres per year and high amounts of grape pomace. This is the pulp, seeds and skins of the grapes.

Grape pomace is a seasonal residue. Grape variety and ripening influence its composition, as does the fermentation process. White grape pomace is generated before fermentation and can directly be used in any process. Red grape pomace is obtained after fermentation. It contains ethanol and must be processed in a distillery.

Some distilleries already recover value-added products from red grape pomace after the ethanol has been removed (value chain 2). But mostly, the residue is used for animal feed, fertiliser or biogas production. This leaves the high amount of phenolic compounds, pigments and carbohydrates unexploited.

What`s to gain?

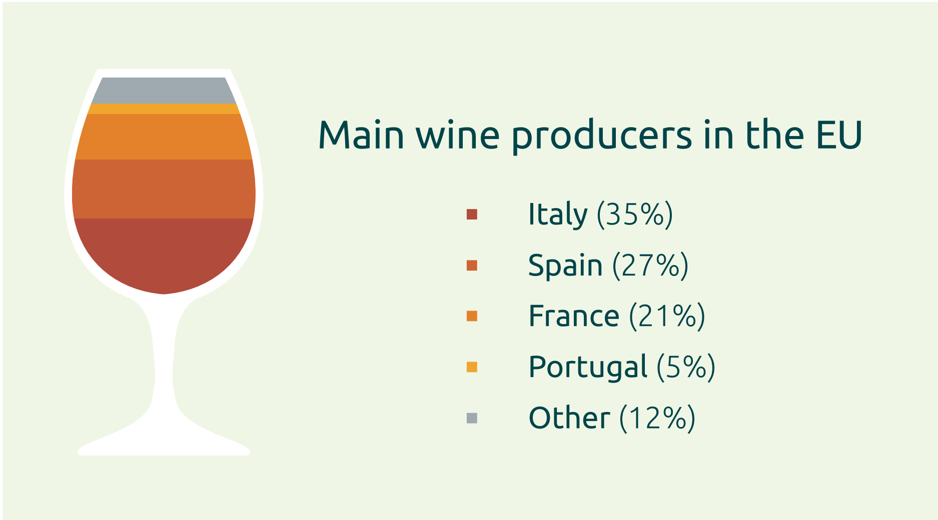
Two value chains were identified. With a maximum of two steps per process and up to five processes per value chain, they generate four or six products:

- Ethanol
- Erythritol, a low-calorie sweetener
- Polyphenols as dyes, raw materials for green chemistry or antioxidant additives to food and cosmetics
- Organic acids as building blocks for the production of bio-plastics, for instance
- Tartaric acid to adjust the pH and sweetness of food and beverages
- Fibres as food additives
- Seed oil
- Enocyanins, pigments that are used as natural dyes in the food industry
- Biogas

