Virtual pyrolysis plant locations in Europe

Availability and quality of biomass resources at four potential sites

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

BIO4PRODUCTS
Creating sustainable resources for process industry

Authors

Dr. A. Kozlo, B. Tambuyser (CAPAX)

Co-authors

M. Vis, T.M. Lammens (BTG Biomass Technology Group)

Editing

Dr. A. Kozlo (CAPAX)

James Ling (Greenovate! Europe)

Acknowledgements

This report was prepared in the framework of the Bio4Products project, and is an abridged version of Deliverable 5.1. The Bio4Products project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 723070, specifically within the SPIRE Public-Private Partnership. The report reflects the authors' view only and the European Commission or SPIRE is not responsible for any use that may be made of the information it contains.

www.bio4products.eu

Executive summary

The report describes the results of Bio4Products task 5.1, on the availability and quality of the biomass resources. The evaluation is based on virtual plant locations (VPL) (in the Netherlands, France, Finland and Romania) in order to make them tangible. The report described the process of VPL selection, where availability and cost assessment played the biggest role in the selection process. The selected locations for virtual plants are analysed in detail, where a specific location and reasoning is pin-pointed. Furthermore, industrial symbiosis, logistics, local feedstock potential and other remarks are investigated. Quality, seasonality, competitive use and biomass supply chains were described in detail to create a complete picture.

For all the types of biomass sources analysed it was concluded that there should be enough biomass available around the virtual plant locations, with the exception of flax shives, that may need to come from further away, or cannot be used all year round. A solution for that was proposed via a multifeedstock location.

Keywords: Feedstock availability, biomass quality, supply chains, sustainability

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

1 Introduction

1.1 The Bio4Products project

The Bio4Products project will demonstrate an innovative two-step conversion method to transform different biomass feedstocks into renewable chemicals. The project will show how these sustainable resources can replace fossil material in a wide variety of end products.

A state-of-the-art technique called fast pyrolysis will be employed which transforms biomass into a flexible bio-oil in a matter of seconds. This oil will then be separated into fractions which can be used for the production of roofing material, resins (phenolic and sand moulding), and engineered wood and natural fibre reinforced products. As well as an environmental impact assessment, the project will conduct economic and market analyses to develop a strong business case for its products.

The overall objective is to create four products for which at least 30% of the original fossil-based stream is substituted with sustainable resources, and which deliver a 75% reduction in greenhouse gas emissions.

1.2 Approach

1.2.1 Biomass quality and availability assessment, supply chains of biomass.

This report describes the results of work carried out in Bio4Products Task 5.1, on the availability and quality of the biomass resources. The goal was to evaluate the overall availability and quality of biomass feedstocks selected in Bio4Products. The evaluation is based on virtual pyrolysis plant locations (VPLs) in order to produce results that can be used in a tangible way. Quality control parameters, general issues of biomass quality and competitive uses of biomass are briefly covered.

The analyses were conducted using different publically available sources, company/supplier interviews, as well as the expertise and experience of Capax ES in the raw feedstock domain market. A discussion on availability was also made within the consortium to understand the needs and importance from two sides – the raw material sourcing, pyrolysis oil off-taker needs, and the required know-how, positioning, cost, running obstacles and risk mitigation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

1.3 This report

The next chapter shortly describes which biomass feedstocks were chosen for the project, as those will be further evaluated in this report. Chapter 3 describes the feedstock availability assessment. For this the biomass availability was investigated at EU level, and on that basis 'virtual pyrolysis plant locations' were defined at local level, where the biomass availability was determined in more detail. Chapter 4 covers biomass quality aspects, also in relation to seasonality, as well as a description of other (potentially competitive) feedstock usages. Chapter 5 describes the supply chains of the biomass production and logistics in detail. Conclusions and recommendations are provided in chapter 6.

2 Selection of biomass types and locations

In the project, a selection of biomass feedstocks was carried out as part of Deliverable 2.1. Feedstock selection was initially simplified and based only on availability. After availability was determined, other parameters were evaluated. The chosen feedstocks were delivered to BTG for processing (fast pyrolysis) and analysis. For each feedstock category the feedstocks selected are described in Table 1.

Table 1. The selection of feedstocks for BTG pyrolysis processes

Feedstock category	Feedstock
Agricultural	Hemp shives
	Flax shives
	Flax pellets
	Wheat Straw
Food/feed processing	Olive kernels
	Sunflower husk
Forestry	Poplar wood slabs
	Softwood
	Hardwood (poplar)
	Phytoremediated poplar wood

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

In the biomass sector any type of feedstock and their parameters are somewhat variable due to a number of different factors, such as climate, soil conditions, and handling of the feedstock. The evaluation of feedstock selection was focused on the EU level. The following parameters were in play during the process of feedstock choices:

- Availability of a feedstock
- Focus on lignocellulosic residual by-products
- Technical suitability, availability, geographical spreading, strategical aspects and sustainability aspects
- Focus on the EU zone as sourcing region
- Maximising the avoidance of the food/feed chain

Considered together, these parameters helped to narrow down the selection of the feedstocks. Because more specific and additional parameters were needed to be taken in consideration, it was further proposed to work with a system of virtual locations (described below). Virtual locations allowed the consortium to screen biomass within the specific EU countries and to assess the situation in a more concise, detailed and accurate manner.

3 Feedstock availability

3.1 Virtual pyrolysis plant location (VPL) definition

For the effective evaluation of selected feedstocks a definition of “virtual pyrolysis plant locations” (**VPL**) have been introduced. The pyrolysis plants are defined to stand “virtually” in a specific region in order to help to evaluate the biomass resources in tangible and clear scenarios for each virtual location selection. A primary selection of virtual locations was made based on the availability of selected feedstocks in countries within Europe.

3.1.1 VPL approach

For any bio-based project it is a key aspect to get the right feedstock strategy. Primarily, this all comes down to getting a bio-based project financed. Firstly, it is crucial to establish long term supply guarantees that last at least 10 to 15 years in duration. This ensures that the project has a continuous flow of biomass, because if there is no continuity in biomass, the plant will not run efficiently and may experience interruptions and therefore loss in output capacities. Moreover, assessing the availability locally to the plant, where considerations such as pre-treatment of biomass is looked into. Aspects such as low bulk density and avoiding high transport costs and considering

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 723070.

greenhouse gas (GHG) values must considered. That being said the feedstock must also be of sufficient quality to meet the technical requirements of the processing plant. Values such as moisture content or ash content (discussed later) are considered as part of the quality assessment. Within that, the consistency and continuity of the biomass quality parameters is crucial. In addition to all these aspects, pricing and sustainability of the chosen biomass is equally important.

3.2 Virtual pyrolysis plant location selection

The selection process of virtual pyrolysis plant locations was carried out by analysing the availability in a more detailed manner. This was done within European countries for all of the feedstocks that were selected based on the primary availability evaluation within the feedstock categories (see Table 2). The analyses were conducted using different publically available sources, company/supplier interviews, as well as the expertise and experience of Capax ES in the raw feedstock domain market. A discussion on availability was also made within the consortium to understand the needs and importance from two sides – the raw material sourcing, pyrolysis oil off-taker needs, and the required know-how, positioning, cost, running obstacles and risk mitigation. Collected information and feedback from all resources used including the industrial partners was taken on board in order to make the best VPL selections. This section will present the process of selecting the VPLs.

3.2.1 VPL availability assessment

As discussed and agreed within the consortium, the assessment of VPL was firstly focused on the availability of the feedstocks within the European countries. For that, an overview of general availability was made and was mapped out. Each of the selected feedstock that is available in a country at high amounts based on the production capacity is marked in abbreviated form in Figure 1. A map displaying general availability of feedstocks used in the Bio4Products project.

.

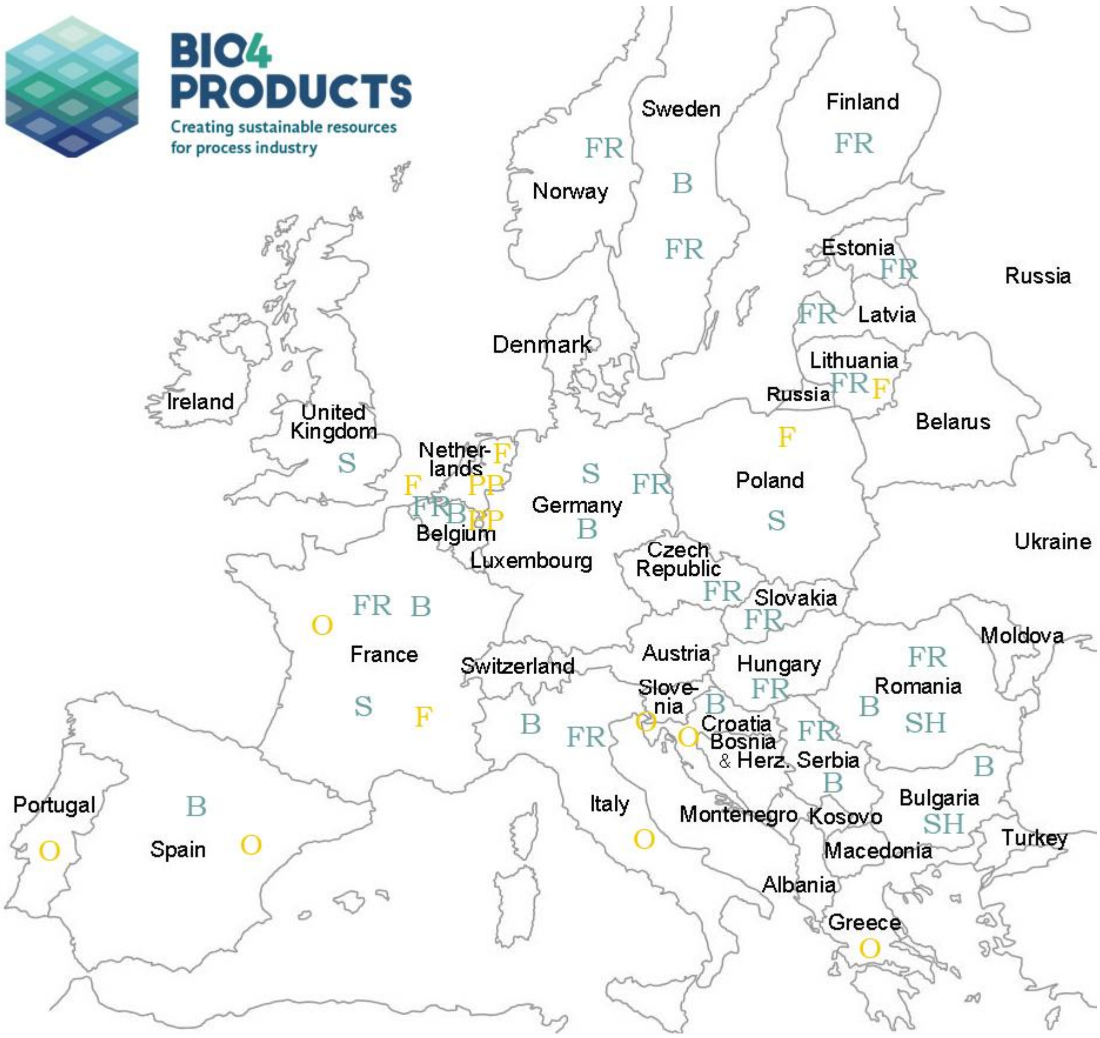
The map shows the availability over Europe of the following feedstocks: straw, sunflower husks, poplar slabs, forestry residues (hardwood and softwood varieties), olive stones, flax shives and phytoremediated poplar. During the overview of the data available, a selection of at least 2–3 top leading producers (countries) for each selected feedstock was evaluated.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

MAIN Feedstocks	Leading countries by production	Production capacity
Straw residues (Source: eurostat)	France	9.536 mil ha (22% within EU28)
	Germany	3.2 mil ha (16% within EU28)
	Poland	5.5 mil ha (10% within EU28)
	UK	1.8 mil ha (7% within EU28)
Sunflower husks (Source: eurostat)	Romania	1 mil ha (24% within EU28)
	Bulgaria	0.82 mil ha (22% within EU28)
Poplar bark (Source: Pro Populus)	France	236 000 ha
	Spain	105 000 ha
	Italy	101 000 ha
Forestry residues – Softwood	Finland	50 mil. m3
	Sweden	70 mil. m3
	Germany	50 mil. m3
Hardwood (poplar)	France	236 000 ha
	Spain	105 000 ha
	Italy	101 000 ha
Phytoremediated poplar	Belgium & Netherlands	60 km2 contaminated land available
Olive stones	Spain, leading producer	51% within EU28 (42 000 ha)
	Italy	11 000 ha
Flax Shives	France & Benelux region (BE, NL) Availability of multiple feedstocks	82 000 ha

Table 2

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.