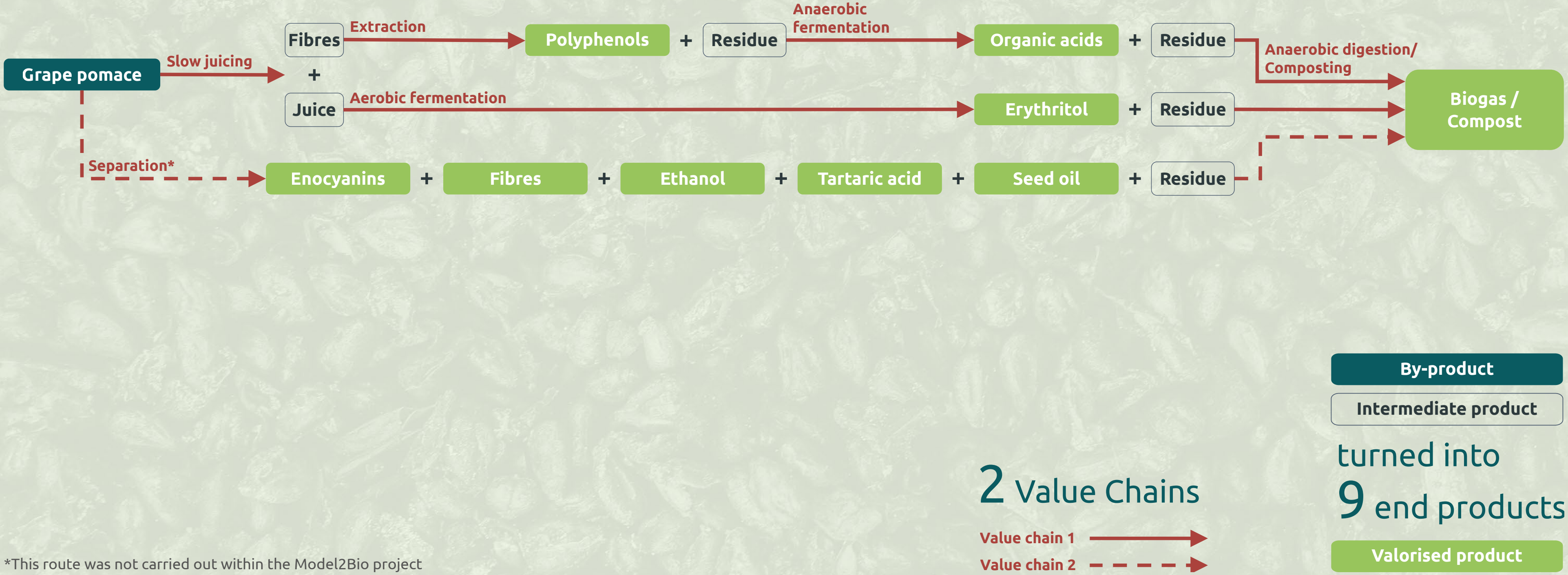
How much are we talking?

About 33 grams of erythritol per litre of residue are produced within 3 days. Slow-juicing is important to make the sugars readily available for microorganisms during the aerobic fermentation. From the fibres separated during this process, polyphenols can be extracted. Here, an enrichment step is needed to reach the antioxidant activity of commercial polyphenols.

Our lab experiments did prove the feasibility of this value chain, which as a next step has to be tested at scale to validate the industrial potential.



New ways for grape pomace



*This route was not carried out within the Model2Bio project

Best practice tips

Industry and academia need to collaborate closely

To use our resources more efficiently, we need new technologies and processes and therefore data: intermediate processes of value chains, quantities of residual streams and their handling.

Agri-food producers play an important role towards innovation by openly giving the needed information to scientists. The more complete the information is, the more efficient innovative technologies will be and the more adapted to industrial needs.

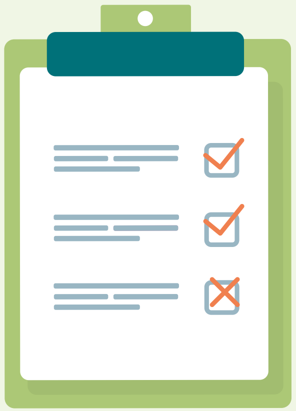
Scientists on the other hand need to acknowledge the constraints of agri-food producers. They may not have the information needed or the time to acquire it. Sometimes, the information may be too sensitive for them to share it with outsiders.

Scientists need to openly communicate in personal conversations:

What information is needed and why? How much work does the company need to invest to obtain and share the information needed? What will happen to the data? What does the company gain in the end?

Checklist for a fruitful collaboration

- ☐ Non-disclosure agreement
- ☐ Anonymise data
- ☐ Share data management plan
- ☐ Create an incentive



Think about the highest value application first

What components to extract?

1. **Components that are of high value or are in high demand should be prioritised for optimal economic exploitation of agri-food by-products.**

   For instance, proteins for the food industry can generate higher revenue than the use of by-products as animal feed, which is among the most common valorisation routes for edible by-products today. The number of livestock and the demand of agri-food by-products as feed may however shrink due changing consumer lifestyles. Concerns about animal welfare, the environment, a healthy diet, but also demographic developments are reducing the demand for animal-based products.

2. **The component needs to be present in enough quantity to make the operation economically feasible.**

   By-products vary in the kind of components they contain and in what quantity. For instance, brewer's spent grain is a good resource for extracting protein and fibres, but not fit for direct fermentation due to its low sugar content.

   Generally, the higher the economic value, the smaller the quantity can be. This is especially the case for compounds of pharmaceutical relevance.

Model2Bio's decision-support tool can help agri-food producers identify promising by-products and which components to generate from them.

In %	Prot	Sugars	Fibre
Veal Blood	85	-	-
Beer spent grain	27	2	56
Tomato	23	2	59
Potato	22	12	42

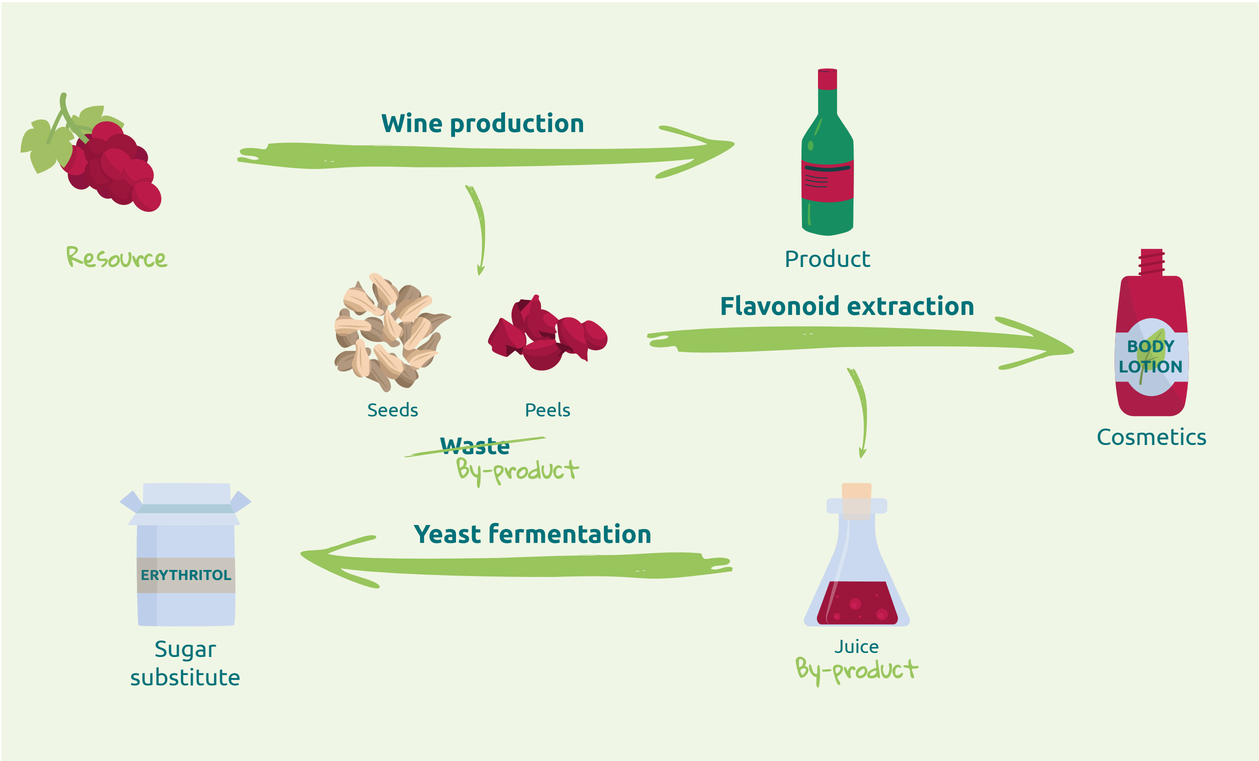
In %	Prot	Sugars	Fibre
Milk whey	22	76	-
Cheese whey	13	85	-
Artichoke	13	19	53
Skin + Seeds Wine	11	28	45

Don't stop at one product! Do cascading instead.