Main feedstock categories (shown in **green**)	S – Straw B – Poplar bark	SH – Sunflower husks FR – Forestry residues
Additional categories (shown in **yellow**)	O – Olive stones PP – Phytoremediated poplar	SH – Flax shives

Figure 1. A map displaying general availability of feedstocks used in the Bio4Products project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

MAIN Feedstocks	Leading countries by production	Production capacity
Straw residues (Source: eurostat)	France	9.536 mil ha (22% within EU28)
	Germany	3.2 mil ha (16% within EU28)
	Poland	5.5 mil ha (10% within EU28)
	UK	1.8 mil ha (7% within EU28)
Sunflower husks (Source: eurostat)	Romania	1 mil ha (24% within EU28)
	Bulgaria	0.82 mil ha (22% within EU28)
Poplar bark (Source: Pro Populus)	France	236 000 ha
	Spain	105 000 ha
	Italy	101 000 ha
Forestry residues – Softwood	Finland	50 mil. m^3
	Sweden	70 mil. m^3
	Germany	50 mil. m^3
Hardwood (poplar)	France	236 000 ha
	Spain	105 000 ha
	Italy	101 000 ha
Phytoremediated poplar	Belgium & Netherlands	60 km^2 contaminated land available
Olive stones	Spain, leading producer	51% within EU28 (42 000 ha)
	Italy	11 000 ha
Flax Shives	France & Benelux region (BE, NL) Availability of multiple feedstocks	82 000 ha

Table 2: Evaluation of selected feedstock producers within the EU. Leading countries for each feedstock and their production capacities are displayed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Table 2 displays the production capacity of these countries. A total of 51% production capacity of Olive stones within the EU (28 countries) belongs to Spain. For straw residues, France had the leading production capacity, taking 22% of total EU production capacity. In the meantime, Romania has 24% of sunflower husk production capacity within the EU. On average, France has 236 000 ha of poplar production, while jointly with the Benelux region (BE, NL) it shares 82 000 ha of production of flax shives. The leading country for softwood forestry residues is Sweden with a total of 70 million square meters land in use for softwood. Although many metal contaminated areas are present in the EU, jointly within the consortium a decision was made that the region of Belgium and Netherlands (Campine region) will be sufficient for phytoremediated SRC poplar material. Phytoremediated SRC wood is a good choice in the Benelux region because of the shortage of land and large competition of all biomass resources. Targeting a feedstock as such is beneficial because there is a lot of land that needs to be phytoremediated and the process of phytoremediation is not yet a fully developed concept particularly at an industrial scale.

The evaluation of feedstock availability throughout Europe gave a good insight to feedstock preferences for virtual pyrolysis plant locations (VPL) based on countries. Within the discussions of the consortium a number of factors were raised as important when considering the locations of VPL: i) availability of the feedstock in the range of 100-150 km distance; ii) good infrastructure for the pyrolysis oil export (port access, good road transport, rail, etc); iii) price of the feedstock.

Following the consortium discussions based on these factors, a primary shortlist of the following 7 countries was made: France, Netherlands, Sweden, Finland, Romania, Spain and Italy.

A decision was made to go with 4 location choices. Additional variables played an influence, with the following criteria discussed within the consortium:

i) the choices should cover each feedstock category – agricultural, food/feed processing and forestry (see Table 1);

ii) project duration and workload based on time available (hence the narrowing down to 4 VPL);

iii) important aspects for industrial partners that play a downstream role (for e.g. country preferences, know-how) – it was concluded that biomass availability still plays the most essential role, because the end product has a higher density than biomass, therefore lowers the transport costs;

iv) cost of the feedstock in that particular location;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

v) operational challenges, such as managing a plant. At this stage, where pyrolysis technology is niche, the choice of countries is therefore based on where the infrastructure and specific know-how is;

vi) risk mitigation, i.e. 10 years of VPL running with securement of feedstock supply at approximately 44 000 tonnes/year of dry biomass;

In order to narrow down to the 4 locations of VPL, all these variables were assessed in different forms, such as consortium discussions and sharing expertise and experience (where relevant), data search, in-house Capax expertise, etc. In particular, variable iv (cost of the feedstock in the desired VPL location) was further investigated and is presented in more detail in section 3.2.2.

3.2.2 Feedstock cost assessment (variable iv)

A feedstock cost assessment was made in order to have an overview of feedstock costs and price ranges between non-densified and densified feedstocks. As displayed in

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Country	Feedstock	Production (theoretical availability)	Competitive markets and applications	Non-densified, delivered (€/t)	Local price, densified (€/t)	CIF Plant gate BTG (€/t)
France	Straw residues	22% within EU28	Feed, animal bedding, energy, construction	70-90	100-120	120-140
	Poplar bark (slabs)	236 000 ha	Mulching, energy	30	100-120	120-140
	Hardwood (poplar)	236 000 ha	Pulp & paper, panel wood, mulching, energy	50-60	110-140	120-150
France (& Benelux)	Flax Shives	82 000 ha	Animal bedding, construction, mulching, energy	70-90	110-120	120-130
Netherlands & Belgium	Phytoremediated poplar	60 000 m³	Energy	35	90-110	110-120
Sweden	Forestry residues (softwood)	70 mil. m³	Timber, Pulp & paper, panel wood, mulching, energy	50-100	120-160	170-210
Finland	Forestry residues (softwood)	50 mil. m³	Pulp & paper, panel wood, mulching, energy	50-60	110-140	120-150
Romania	Sunflower husks	24% within EU28	Fertiliser, feed, energy	50-60	80-100	120-140
Spain	Olive stones	51 % within EU28	Energy, additives	50-70	-	100-120
Italy	Olive stones	13 000 ha	Energy, additives	50-70	-	100-120

Table 3, benchmark prices were investigated for each feedstock, and three price scenarios were assessed.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

The prices of the “non-densified, delivered” column are based on the average region sourcing distance with an assumption that the feedstock is in the range of 100-150 km to the VPL. For example, the price of straw residues ranges between 70 and 90 € per tonne delivered to the VPL in France. This feedstock is typically used in animal feed and bedding markets as well as construction applications and the energy market. If the straw is densified by pelletising, the market price rises by approximately 30 €/tonne more.

Another feedstock within the delivery radius range, hardwood, is priced around 50-60 €/tonne at ~45% moisture content. This feedstock is popular in panel wood as well as pulp and paper production. It is also used in the energy market and mulching applications. The slabs of poplar (including bark material) come from sawmill activities, where the majority of it is used in mulching and energy markets. The prices for non-densified wood slabs are usually around 30 €/tonne, however this feedstock is typically around 60% moisture content and high ash content (~6-8%) and densification or other processing (such as drying) significantly increases the price to 100-120 €/tonne.

A region of flax production - and therefore the availability of shives - is located on the northern part of France and extends into northern (coastal) Belgium and The Netherlands. This feedstock residue is highly used in animal bedding, but also other markets such as construction, energy and mulching. An average price of the non-densified feedstock is 70-90 €/tonne, while the densified price is ~30€ higher.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 723070.

Country	Feedstock	Production (theoretical availability)	Competitive markets and applications	Non-densified, delivered (€/t)	Local price, densified (€/t)	CIF Plant gate BTG (€/t)
France	Straw residues	22% within EU28	Feed, animal bedding, energy, construction	70-90	100-120	120-140
	Poplar bark (slabs)	236 000 ha	Mulching, energy	30	100-120	120-140
	Hardwood (poplar)	236 000 ha	Pulp & paper, panel wood, mulching, energy	50-60	110-140	120-150
France (& Benelux)	Flax Shives	82 000 ha	Animal bedding, construction, mulching, energy	70-90	110-120	120-130
Netherlands & Belgium	Phytoremediated poplar	60 000 m^3	Energy	35	90-110	110-120
Sweden	Forestry residues (softwood)	70 mil. m^3	Timber, Pulp & paper, panel wood, mulching, energy	50-100	120-160	170-210
Finland	Forestry residues (softwood)	50 mil. m^3	Pulp & paper, panel wood, mulching, energy	50-60	110-140	120-150
Romania	Sunflower husks	24% within EU28	Fertiliser, feed, energy	50-60	80-100	120-140
Spain	Olive stones	51 % within EU28	Energy, additives	50-70	-	100-120
Italy	Olive stones	13 000 ha	Energy, additives	50-70	-	100-120

Table 3: Cost overview of feedstocks in the narrowed down choices of the VPL locations. The prices provided are average feedstock price estimation in 2017 and may vary based on a number of factors.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Currently, there is no use for phytoremediated poplar material apart from the energy market, however other applications (such as production of pyrolysis oil) are possible. An average price for non-densified material is 35 €/tonne. Comparing softwood between Sweden and Finland, it was found that Sweden has a much higher cost for the chipped non-densified biomass.

The poorest quality softwood is typically delivered for 50 €/tonne (forestry chips), while a higher quality chip is sold for 100 €/tonne (sawmill chip quality) in Sweden. On the contrary, in Finland the price of the feedstock ranges between 50-60 €/tonne. Both countries have a high demand of this feedstock for energy, panel wood production, mulching and pulp and paper markets. On top of that, Sweden also has high demands of softwood for the timber market.

In Romania, the sunflower husk market is mainly focused at feed, energy and fertiliser markets. A non-densified husk ranges between 50-60 €/tonne, while the pelletised form can be nearly double this price. A price overview of ground olive stones showed higher prices in Italy (130-150 €/tonne) compared to Spain (90-110 €/tonne). Most of this olive feedstock residue is used in the energy and additive markets.

In conclusion, comparing the prices between the densified and non-densified material is important when calculating the costs of the feedstock and transportation. This is especially important for the business plan of the VPL plant, because the feedstock price is key and directly correlates with the pricing of end products (such as pyrolysis oil). Densified material delivery can be a necessary cost in order to reduce the costs of logistics. It offers a higher bulk density of the feedstock as well as a number of advantages in handling, storage and greater conditioning.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Country	Feedstock	Production (theoretical availability)	Competitive markets and applications	Non-densified, delivered (€/t)	Local price, densified (€/t)	CIF Plant gate BTG (€/t)
France	Straw residues	22% within EU28	Feed, animal bedding, energy, construction	70-90	100-120	120-140
	Poplar bark (slabs)	236 000 ha	Mulching, energy	30	100-120	120-140
	Hardwood (poplar)	236 000 ha	Pulp & paper, panel wood, mulching, energy	50-60	110-140	120-150
France (& Benelux)	Flax Shives	82 000 ha	Animal bedding, construction, mulching, energy	70-90	110-120	120-130
Netherlands & Belgium	Phytoremediated poplar	60 000 m^3	Energy	35	90-110	110-120
Sweden	Forestry residues (softwood)	70 mil. m^3	Timber, Pulp & paper, panel wood, mulching, energy	50-100	120-160	170-210
Finland	Forestry residues (softwood)	50 mil. m^3	Pulp & paper, panel wood, mulching, energy	50-60	110-140	120-150
Romania	Sunflower husks	24% within EU28	Fertiliser, feed, energy	50-60	80-100	120-140
Spain	Olive stones	51 % within EU28	Energy, additives	50-70	-	100-120
Italy	Olive stones	13 000 ha	Energy, additives	50-70	-	100-120

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Table 3 also displays a price indication for CIF (Cost Insurance Freight) plant gate BTG in Netherlands. There was an interest to have an import price of biomass to see the differences in pricing costs and effect of transportation distances.

3.2.3 Final VPL selection

In order to finalise the selection of four VPL locations, the consortium agreed to ensure that the feedstocks that are chosen cover all the defined categories (agricultural, food\feed processing and forestry) within all VPL. For strategic reasons, a VPL plant in France was made a multi-feedstock VPL (better feedstock buying position, higher choice, easier securement of feedstock) and seasonal variation of the feedstock. Apart from the feedstock category parameter, the chosen feedstock in a particular location has to have a high availability based on quantity (a typical 5t/h plant needs 44 000 tonnes of dry biomass per year) and be available within the radius of 100-150 km distance. The logistical aspects of the locations were also looked into to ensure there are multiple good access points. In addition to that, the surrounding infrastructure was also taken into account. This is because the presence of other biorefinery complexes means that the VPL has the ability to sell their leftover heat and steam and incorporate other synergistic aspects within the complex.

As a result of the above considerations, the following locations have been selected with relevant feedstock choices as the four VPLs:

VPL 1. **The Netherlands, Bergen op Zoom**

a. SRC Poplar, phytoremediated

VPL 2. **France, Marne region (Multi-feedstock VPL)**

a. Wheat straw
b. Flax shives
c. Forestry chips (hardwood)
d. Poplar wood slabs (sawmill residues)

VPL 3. **Finland, South Karelia region**

a. Forestry residues (softwood)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

VPL 4. Romania, Moldova region

a. Sunflower husks

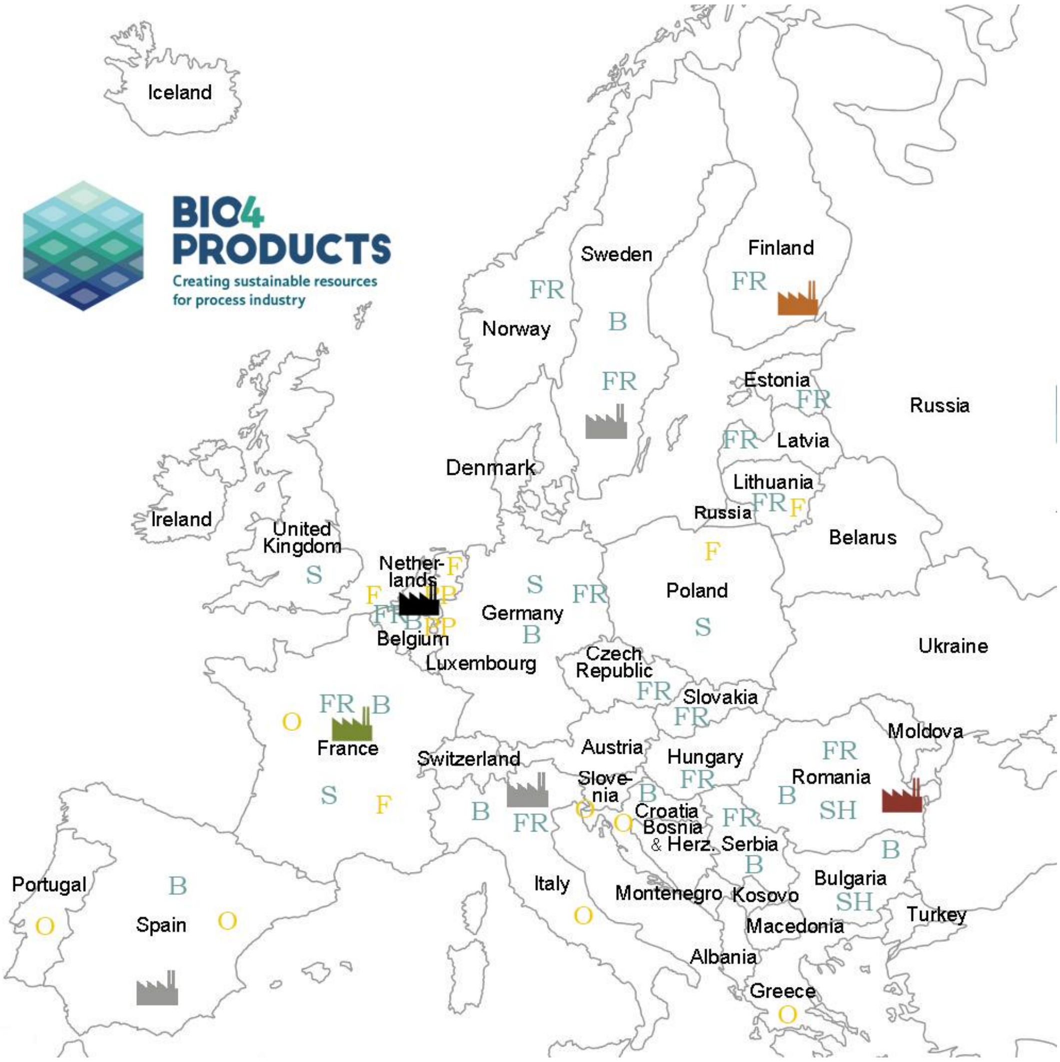
The remaining feedstocks not included in this list were excluded in further analyses.