Agri-food residues contain valuable industrial compounds that can be extracted, or by-products that can be used in fermentation to produce bio-energy or substitutes for glucose and palm oil. But the potential of our resources does not stop there. The residues left after valorising an agri-food by-product possess industrial potential as well. Cascading aims to fully use the diverse potential of resources.

This process tries to first extract the most valuable products and use the residues generated during the first process for additional valorisation, like fermentation. In each process, a new product is generated, yielding two or more products from one original resource.

For instance, grape pomace is high in fibres, which contain flavonoids. These valuable compounds for the cosmetics and food supplement sector can be extracted after the fibres are separated from the pomace in a process called 'slow juicing.' The juice remaining after the separation process is rich in glucose and fructose. The yeast Moliniella can transform these sugars into erythritol, a low-calorie sweetener that is considered a safe sugar alternative for people with diabetes.



The Model2Bio tool can determine the most sustainable and economic cascading path, needed equipment and optimal operation parameters for the valorisation of agri-food residues.

Bio-energy production as transition

Creating the necessary infrastructure to extract high-value components from agri-food residues can be too big of a leap if a region's activities are mostly geared towards landfilling or incineration. A viable transition process is to establish larger enterprises that utilise the by-products of several smaller companies to produce bio-energy.

Small dairy companies can sell their cheese whey to an anaerobic digestion company, so can vegetable processors. This not only strengthens the regional economy, but also opens up new economic potential for vegetable processors. In Greece and Spain, they give their residues away for feed.

In regions with a high number of small family businesses it is important that the biogas-producer can reuse a mixture of by-products. This ensures that the anaerobic digestion plant has a constant supply of feedstock, because small businesses in a single sector may not be able to provide all of the needed feedstock due to their lower production capacity.

The anaerobic digestion plant should be located in the middle of the agri-food producers or another strategic location nearby, as costs and CO_2 emissions of transporting by-products influence the feasibility of their reuse drastically. The length of the transport route is in fact one of the main criteria that determine whether a valorisation route is economically and environmentally feasible.

Model2Bio's decision support tool can model hypothetical scenarios to identify the most strategic location for an anaerobic digestion plant and other bio-industries.

In regions with a high number of small family businesses it is important that the biogas-producer can reuse a mixture of by-products.

Simulation tools to maximise the value of agri-food by-products

The obvious valorisation strategy is to maximise the extraction of value-added compounds based on technical criteria, but what is the point of extracting valuable products if the costs of their production and logistics exceed their market value?

Considering only the technical aspects is not enough. Valorisation decision made currently focus on cost minimisation only, although environmental and social criteria are included in decision-making process little by little. Logistics and location of the companies, for instance, can steer the optimal valorisation in a different direction. The problem in an area should be identified and considered. A holistic perspective should be applied, taking into account technical, economic, environmental and social aspects.

Under this holistic perspective, the problem becomes complex and it is necessary to use tools that allow us to analyse all the variables.

Each region has its companies and its particular economy, so it is difficult to intuitively extrapolate solutions from one region to another.

The Model2Bio tool can help to select the best recovery options in a flexible and simple way, considering not only technical and economic aspects, but also environmental and social ones.

Safety

By-products of the agri-food industry often contain high moisture and remaining sugars, making them a good source for microbial spoilage. To understand the risk of microbial spoilage, a microbial analysis should be performed either after production or before transport from time to time. However, if food application is the intended reuse for a by-product, stabilisation of the by-product is needed. This can be done by drying, cooling, acidification, pressing, fermentation, or pasteurisation, for instance. These stabilisation techniques are often technically feasible but have a high energy and consequently economic cost. This should be taken into account when developing new valorisation routes for agri-food by-products.

Agri-food residues can contain hazardous chemicals like heavy metals or pesticides or remnants of chemical extraction solvents, to name a few. Moreover, extraction and enrichment processes can not only concentrate the targeted compounds, but also increase the amount of undesirable compounds like heavy metals. The concentration of hazardous compounds should be checked in the by-product and final extract. These potential chemical risks should further be taken into account when evaluating a by-product's valorisation as food or feed ingredient.