Main feedstock categories (in **green**)	S – Straw B – Poplar bark	SH – Sunflower husks FR – Forestry residues
Additional categories (shown in **yellow**)	O – Olive stones PP – Phytoremediated poplar	SH – Flax shives

Figure 2. Map displaying chosen Virtual Pyrolysis Plant Locations in the EU zone

displays the location of the VPL selections on the map. Within the map a preliminary VPL location shortlist is included, which was supported by the availability parameters of the feedstocks (marked in grey factory icons). Section 3.3 VPL location analysis will discuss the details and reasoning on the final four locations selected.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.



VPL - Feedstocks:	France – Multi-feedstock Netherlands – Phytoremediated poplar Other – excluded	Romania – Sunflower husks Finland – Forestry residues
Main feedstock categories (in green)	S – Straw B – Poplar bark	SH – Sunflower husks FR – Forestry residues
Additional categories (shown in yellow)	O – Olive stones PP – Phytoremediated poplar	SH – Flax shives

Figure 2. Map displaying chosen Virtual Pyrolysis Plant Locations in the EU zone

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

3.3 VPL location analysis

This section will cover a detailed analysis of the four selected VPL locations. Within the analysis, VPL location will be defined, feedstock potential around the area and its distance will be accounted including the logistical aspects. Each VPL feedstock quality parameters and seasonality will be highlighted.

3.3.1 The Netherlands

In the Netherlands, a Green Chemistry campus was selected as a VPL location. Here it is assumed that the VPL is running on SRC phytoremediated poplar wood. The choice of this location was based on a number of factors. The choice for the Netherlands was made due to the availability of nearby pyrolysis plant expertise located in Empyro, Enschede. Bergen op Zoom is where the Biobased cluster resides – at the green chemistry campus. There industrial symbiosis is possible, with e.g. Sabic, Cargill, and others. The location of the Green Chemistry Campus (Bergen op Zoom, **Error! Reference source not found.**) is at a proximate distance to the Campine (Kempen) region, where a lot of phytoremediation land is available. Therefore, Bergen op Zoom is an ideal location based on the transport distances to the area where SRC feedstock can be grown.

Figure 3 A map displaying the region of the VPL location in the Netherlands, Bergen op Zoom

VPL location

The biocomplex in Bergen op Zoom is a large bio-based cluster spanning from Leiden to Reims. Well-known companies are situated there, such as Sabic, Dow chemical, Arkema, Cargill, Norwegian Yara, Zeeland Refineries (Total/Lukoil) are situated in the area of Sloe. There are a lot of plans for additional biorefinery unit developments, such as a polyvalent pilot facility for biochemical and chemical operations, “Blue gate” harbour area for biomass treatment and isobutanol production from biomass plant.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 723070.

Figure 4: A view of the Green Chemistry Campus in Bergen op Zoom, The Netherlands.

Logistics

Harbour facilities are available at nearby Theodorushaven. There are also good road and rail connections to and from the Green Chemistry Campus.

Feedstock potential

The feedstock is available within ~100 km distance from the location in the region of Kempen (Campine, BE, NL). There is a total of 700 km^2 (70 000 ha) of heavy metal polluted land available. Considering an average yield of 4-8 t/ha per harvesting cycle, it is possible to account ~140 000 GMT\y biomass potential. Using the 2 year growing model, it was calculated that the total available land may yield around 300 kilo-tonne/year of feedstock within a ~200 km radius.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Other considerations

SRC of Willow and poplar are a fast growing and high biomass producing species. The Kempen region is a metal contaminated agricultural soil. In this region, a lot of research on land phytoremediation has been executed and there is a range of experienced institutes and universities that can offer good know-how in order to achieve advantageous biomass yields and environmentally beneficial phytoremediation models.

The contaminations of zinc (Zn) and cadmium (Ca) that can be found there are 377 mg/kg soil and 6.5 mg/kg soil respectively (Van Slycken et al 2012). During the SRC growing model that cycles in 2 years, a potential uptake of heavy metals is around 2 kg Zn/ha/year and 72 kg Ca/ha/year. This recorded uptake has been noted as significantly higher than rapeseed or energy maize crops. If leaves are also harvested, a 40% increase of Cd and Zn removal can be achieved (Jansens et al 2015). To maximise the production of biomass, clones such as Wolterson, Fritzi Pauley & Balsam spire can be used. The majority of heavy metals accumulate in the foliage (~150 ug/g Al, ~500ug/g Zn) and some in the biomass (mostly bark, 0.7 ug/g Al, ~70ug/g Zn – depends on different metals present in the soil). During the pyrolysis process, the metals found in the biomass stay in the ashes.

3.3.2 France

The feedstocks availability analysis, as described earlier, have shown that France is an ideal country to consider as a multi-feedstock VPL. The following feedstocks are being analysed in this VPL: i) Wheat straw; ii) Flax shives; iii) Hardwood (forestry chips) and; iv) Poplar wood slabs (sawmill residues). The availability of different feedstocks was evaluated in each region of France. To find the best proximity to the four feedstock choices, a decision was made to place the VPL in Bazancourt-Pomacle, Marne region, Les Sohettes industrial complex. In Figure 5 the VPL is marked with a black dot. The surrounding regions with high biomass availability are also marked: Beauce – availability of wheat straw; Somme – flax shives; Ardennes and Nord regions – forestry hardwood; Marne – Sawmill residues.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

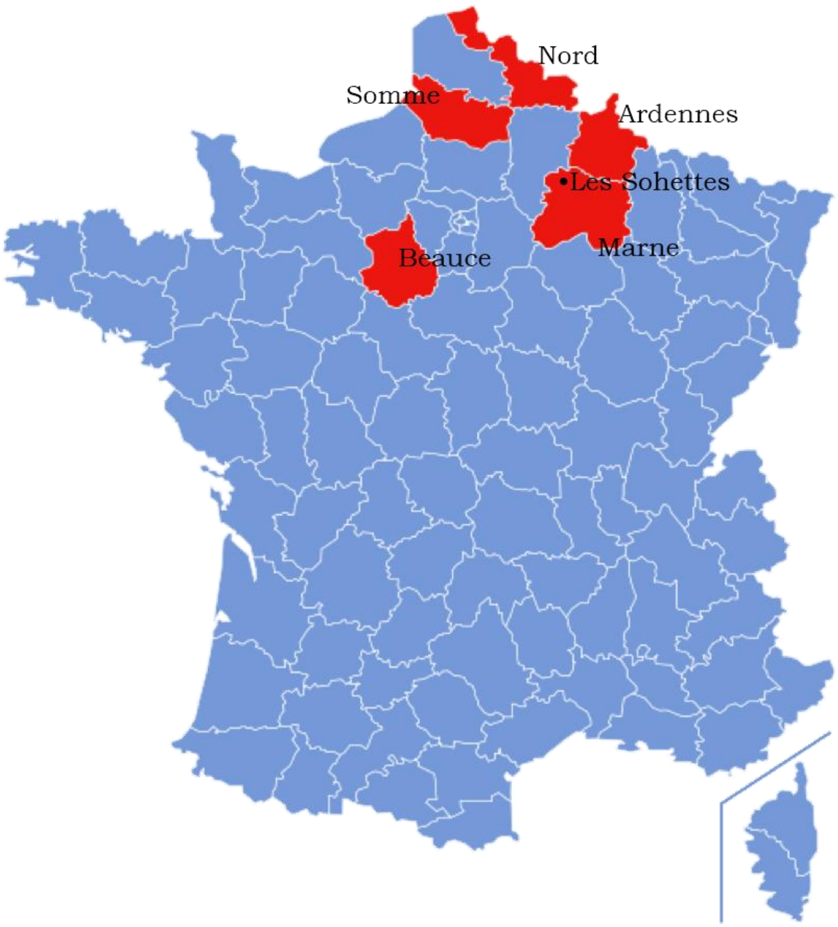


Figure 5: A map displaying VPL location in France.

VPL location

Les Sohettes is a model integrated biorefinery, where there is an abundant supply of farmer cooperatives, companies, universities and research centres. The plant refining complex contains a competitiveness hub "Industries et Agro-Resources", which actively supports the development of biorefining. The following industrial players are situated in Les Sohettes: Bioamber - succinic acid production; Chamtor – Glucose and starch production; Cristal Union group – sugar production/distillation; Soliane – active cosmetic ingredients; Futurol – Bioethanol pilot factory; Biomass co-generation plant; Vivescia – wheat storage. Additionally, a number of reseach centres are available, such as Biodemo and A.R.D. Figure 6 displays a scheme of the biorefinery complex and how the synergies work within this industrial zone.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

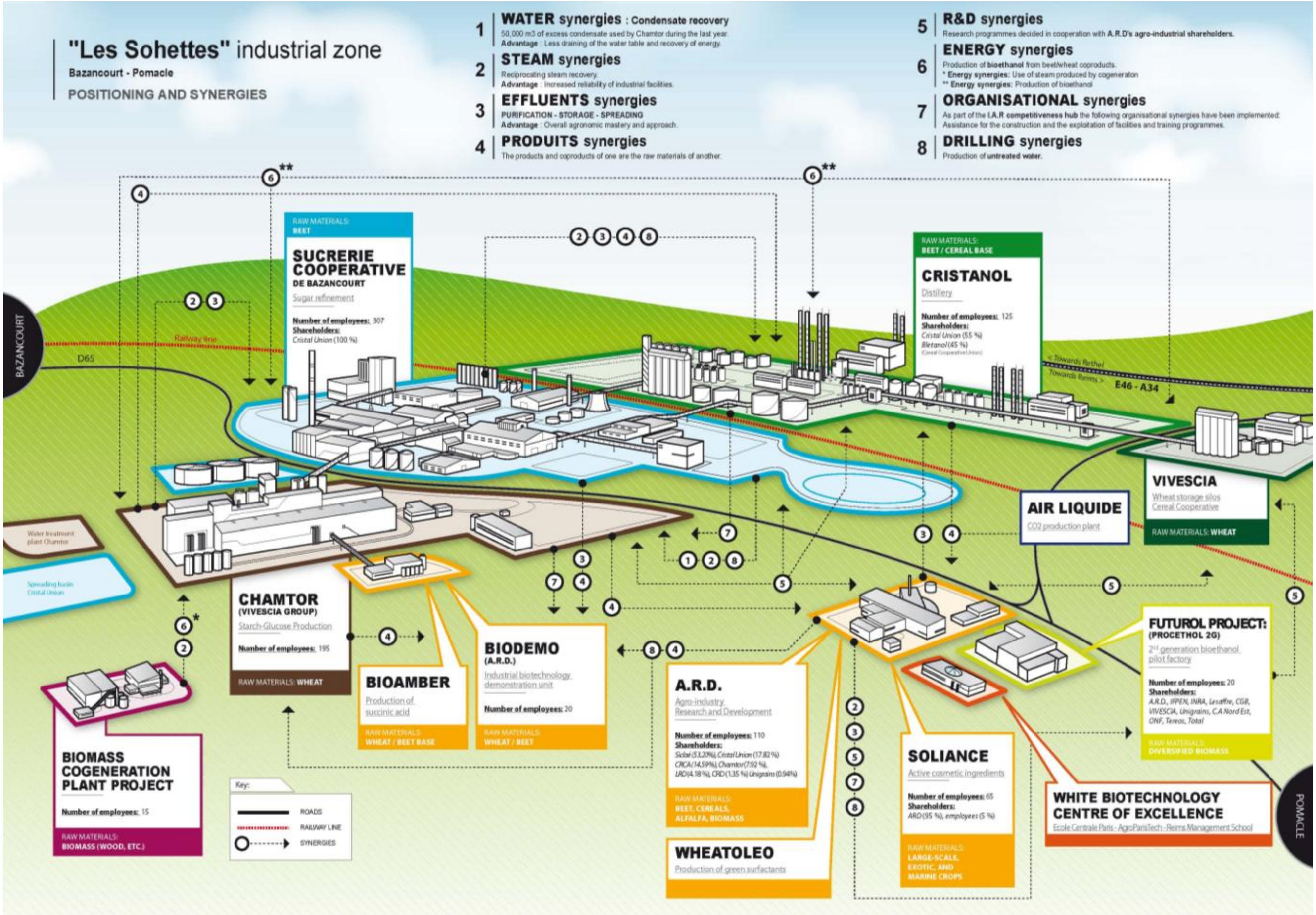


Figure 6: Les Sohettes industrial zone in Bazancourt-Pomacle. The figure displays positioning and different synergies in the biorefinery complex. Adapted from A.R.D.

Logistics

Feedstock transport distance to Les Sohettes, Bazancourt from all locations is on average 150 km range. There is a good road connection to Reims, where the motorway splits and leads to Paris and Troyes. A railway line passes though the complex, which provides rail access for the transportation of goods.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Feedstock	Region	Overall availability	Feedstock (residue) availability
Wheat (straw)	Beauce	200 000 ha	1.1 million tonnes
Flax (fibre)	Somme	12 000 ha	18 000 tonnes
Forestry hardwood (poplar)	Ardennes	200 million m^3	140 million m^3
	Nord	50 million m^3	45 million m^3

Table 4: Feedstock potential in different regions of France.

Overall feedstock availability and residual feedstock availability is displayed for year 2017.

Feedstock potential - Wheat straw

The region of Beauce is one of the most productive agricultural regions in France. Overall grain harvest in France was 62 million tonnes in 2010. Grains are grown on 13 million hectares throughout the country. In the Beauce region alone, there is 200 000 ha of land dedicated to wheat growing (see **Error! Reference source not found.**). The yield of wheat grain/seed typically constitutes 51% of harvest, which leaves around 43% for straw. On average, 5-6 tonnes per hectare will be wheat straw. Therefore, the theoretical availability of wheat straw is equivalent to 1 million - 1,2 million tonnes in the region.

Feedstock potential - Flax shives

The Picardie administrative region is divided into 3 departments: Somme, Aisne and Oise. Temperate oceanic climate and fertile soil made this coastal region dominant with agricultural land (68%) and therefore strong agricultural production in flax and other products. A total of 12 000 hectares (see **Error! Reference source not found.**) of flax is grown in these departments (see Figure 7: A map displaying flax production regions in France and Benelux.). Although some other departments such as Seine-Maritime or Eure have even higher agricultural production of flax, Somme, Aisne and Oise have sufficient quantities available accounting for the distance to the VPL location in Les Sohettes and therefore were chosen for their proximity rather than just availability.

Generally speaking, from one hectare of agricultural land it is possible to yield 1.2-2 tonnes per hectare of flax (1.5 tonnes per hectare on average). As a result, around 18 000 tonnes of flax are available on an average harvest. The flax fibres are composed of the following fractions: long fibres (textile grade material), short fibres, shives,

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

seed and dust. The fibre content in flax ranges between 13-18% on average. In the meantime, around 70-80% of total straw is shive, which makes around 14 000 tonnes of potential shive available in the region.

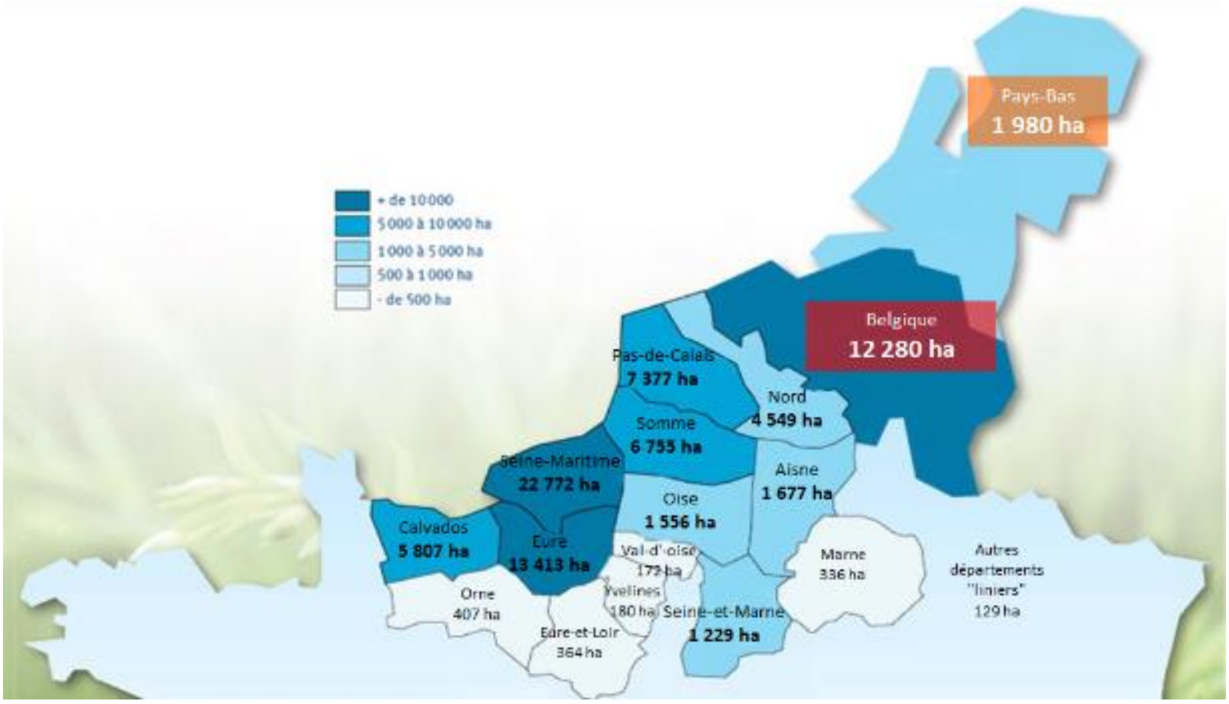


Figure 7: A map displaying flax production regions in France and Benelux. Data provided on the map represents flax yield in 2014. Adapted from Universite du Temps Libre du Pays de Morlaix.

Feedstock potential – wood

France is first amongst European countries for total consumption of wood energy and occupies (with 151 toe per 1000 inhabitants) sixth place for its consumption per capita. 18% of the wood is used in the industrial sector, especially in wood and paper industries. The by-products of sawdust, bark, paper residues are typically used for the production of heat and electricity. The advantage of wood energy development is that it contributes to a better mobilisation of wood capitalised in the forest, thinning and maintenance of forest areas, hedges and various tree formations. Wood chips constitute wood material that has been crushed from either whole trees or parts of trees (residual branches or wood residues called slash) that come directly from the forest. The availability of sawmill chips come from wood processing sawmill by-products.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

In Ardennes, the majority of biomass is used for the production of renewable energy. A total of 200 million m^3 of woody biomass are available in the region (see **Error! Reference source not found.**). 70% of total wood available is hardwood. As a result, a total of 140 million m^3 hardwood is available in the Ardennes and Marne regions jointly (Figure 8). Meanwhile, the region of Nord has a total of 50 million m^3 of woody biomass available (see **Error! Reference source not found.**), of which 90% is hardwood. That makes it 45 million m^3 of hardwood available in the region. In total, the selected regions (Nord, Ardennes and Marne) jointly have 185 million m^3 of hardwood available (see Figure 8 and **Error! Reference source not found.**).

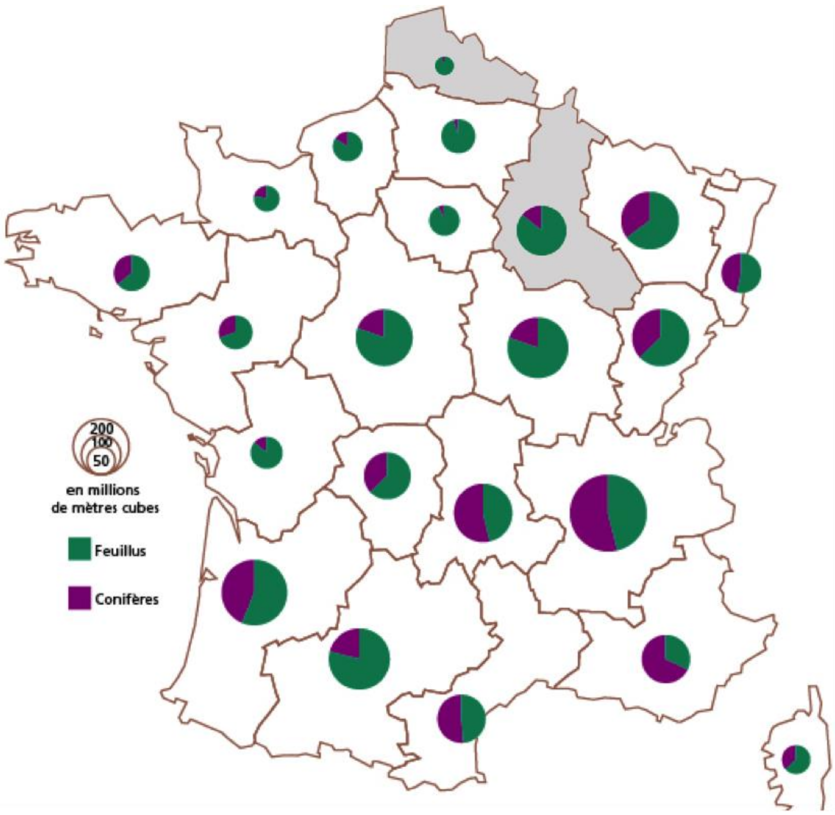


Figure 8: A map of France displaying the availability of woody biomass in different regions. The regions of Nord, Ardennes and Marne (jointly) are highlighted. Altogether around 185 million m^3 of hardwood is available across these regions. Feuillus – hardwood; Coniferes – softwood.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

3.3.3 Finland

In this location a VPL is assumed to be running on forestry residues, specifically softwood residues. The choice of this location was based on a number of factors. The choice of Finland over Sweden was made due to the proximity of market players (nearby pyrolysis oil users in Finland, Russia, etc., especially Hexion) and an overall better feedstock price (lower exploitation costs, etc). After the availability evaluation region by region (see Figure 10), the VPL was placed in South Karelia Region, situated in the south-eastern part of Finland (Figure 9). A total of 13.8% of the country's wood is available within the region (see Figure 10), where different potential sites were evaluated and the choice was made to place the VPL in UPM Lappeenranta Biorefinery. This biorefinery complex has been built at the Kaukas mill site situated about 220 km from Helsinki.

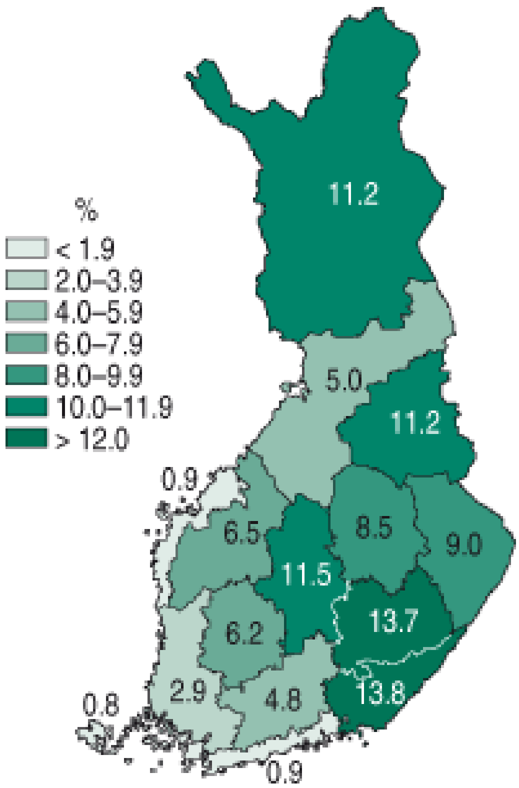


Figure 9 (left): The region of South Karelia in Finland. The biorefinery of Lappeerata is highlighted.

Figure 10 (right): Percentage of wood availability and its distribution throughout the Finland. Bottom right shows the region of South Karelia at 13.8%. Source: Statistics Finland

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

VPL Location

The Lappeenranta biorefinery produces renewable diesel via hydrotreatment technology (Figure 11). Three areas of competence are highlighted within the biorefinery complex: availability and access to biomass, capabilities and technology availability, synergistic and efficient industrial platform.

Figure 11: UPM Lappeenranta Biorefinery complex in South Karelia, Finland.

Logistics

The biorefinery is located near Lappeenranta, about 30 km from the Russian border. Lappeenranta is connected to other cities and municipalities by road. The Allegro train station has multiple directions within Finland and towards St. Petersburg in Russia. Water accessibility is available during summer via Lake Saimaa and the Saimaa canal.

Feedstock potential

The total forest land available in Finland is around 21.1 million hectares (73% of total Finnish land) of which only 20% is available for wood supply. This converts to an average of 2 024 million m^3 o.b. (over bark) of wood available for supply markets (**Error! Reference source not found.Error! Reference source not found.**). The southern

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

boreal region alone has 55 600 hectares of forest available. In South Karelia, 13,301 m^3 of total wood is available of which 17.6% constitutes total wood residues available (2,341 m^3).