Summary and policy recommendations

Making the most of our resources increases a company's profitability and sustainability, and it protects jobs, rural economies and our environment. To help the agri-food industry progress towards a circular bio-economy, a decision-support system was developed in the Model2Bio project. The tool helps to identify promising residues and determines economic and sustainable valorisation processes. It also identifies strategic locations for new bio-industries.

The by-products generated during food production contain valuable industrial compounds that can be extracted such as proteins, natural food dyes, active ingredients for bio-pesticides and raw materials for sustainable chemistry. Agri-food by-products are also a good substrate for growing microorganisms which produce valuable industrial compounds including microbial oil to substitute palm oil or organic acids as building blocks for the production of bio-plastics. The residues left after valorising an agri-food by-product possess industrial potential as well and it is important that they, too, are valorised.

Cheese whey, brewer's spent grain, potato peels and grape pomace have great potential. They are generated in large amounts in different European countries and contain many components of industrial value. In total 10 different value chains were developed for these residues, each yielding between two and six different products:

- Glycoalkaloids as active ingredient in pesticides
- Proteins
- Polyphenols as dyes, raw materials for chemistry or antioxidant additives to food and cosmetics
- Organic acids as building blocks for the production of bio-plastics or flavours
- Fibres as food additives
- Ethanol
- Erythritol, a low-calorie sweetener
- Tartaric acid to adjust the pH and sweetness of food and beverages
- Microbial oil
- Seed oil
- Enocyanins, pigments that are used as natural dyes in the food industry

Nature`s biocapacity is limited and we have to make the most of our resources

The by-products generated during food production contain valuable industrial compounds that can be extracted.

Financial incentives may be needed for companies to invest in new machinery.

New machinery is likely needed to reuse agri-food residues, such as equipment for pre-treatment, separation, extraction or concentration. Devices to stabilise by-products through fermentation, sterilisation or drying (e.g. with microwave technology) are also important. Reducing the water content of fresh residues avoids microbiological spoilage, and residues can then be safely stored until they are processed on site or transported to a bio-industry. For seasonal residues, stabilisation additionally ensures a constant supply all year round.

The economic profit for valorising residues must be high enough to make the acquisition of new machinery economically worthwhile. Making higher profits than with traditional management options may not be enough and a good return of investment needs to be achieved.

Strategic locations for bio-industries need to be identified and their establishment subsidised.

The valorisation of agri-food residues depends on the infrastructure of the region they are generated in. A by-product producer and a valorising bio-industry cannot be too far apart. The length of the transport is one of the main criteria that determine whether a valorisation route is economically and environmentally feasible. Relevant bio-industries have to be attracted to strategic locations and progression should occur in accordance with existing infrastructure. If, for instance, landfilling is the main route for by-products in a region, an anaerobic digestion plant is a feasible first investment. When it transforms a mix of by-products into bio-energy, it can valorise different by-products from the area.

Funding for more research is needed.

The reuse of agri-food residues is challenging due to their complexity and variability. To identify potential uses for agri-food residual streams, we need to understand the generation of residues and then their composition. Deeper knowledge is needed: What is the volume of a residual stream? How were they processed and stored? What components do they contain? In what quantity?

New technologies are important for valorising by-products efficiently and digital solutions can help to identify the best valorisation route. Their development needs thorough research for which grants have to be made available. This should also include further investments to make more pilot infrastructure between lab and industrial scale available; it is important to test valorisation routes at a scale that is more relevant for the industry.

Data need to be collected and made available to scientists.

Some European regions have databases on agri-food residues, but they generalise data per sector. Scientists lack data on the volume and handling of agri-food residues per company. This slows down the development of innovative and efficient solutions for the circular bio-economy. This bottleneck could be removed by collecting information about residues from agri-food companies across the EU into an openly accessible database managed by the European Union.

Find more detailed information in our white paper on the management of agri-food residual streams.

Our Partners

Scan for more information

This project has received funding from the Bio Based Industries Joint Undertaking (JU) under grant agreement No 887191. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Bio Based Industries Consortium.