	Logs (1000 m^3 over bark)	**Pulpwood**	**Roundwood**	**Wood residues**
WHOLE COUNTRY	25927	39367	67426	9336
2 Varsinais-Suomi	1010	53	1063	..
4 Satakunta	2302	2827	5447	1256
6 Pirkanmaa	2086	124	2211	191
7 Päijät-Häme	1812	571	2384	527
8 Kymenlaakso	1304	5972	7616	1581
9 South Karelia	**2402**	**9469**	**13301**	**2341**
10 Etelä-Savo	2505	229	2734	-
11 Pohjois-Savo	2093	1863	3956	209
12 North Karelia	2006	2521	4539	591
13 Central Finland	1864	3194	5058	705
14 South Ostrobothnia	719	414	1134	59
17 North Ostrobothnia	1815	2446	4261	473
19 Lapland	939	4607	5550	489

Table 5: Forest industries' wood consumption in Finland and by Finnish region. Units are displayed in 1000 m^3 over bark. Adapted from Natural Resources Institute Finland. Regions that have no or trace wood available are not displayed. The selected region South Karelia is highlighted in bold.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

3.3.4 Romania

A VPL in Romania was chosen, where it is assumed that sunflower husks are used as a feedstock to run the plant. After the evaluation of all the regions, a region of Moldova was selected for the feedstock localisation (growing). Considering other factors, such as feedstock processing and transportation, three municipalities (counties) were selected at the border of Moldova: Galati (Moldova region), Braila (Muntenia region) and Tulcea (Dobrogea region). In these municipalities (see highlighted in Figure 12) there are the largest sunflower mills and factories located to current date.

Figure 12: A map displaying municipalities/counties surrounding the selected VPL site in Romania.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

VPL location

The VPL is placed in the city of Galati, within the Galati region. It is situated just above the city of Braila, 30 km to the north on the left bank of the river. The area has a number of sunflower oil factories within a radius of 7-10 km, such as Prutul, Mund oil and Galatex. The VPL can exchange synergistic effects with these factories in the neighbourhood. The oil factories may supply the sunflower husks, while the VPL may sell leftover heat from pyrolysis processes.

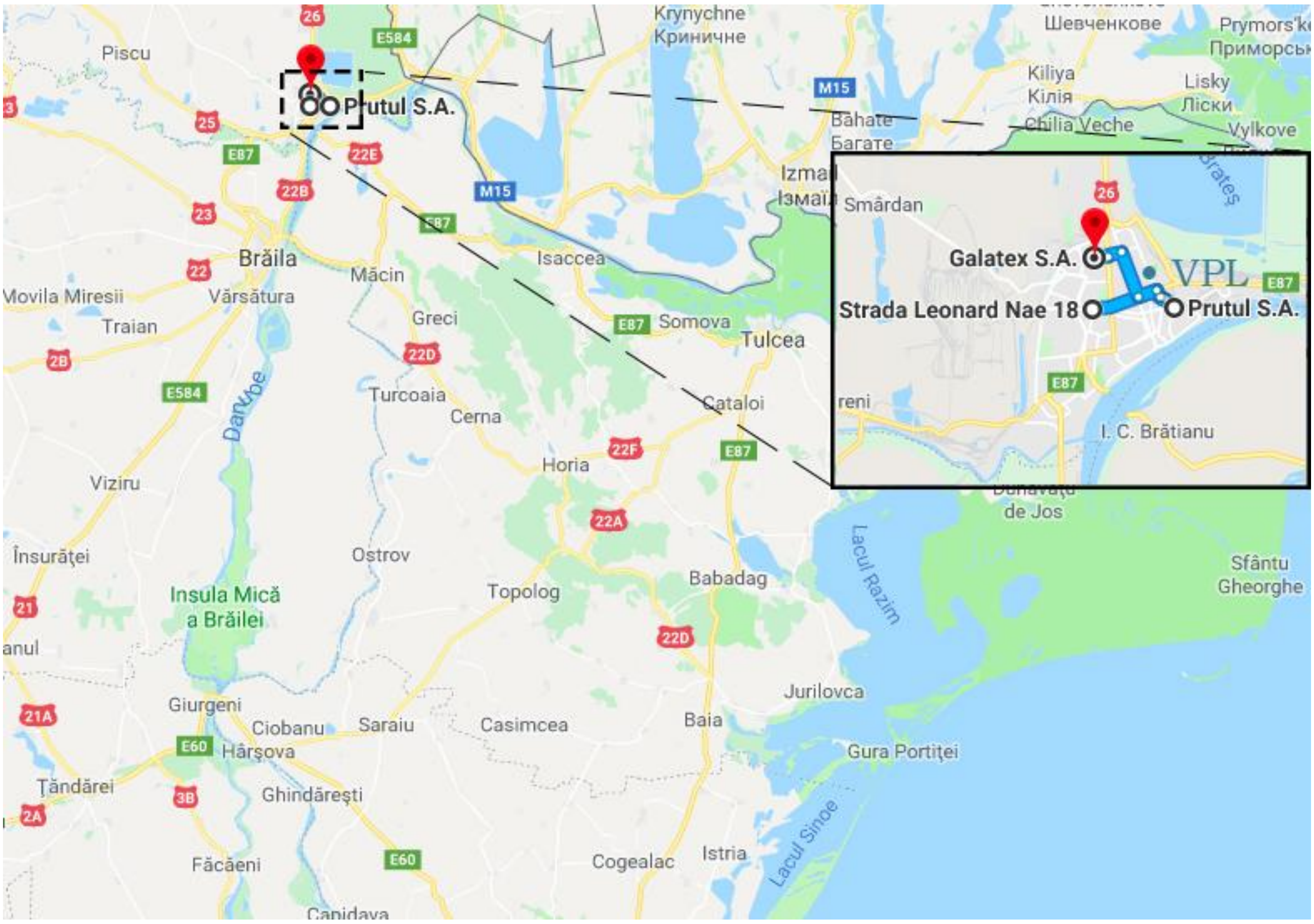


Figure 13: A map displaying the VPL location area in Romania, Galati region, Galati town. The VPL is placed in close proximity to three sunflower oil factories.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Logistics

The river Danube connects Constanza, Tulcea, Galati, Braila and makes water transport convenient. All the big cities have port-canal facilities. The goods can also be transported via the Danube-Black Sea canal towards Budapest (Hungary), Vienna (Austria) and Passau (Germany). Transport via the Black Sea is available from the large harbour in Constanza. Good road and rail transport is available throughout the country and in the direction of Western Europe.

Feedstock potential

Romania is a well-known agricultural region for sunflower growing. A total of 1 million hectares of land is available for sunflower seed production in Romania. Out of the total land available, 312 000 hectares of sunflower dedicated land are located in the Moldova region alone. During the harvest, the yield of sunflower per hectare is on average 2 tonnes. That makes a total 1.95 million tonnes of sunflower seed available per harvesting season, of which around 624 000 tonnes of seeds per hectare are harvested in Moldova region. When processed, 20-25% of the seed constitutes the hull. This makes on average 82 000 tonnes of hull available in Moldova region alone. When densified (pelletised), the bulk density of sunflower husk is typically between 600-650 kg/m^3.

4 Quality, seasonality and competitive usage of biomass

4.1 Biomass quality influences

The biomass feedstock quality can be influenced by a variety of different factors during each step of the entire supply chain. This can occur starting from the field or forest to the delivery at the end-user. For instance, quality may be affected during harvest operations. The end user can also influence the feedstock quality if storing and processing is not done properly. Some of the main influential factors on biomass quality are:

- growing conditions
- meteorological conditions
- harvesting operations
- handling and storing operations

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

It is essential that a pyrolysis plant has defined acceptance criteria for biomass quality.

4.2 Factors influencing biomass quality control

In order to make sure that a feedstock that is delivered is in compliance with the feedstock requirements of the pyrolysis process, it is essential to have a strict control on quality parameters at the pyrolysis plant. Within the acceptance criteria, the most common quality nonconformities are related to:

- particle size deviations
- moisture content of the biomass
- contamination with undesirable substances

Factors that influence the size of particles are mostly related to mechanical and handling operations. When lignocellulosic biomass is calibrated, different grinding, chipping, cutting and sieving technologies are used. It is essential that machinery is well maintained and that the processing is done correctly. For example cutting knifes should be kept sharp, and sieves not broken. Chipper knives that are not sharp, will lead to oversized material that is bruised and not cut.

The moisture content of the biomass can be influenced during handling and storing of the material. As an example, if biomass is stored on a wet surface or in humid conditions, it will lead to water uptake and degradation of the biomass.

During handling and storage, occurrences that lead to breach, contamination, extra fines and as a result moisture uptake can arise. For example, a biomass that is pelletised and then handled improperly can have a lot of pellets that are broken up. This results in the material loss and extra fines that are undesirable in biomass processing system.

In the case of biomass contamination, impurities can occur during handling operations. For instance, if the truck is not clean the biomass may become contaminated with the residues of previously handled biomass. This and similar types of contaminations can occur during charging and transporting operations.

Weather conditions can also influence the biomass quality (as well as yields). This can be due to late frost, dry weather conditions or severe rainfall. Such meteorological conditions can also influence the harvesting operations that may result in contamination of the biomass. It especially occurs when harvesting needs to be done in very wet conditions. In this instance soil can stick to the biomass leading to contamination and resulting in higher ash contents. This specific example has recently become an increasing occurrence in Western Europe due to climate change. In winter forestry exploitations are specifically suffering from this and other similar issues.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

4.3 Feedstock seasonality

Seasonality can have an influence on the availability of feedstocks. Availability issues can be tackled by using the right conditioning and storing techniques for individual feedstocks. Depending on the feedstock requirements different conditioning methods are applicable. Conditioning methods range from straw balling, wood drying to pelletising. In particular, pelletising can be used for majority of agriculture and forestry raw materials and residues. Products such as wood pellets, straw pellets, sunflower husk pellets can be produced.

Availability issues can also be dealt with by using correct sourcing strategies. This means that the processing plant can source biomass from different suppliers, different regions and even different countries. The transportation of large quantities of biomass over longer distances by ship can actually have a lower CO_2 impact in comparison to regular transport for smaller amounts of biomass by trucks.

Another feedstock strategy to counter seasonality effects, and as a result to avoid supply scarcity, is a multi-feedstock plant. That is why Bio4Products integrated a VPL (Virtual plant location) that considers a multi-feedstock scenario. The scenario of this VPL was placed in France, Beauce region. In this scenario, agro residues like wheat straw and flax shives are combined with woody biomass coming from the forest and wood slabs from sawmills. This ensures more biomass security throughout the entire year.

Lastly, a processing plant can consider having their own production of biomass. This scenario can avoid some feedstock price issues, such as fluctuations due to economic variables, feedstock availability and demand from competing players locally. Not being in a price squeeze and being able to better spread the deliveries are also advantages of this model. Having your own biomass production can be implemented by using wood and SRC plantation models.

Overall, any processing plant including a pyrolysis plant is strongly advised to have a minimum storage capacity for the feedstocks to counter the seasonality. However, it is important to consider the cost of handling, conditioning and storing of biomass. The longer these processes are, the higher the price of the feedstock will be. Despite that, a plant that cannot run on a constant basis is significantly less cost effective and profitable compared to the plant that has well organised storage facilities and is able to operate without interruptions.

4.4 Competitive uses

The trends of feedstock usage are shifting and society is evolving to a more bio-based economy. As a result, the competitive use of lignocellulosic biomass is completely changing. This includes any types of biomass, be it raw

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

materials, by-products, residues or waste streams. The main historical applications of biomass have been markets such as:

- food & feed
- pulp & paper
- panel wood
- soil amendments
- energy.

The feedstock market is moving away from these historical applications and new emerging and more sustainable applications are already in place or being developed. Some examples of such new processes/technologies are:

- Thermal conversion processes
    - fast pyrolysis
    - torrefaction
    - gasification
    - production of biochar (slow pyrolysis or carbonisation)
- Biorefinery processes
    - organosolv
    - fermentation

Some traditional users are using fewer raw materials and more recycled products (e.g. the panelwood industry, in western countries old paper mills have closed down). Wood based renewable energy projects use an important part of the available woody biomass. As a result, it is expected that with the development and growth of the bio-based industries, the demand for biomass feedstocks will rise and biomass prices will also evolve upwards.

From a sustainability point of view, the valorisation of a product is a preferred route above any energy application. The preference over energy applications exists because the product will function as a carbon sink. However, some biomass feedstocks are abundantly available in certain parts of the world (for example forestry slash, bagasse, palm oil kernels, old palm tree plantations, sawmill residues), and as a result become an environmental problem because they are not utilised. Open field burning of biomass or controlled composting (rotting) are still being practiced and result in the release of CO_2, methane gas, and fine dust, while contributing to soil and water contamination. In that case it is better to valorise the biomass even as a fuel or energy source, because the biomass is valorised in a more environmentally controlled way.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Relevant competitive uses of the biomass feedstocks considered in this project are listed in **Error! Reference source not found.**.

Feedstock (category)		Examples of competitive use
Wheat straw (A)		• Animal feed, bedding • Fuel • Basket making • Thatching • Green construction • Mulching • Pulp manufacturing
Flax Shives (A)		• Animal feed, beding • Filler (plastic composites) • Fill insulations • Other building products • Horticultural uses • Absorbency products • Biofuel
Sunflower husks (FP)		• Feed additive • Gardening applications • Construction applications • Fuel source • Bulking agents and fillers

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Forestry chips, hardwood (F)		• Panel wood • Energy market • Mulching • Torrefaction products
Forestry residues, softwood (F)		• Panel wood • Energy market • Mulching • Torrefaction products
Sawmill residues, wood slabs (F)		• Panel wood • Fencing • Energy market • Mulching • Torrefaction products • Domestic heating
SRC poplar, phytoremediated (F)		• Gasification • Torrefaction • Pyrolysis oil • Biofuel

Table 6: Selected feedstokcs and their competitive use examples. Categories represent: A – Agricultural, FP – Food/Feed Processing, F – Forestry residues.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5 Biomass supply chains

The supply chain systems define the harvesting, production, conversion, pre-treatment and utilisation systems of the biomass as a whole. It is a complex set of systems since different sources and types of biomass, particular sites of origin and projects are rather variable.

The following feedstocks are being considered within the VPLs (virtual plant locations):

VPL 1.	SRC , phytoremediated Poplar (The Netherlands, Bergen op Zoom)
VPL 2.	Wheat straw (France, Marne region - Multifeedstock VPL)
	Flax shives
	Forestry chips (hardwood)
	Sawmill residues (Poplar wood slabs)
VPL 3.	Softwood forestry residues (Finland)
VPL 4.	Sunflower husks (Romania, Moldova region)

For each biomass, a supply chain is presented below.

5.1 SRC poplar

5.1.1 Overview

SRC (short rotation coppice) are fast growing poplar tree species that produce high biomass yields in a short duration of time compared to other woody biomass crops. SRC is typically directed towards the energy market and is a good alternative to annual energy crops. Coppice is characterised by the ability to re-grow after being cut-down.

SRC varieties are selected based on the site-specific characteristics of the plantation (for example, soil and water conditions are an important factor for SRC yield). For economic viability, the plantation size should be at least 2-5 ha per plantation block (ideally 4 ha). The shape also plays a role, with longer, rectangular plantations being easier to plant and harvest.

A short rotation of poplar is typically 2-5 years. Firstly, a good initial soil preparation is necessary. The land is de-weeded and ploughed (if soil compaction is not an issue), with a typical soil ploughed at a depth of 25 cm, and heavier clay based soil at 6 to 10 cm. The planting scheme used is depends on the species of SRC.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5.1.2 2 year rotation model (agricultural model)

This model has the advantage of achieving biomass availability rapidly and on regular basis. The disadvantage however is the lower quality of the biomass which results in a higher ash content (above 3%) and fines.

- 5.500-6.500 cuttings/ha with 3 m between the rows and 0,50 m- 0,60 m in the row (depending on clone)
- Harvesting operations start after the second growing season, between late November and the beginning of December.
  - The trees can reach 7-9 m high, and have a diameter of 8-10 cm at trunk base.
- The yield can vary between 50-90 fresh tons/ha (50-55% moisture) to 25-45 tons/ha bone-dry.
  - The yield will depend on: soil, climate, weather conditions, etc.
- Harvesting is done with a maize harvester, using an adapted header. The trees are chipped and transported to the end-user or stored. Ideally storage is done in a semi open building on a solidified floor. Via natural convection the chips will dry to 30% moisture content.
  - Harvesting is done 5 times, so one tree grows for 10 years.
- It is also possible to cut the trees whole and store them at the production field. This can be done by using a harvester. The advantage of this is that you can save on storage capacity and that you spread the supply in time. The trees will dry on the field. Since they are not chipped the conditioning is better.

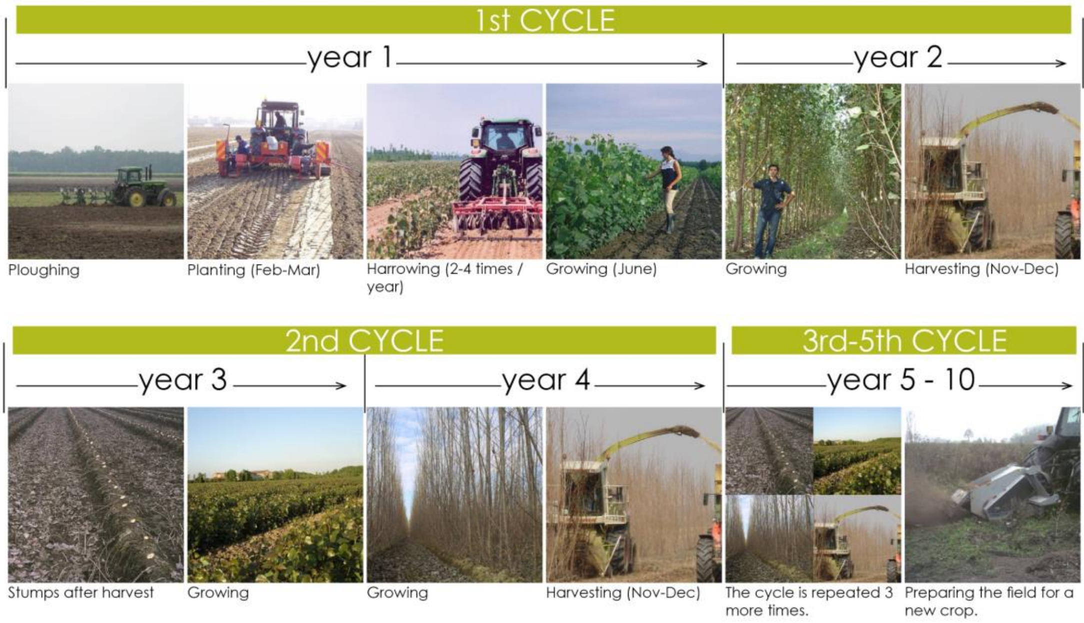


Figure 14: A supply chain of two year rotation model of SRC (short rotation coppice) poplar. Courtesy of Capax Environmental services.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5.1.3 5 year rotation model (forestry model)

This model produces high quality wood and more diverse valorisation options. Lower ash contents (between 1-3%) and higher cellulose, hemicellulose and lignin contents are achieved by achieving more favourable wood versus bark and fines ratio.

- 1.100-1.600 cuttings/ha with 3 m between the rows and 2 m-3 m in the row (depending on clone)
- Harvesting is done after 5-6 years, late November and beginning of December.
    - The trees will have a stump diameter of + 20 cm.
- Yields can reach up to 150-250 fresh T/ha or 75-125 bone dry T/ha
- The harvesting is done via a harvester or excavator with a shear head. The trees can be stored on the field or directly chipped on location.
    - Harvesting is done 2 times, after 10 years replanting is recommended.

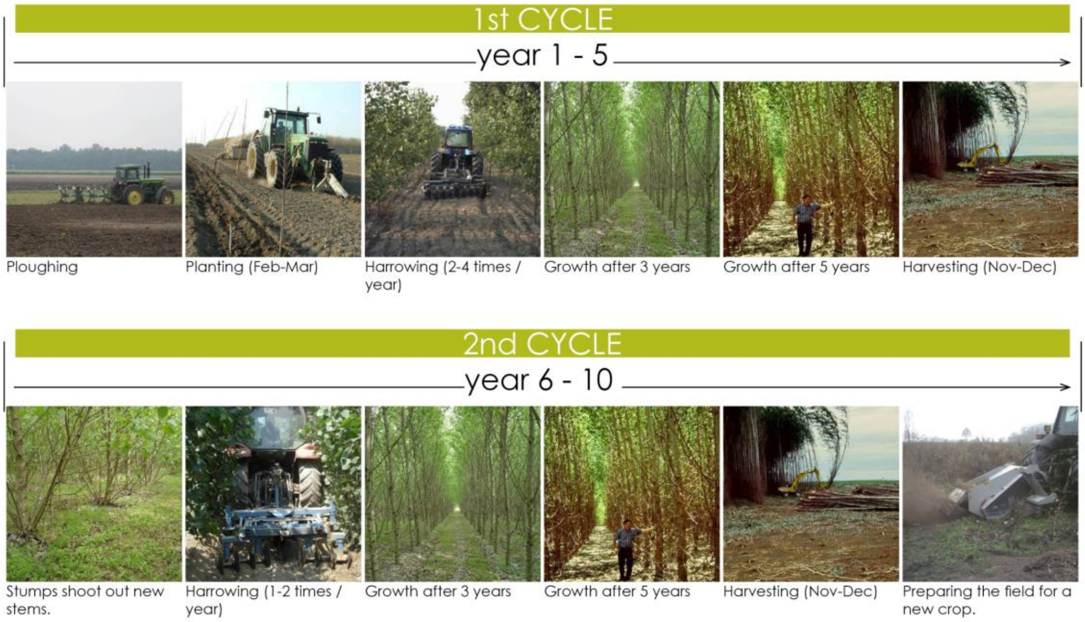


Figure 15: A supply chain of five year rotation model of SRC (short rotation coppice) poplar. Courtesy of Capax Environmental services

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5.1.4 Harvesting methods

The demands from the customer's point of view (that depend on the end market use) play an important role in choosing harvesting methods. The harvesting has an impact on economics, logistics, quality, characteristics and other aspects. Often, harvesting operations need to be adapted in relation to the demands and environmental parameters (for e.g. location). Types of harvesters are described below.

Energy Harvester

Single row or double row harvesters exist. The trees are harvested and directly chipped and blown into a wagon (a wagon can also be installed behind the tractor). The harvesting machine is installed on the tractor, and unfolds in the field. Harvesting starts from the outside, 12 m space on the head of the field is necessary.

Technical details of JF Z200 hydro/E:

- Weight 2 T
- Speed 2-5 km/h
- Max. diameter of the tree stem 4 cm (otherwise another harvester type is needed)
- Fuel consumption 35l/h

Stemster MKIII

The stemster harvests the trees without immediately chipping the wood. The advantage of this method is the fact that the trees can be stored on the field. This means that the wood can be stored longer without degradation. The moisture content therefore goes down. Also the end user needs less own storing capacity. The harvesting is done quicker and the trees can have higher diameters. Chipping can be done depending on the demand of the end-user.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Technical details:

- Weight 7 T (bigger soil impact)
- Speed 7 km/h (0,3-0,5 ha/h depending on the soil conditions, trees)
- Max. diameter of the tree stem 8 cm diameter

Corn harvester with SRC harvesting header

The most common harvesting method to date is via a corn harvester with SRC header. The trees can be harvested with diameters up to 15 cm (important for the Italian model), but the trees are immediately chipped. So storing and conditioning are potentially more complicated than with a stemster. For farmers there can be an advantage, because the same machine for harvesting corn can be used for SRC. This means more useful operation hours/Y, at a moment when the corn harvesting is already ended.

Technical details:

- Weight 14 T (big soil impact)
- Speed 7 km/h (0,3-0,5 ha/h depending on the soil conditions, trees)
- 12-15 cm diameter

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Biobaler

Applicable for the traditional Swedish double row growing model. For the Italian model (single row growing) the trees are too big for this machine. The big advantage is that the density of the bales is 500-600 kg. Chips have a bulk density of + 250 kg/m³ (fresh tones). Storing can be done on the field. The disadvantage is that the bales are bundled with a rope and that a grinder is later on necessary to process the wood. The harvesting is performed with a chisel and not with knives, therefore the plantation may be injured (stem injury and shatter may cause rotting and resprouting problems).

5.1.5 Transport

Depending on the growing model and the harvesting methods the wood can be transported and stored in different ways.

Chipped material

Chipped material can be transported a short distance via tractors. For longer distances a walking floor truck (90 m³) is preferable. This will lower the transport costs and CO_2 impact. On average a walking floor will transport 25-28 T of fresh woodchips. Storing is ideally done underneath a half open building. The chips will dry down to 25-30% of moisture content and degradation will be slowed down.

Stems or logs

The 5 year growing model has the option of transporting stems or logs. The transport will be done with a tree stem truck. An average of 24 T will be loaded and transported. The advantage of stem wood or logs is that they can be stored outside at the refining plant and be processed when needed. The moisture content can go down to 38 % of stored logs.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5.2 Wheat straw

5.2.1 Growing and harvesting

Wheat is propagated by seed and grows well in a variety of soils. Optimal growth is achieved in loam to sandy loam soils at around pH 6-7.5. It is an annual winter and spring crop that has a growing season of 130-190 days. Winter wheat grows well at temperatures ranging from 5-25 °C, while spring wheat requires higher temperatures ranging between 22-34 °C. Wheat requires good moisture conservation (600mm pa). Seeds are planted at a density 70-90 kg\ha in mid-April to mid-July for winter wheat and mid-August to mid-September for spring wheat.

The wheat is harvested when the grain is dry (at 13-16% moisture content). A combine cut is used for separating, cleaning and cutting the grain. To minimise grain losses, special techniques such as reaping, threshing and winnowing are used. The separated kernels are delivered to storage silos for further drying. Conventional swath mower leaves freshly cut wheat remains behind to dry for 3-5 days. Once the hay is dry, a baler (round baler, small or large square baler) packages the material by densifying it for easier transportation. Bale moisture content must be below 20% to minimise loss and prevent spontaneous combustion.

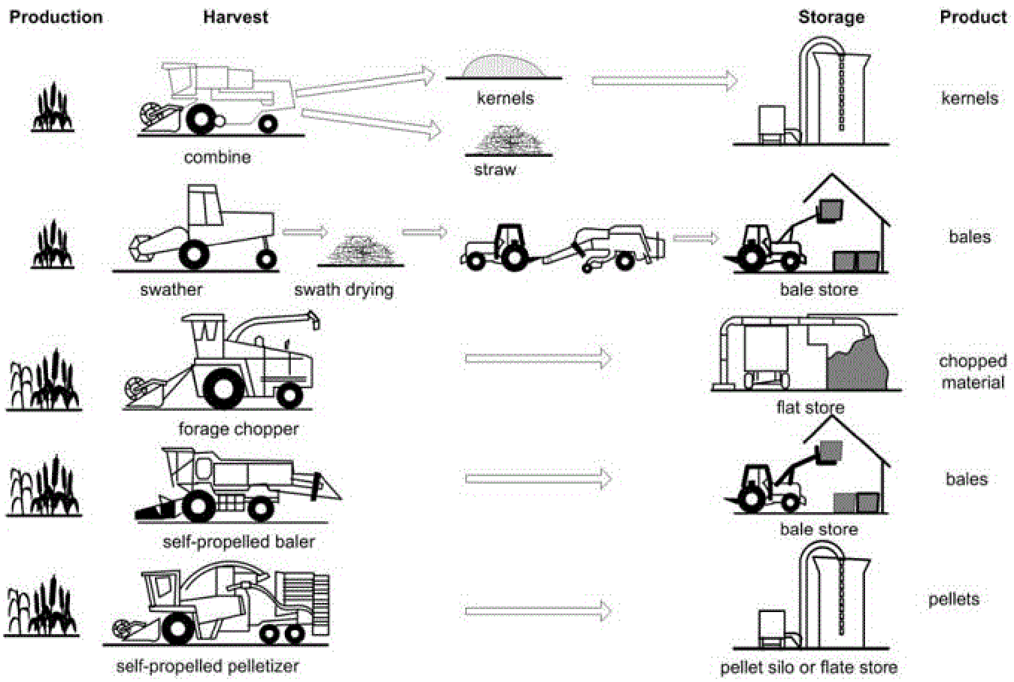


Figure 16: Herbaceous biomass harvesting options (Handbook of biomass combustion and co-firing)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5.2.2 Transport

The material is transported with flatbed trucks. An average bale weight for wheat straw is around 200-400 kg depending on size and moisture content. A full truckload is 25 tonnes.

Figure 17: An image of a flatbed truck.

5.3 Flax shives

5.3.1 Growing

Flax is a widely adapted self-pollinating crop that is used for industrial, food and feed purposes. The major factors that influence the yield of flax are: drought, excessively wet soil, heat stress and dense planting. Ideally, medium to heavy textured fertile soil is used to achieve maximal flax growing gains. Flax growing is typically followed by a cereal crop growth in order to recuperate the soil. Early seeding produces more reliable yields and reduces the risk of crop diseases. Thus, early to mid-May seeding contributes to better oil content and quality as well as high quality straw. However, reasonable yield expectations can be achieved by sowing up to mid-May (dependent on flax varieties). A firm, moist and weed free seedbed with planting 15-20 cm apart and 2.5-4 cm deep ensures a good seedling emergence.

Depending on flax variety, the crop can grow 40 to 91 cm in height in 90-125 days. A vegetative period lasts between 45-60 days followed by 15-25 day flowering period. Maturation occurs in 30-40 days from flowering. However, cool and wet conditions can delay maturation of the crop.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5.3.2 Harvesting and processing

A number of factors are considered before selecting a harvesting system for flax. Residue management requirements are assessed, considering fibre recovery and straw management. The overall agronomic plan and harvest system placement within this plan can vary. For example, straight combining is the preferred method, but other combines, headers and windrowers can also be used. When using conventional straight combining, it is important that cutter bars are clean and sharp due to the tough and fibrous nature of the flax straw. An alternative straight combining uses a stripper heading with a counter-rotating rotor. In this instance the grain and chaff are stripped from the crop and deflected back to conventional auger and the pan. The advantage of this method is improved harvesting efficiency via reduced bulk entrance and minimally damaged straw. The straw is harvested at a later date and also has a higher cellulosic content recovery. Swathing is used to prevent movement of the swaths due to strong winds. A stubble height of 10-15 cm holds the swaths on the ground. Alternatively, chemical desiccation is used to accelerate drying 7-14 days before harvest. The swath may be threshed, however many combine settings must be adjusted to minimise seed coat damage, especially when seeds are used for sowing (damaged seed coat reduces germination rate).

The harvest of the flax residues is comparable to cereal crop harvest (see paragraphs 5.2.1 and 5.6.1). Residues are chopped and spread in the same manner, then baled and retted. Alternativelly, pulling up the crop with the roots can be performed to increase fibre lengths. A number of treatments are available to improve retting, for example retting bacteria and fungi digestion or a forage macerator (conditioner) that both improve bale density and reduce chive content while increasing fibre content.

The separation of the fibre from the rest of the stalk is performed via retting (for example via pond, dew, tank, steam, field retting or other retting techniques) where the inner stalk is rotted away without injuring the outer part of the straw. The straw is then broken up into short pieces and the outer straw is scotched from the fibre. The stems are then hackled in order to remove the straw and short fibres out of the long fibres. The streams and results of these processes are displayed in Figure 18, where the applications for each by-product are highlighted.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

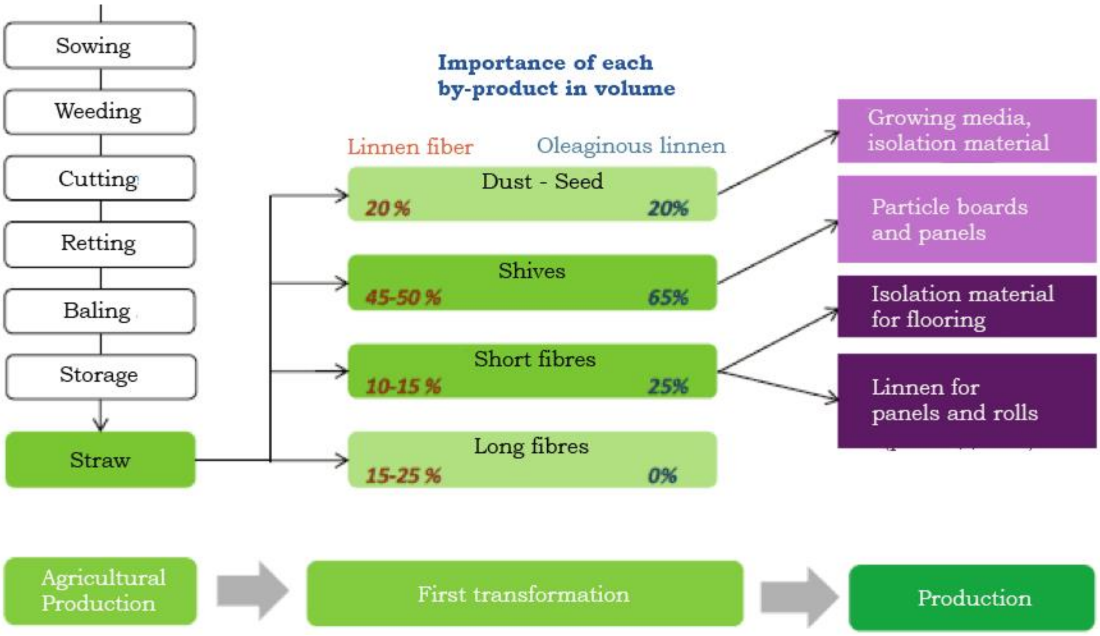


Figure 18: A chart displaying flax production and transformation streams and applications.

5.3.3 Transport

After decortication (as described above), flax shives are yielded and will be transported using a walking floor truck. The bullk density of non-pelletised shives is around 130 kg/m³. On average, 12-13 tonnes per truck will be transported. When pelletised, the bulk density is around 1 tonne/m³. In that case around 28 tonnes can be transported with a 90 m³ walking floor truck.

Figure 19: An image of bale transport.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5.4 Forestry chips (hardwood and softwood exploitations)

5.4.1 Origin

Forest biomass can come from different sources, such as logging operations, forest thinning or improvement projects. Feedstock such as limbs and tops of trees are harvested and may include processes like felling, piling, bundling, forwarding, chipping and trucking. In a typical forest harvesting, round wood products are cut as whole trees and piled. They can then be forwarded by a feller or buncher, where they are debarked and de-limbed. Most round wood products go to the timber or pulp and paper market (as further described in section 5.5). Around 13% of total softwood or 24% of total hardwood volume comprises logging residues, which are mostly tops and limbs. A mechanical bundler can be used to bundle the limbs after de-limbing. Trunk size bundles are made for efficient hauling or storage. Some fellers or bunchers have an integrated bundler systems. Further size reduction (for e.g. chipping, pelletising, briquetting) can be applied at a biorefinery, satellite pre-processing facility or industrial bioenergy power plant.

5.4.2 Residue harvest and processing

The residue can be harvested as biomass or left in the forest for enhancing soil nutrient cycle dynamics. There are four main supply chains of harvesting forestry residues. Slash from final fellings, unmerchandised wood, slash and small trees from thinnings and cleanings are used. They can be processed by the following procedures:

- **terrain chipping**; Highly mobile chipper moves in the terrain on the strip roads with a tippable chip container. The biomass is transferred with a grapple loader to the feeder. Chipped material is hauled to the road side and tipped into a truck container.
- **chipping at a landing (roadside chipping);** The biomass is hauled by independently operated forwarders to the landing and bunched into piles. Farm-tractor driven chippers or heavy truck mounted chippers/crushers are used. The chips can be directly blown into a container that hauls the load to the plant.
- **terminal chipping;** The system is similar to chipping at a landing, except the biomass is hauled to the terminal for size reduction and then transported to the plant in the form of chips. A terminal is a tool to control procurement and store biomass un-comminuted. The biomass is processed on the basis of demand and forest working conditions.
- **chipping at a plant;** Heavy stationary crushers can be used (instead of mobile chippers) that are suitable for comminuting all types of biomass. Truck transportation of biomass in this case is executed in the form of loose logging residues, pieces of wood or whole trees. Low bulk density can be addressed by baling into 70 cm x 3 m long bales that are transported to the roadside with a conventional forwarder.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

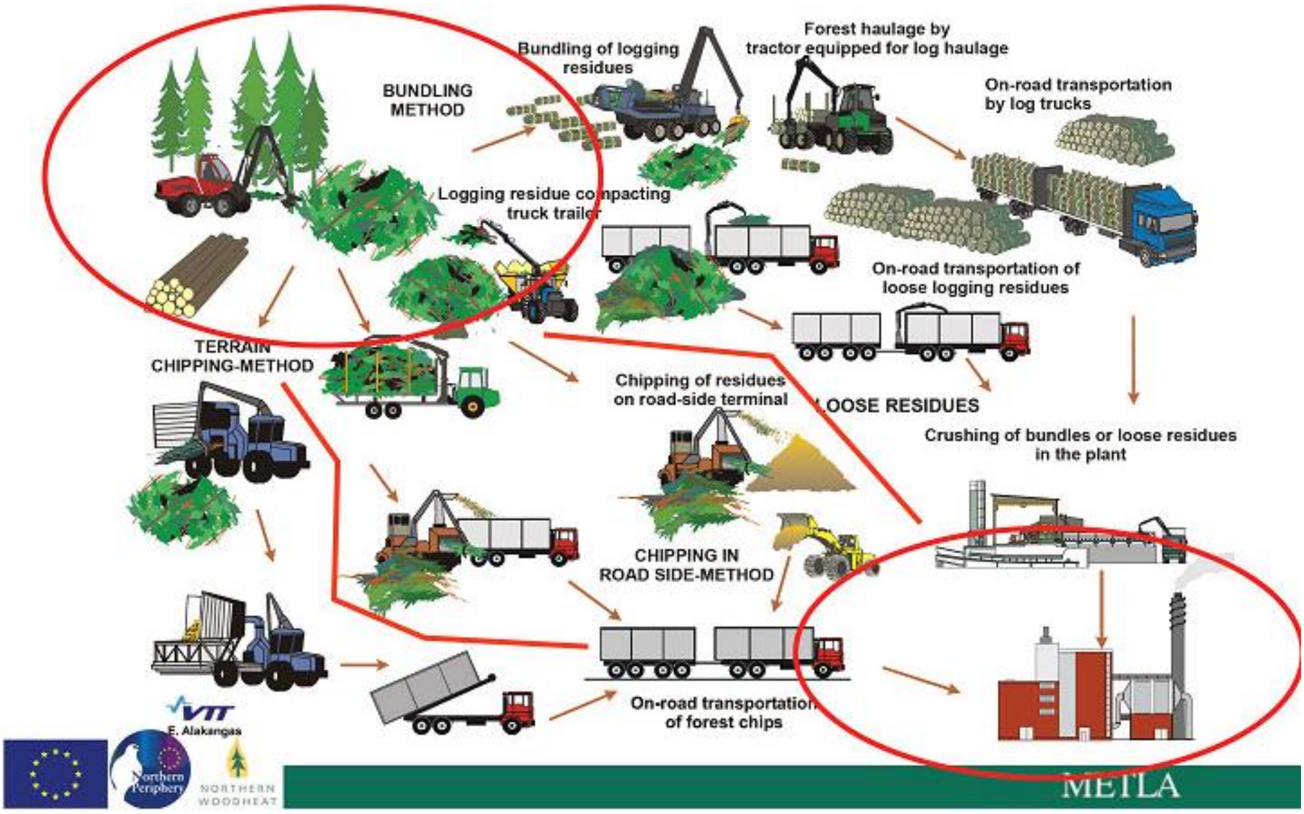


Figure 20: A diagram showing the process of acquiring logging residues from forestry activities. Adapted from VTT, Wood energy technology programme.

Chipping residues improves storage and transport, however it can also lead to higher cost of harvesting operations. The major advantage of chipping is size reduction and homogeneity (uniformity) achievement that can be necessary for the end users (for example energy market). Wood chipping involves a mechanical process that includes a set of knifes, auger or hammers. An engine powers the flywheel, which is mounted with the knives. Local processing of biomass allows the production of uniform particle size, consistent moisture content and flowability of the material. As a result, downstream biomass transport and logistics allows a diverse range of biomass processing under common equipment with economy of scale and system level efficiencies.

5.4.3 Transport

Different ways of transportation are possible for woody biomass. The majority of woody biomass is transported as woodchips. The average bulk density of fresh wood chips is around 250-300 kg/m³. On average, 25-28 tonnes fit in on a 90 m³ walking floor truck.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

In Scandinavia woody biomass from soft wood (so called slash) is often bundled and transported as such and delivered to the end customer. Bales weigh between 400 and 850 kg depending on length, debris characteristics and moisture content. 24T truck loads with flatbed trucks can be achieved.

5.5 Sawmill residues (slabs)

5.5.1 Origin

Round wood harvested in forestry activities (as described in section 5.4) can be used in a sawmill, where a number of by-products and final products can be produced. In the sawmill the goal is to produce boards and planks based on customer requirements. The quality of the raw material is therefore of importance. During the process of the board and plank production, by-products such as bark, chips, sawdust and slabs can be produced (Figure 21). Production varies and depends on sawing technology, where the process can be fully automated and computerised. Typically, hardwood is processed in separated hardwood sawmills.

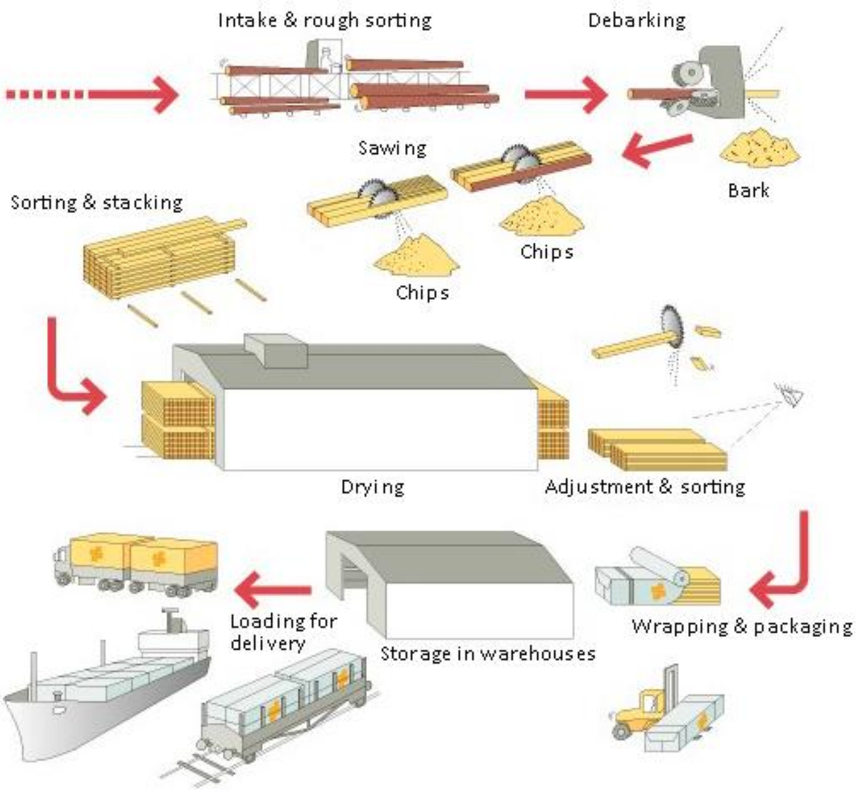


Figure 21: The process of typical sawmill activities. Adapted from European wood organisation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5.5.2 Slab production and processing

Once the timber is delivered, it is taken in to the sorting facility, where the quality of wood is assessed by measuring and assigning dimensional classes to the wood types and qualities. Transportation of logs vary for different mills and highly depend on the size of sawmill operations. If not yet performed at logging operations (as described in section 5.4), the timber goes through the debarking process. A rotary machine with cutting tools is used to rub away the bark. During this step, the timber is evaluated and log washers can be used to remove stones, ground or other material that can come from the logging activities to prevent damage to the machinery. Depending on the sawmill activities, such as sawmilling, plywood or particleboard production, these processes can vary greatly.

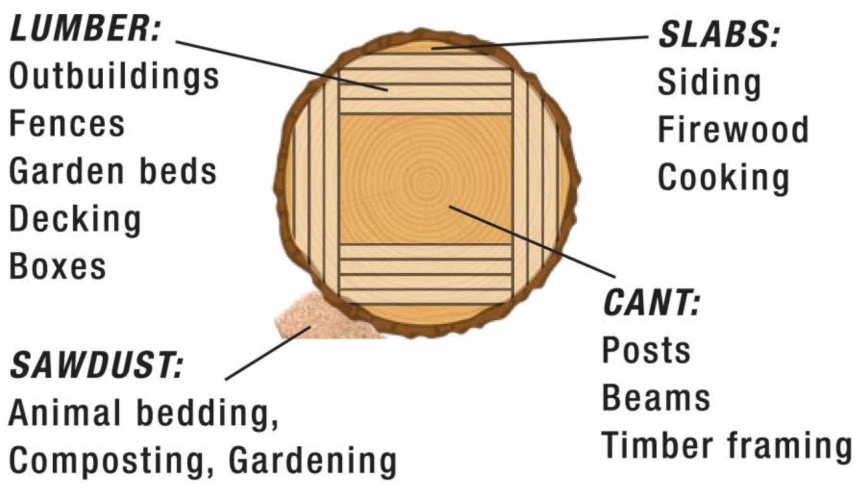


Figure 22: Schematic picture of log posting and applications of the decomposition parts of the log.

Generally, various posting and sawing patterns are adapted geometrically to get the maximum volume of the processes (Figure 22). In this part of the process wood slabs are cut away from the logs. The posting determines how the log is sawed. Different manners are available, such as cutting, quarter or lighthouse sawing. For instance, cutting sawing is most commonly used for hardwood. Quarter sawn wood is more often applied for furniture manufacturing, while it is a relatively expensive and lower yield processing. The sawn lumber is sorted and stacked for drying for about 18% of moisture content. Because some wood pieces may shrink and deform, adjustments and tuning are executed post-drying by cutting, mechanical assessment, sorting and examining the wood visually. Various sorting criterion are available to keep the uniformity in these operations.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

The slabs that are produced during the posting and sawing processes are further broken down which results in upgrading of the slabs. Thick slabs are processed into planks, while rough round edges are removed by chipper edger or circular saw. Slabs are then bundled and picked up by a transporter where they are brought to a chipping facility.

5.5.3 Transport

Slabs are in general bundled at the sawmill. On average fresh slabs bundled weigh around 1-1.2 tonnes. They are transported with a flatbed truck or with containers. An average transported weight will be around 24 tonnes (depending on the wood species, moisture content, and bundle).

Figure 23: Sawmill wood slabs from Eeckhoute

5.6 Sunflower husks

5.6.1 Growing and harvesting

Sunflowers are typically planted around March, mid-April or May-June, depending on varieties and location. Most varieties are heat and drought tolerant, growing best in locations with direct sunlight and long hot summers. Weeding is critical during the first months of growth. The sunflower harvest window spans from late August to October-November. The maturity is indicated when the back of the flower head becomes dry and brown, about 30-45 days after bloom. It is however important that the seeds are not too dry (around 35% moisture content) because excessive yield losses can be experienced.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

Row-crops can be used for the harvesting with no modifications. Platform heads can also be used, however a head and seed loss has been reported. Alternatively, corn headers can be used with a small modification of stationary knife cutting. Combines that are used for small grain threshing can also be adapted by operating a head stripper principle.

The threshing is conducted by minimising the stalks and heads divided in large pieces to minimise excessive trash in the grain. The seeds are collected in bins with perforated floors that are preferred to the ones with ducts. If sunflower storage is required, cleaning before storing can be necessary to reduce incidence of storage problems. Awareness of fire hazard when storing is taken into account by minimising dust and chaff.

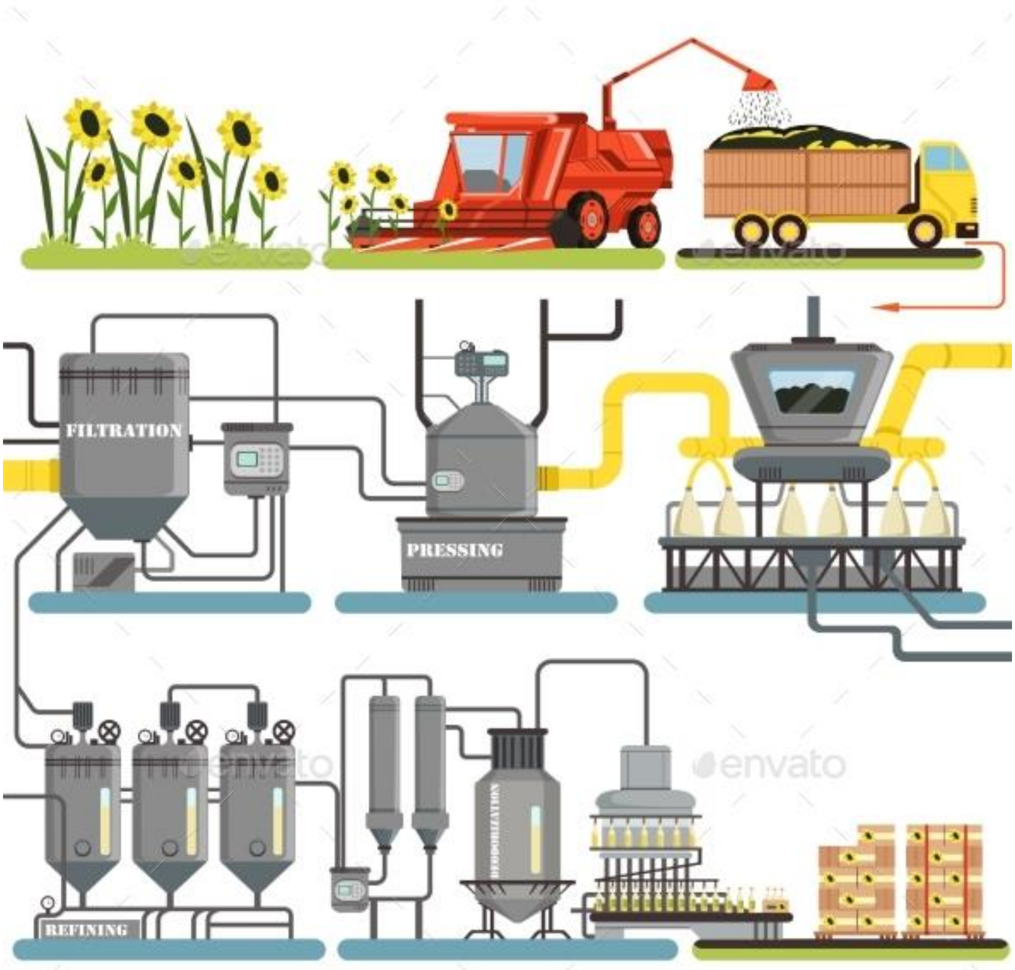


Figure 24: A schematic representation of sunflower harvesting and processing. Adapted from Envato.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

5.6.2 Sunflower processing

After delivery to the oil factory, sunflowers are cleaned and prepared for dehulling. After cleaning, they are sent to dehulling machines, where a number of blades propel the seeds against corrugated impact plates. This breaks the seed and aspiration helps to separate the hull from the core (called the meat). Sunflower seeds are cooked and mechanically pressed for oil by full-pressing of pre-pressing. The seed residue is then sent to solvent extraction, while the oil goes through a screening tank for primary fines removal. Then the oil is clarified by being pumped to a decanter or pressure leaf filter.

The hull of the sunflowers is made up of ash, crude protein, lipids, reducing sugars, and carbohydrates. They can be grinded into a fine powder. The powder can be pelletised or used directly. The pelletisation process works with pressure and high temperature by a rotating roller or a die pellet machine. This process increases bulk density and prepares the hull for more economical and easier transport.

5.6.3 Transport

It is best that sunflower husks are densified before transportation. This is because of the low bulk density of the husks that ranges between 70-100 kg/m³. After pelletising, the bulk density increases and ranges between 250-350 kg. Transportation then is ideally performed with walking floor trucks. An average transport weight will be around 25-28 tonnes/truck.

6 Conclusions and recommendations

The goal of this report was to create insight into the biomass value chains, evaluate the overall availability, and variations in availability as well as biomass quality for the biomass feedstocks that were selected in the project. The evaluation was based on four virtual plant locations ('VPLs', in the Netherlands, France, Finland and Romania) in order to make these assessments in a tangible way. Results are summarised in **Error! Reference source not found.**Table 1. Quality control parameters and general issues of biomass quality as well as competitive uses of biomass were briefly covered as well.

A fast pyrolysis plant with the size of Empyro uses around 40 kton/yr of dry biomass. This means that for all the types of biomass there should be enough available, with the exception of flax shives. Those may need to be sources from further away, or cannot be used all year round.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.

VPL	Feedstock	Local availability
Netherlands, Bergen op Zoom	SRC poplar, phytoremediated	300 kton/yr
France, Les Sohettes	Wheat straw	1,100 kton/yr
	Flax shives	14 kton/yr
	Hardwood (i.e. poplar)	185 million m^3
Finland, Lappeenranta Biorefinery	Softwood forestry residues	2.3 million m^3
Romania, Braila city	Sunflower husk	82 kton/yr

Table 7: The regional availability of the biomass around the virtual pyrolysis plant locations.

Factors that typically influence the quality of biomass are growing conditions, meteorological conditions, harvesting operations, and handling and storage operations. The three operational issues that are the most common are particle size deviations, (too high) moisture content of the biomass, and contamination of the biomass with undesirable elements. It is essential that a pyrolysis plant has defined acceptance criteria for these biomass quality parameters and executes a strict control on them.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723070.