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Deliverable D2.1

DESCRIPTION OF FULL BIOMASS SUPPLY CHAINS **including logistical concepts for different feedstocks and regions in Europe and final selection of case studies and logistical concepts to be tested for diverse feedstocks & regional context**	
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Table of Content

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

1. Introduction

1.1 Objectives and approach

This report is the first deliverable elaborated in WP2 'Design and assessment of optimal logistic chains' of the BECOOL project. It presents a description of logistical concepts and exemplary chains for advanced lignocellulosic biofuels for different feedstocks and different regional conditions.

A logistical concept is broader and more general than a specific biomass value chain. A chosen logistical concept still needs to be further specified and translated in order to obtain a specific biomass value chain (specify all the components). Often several possible biomass value chains fit within that general logistical concept.

Definition: A logistic chain in this context is a specific transport route for biomass from field (edge) to conversion plant (gate) encompassing transport, storage, handling and pre-treatment.

Based on the feedstocks and cropping systems selected in WP1 and the advanced biofuels conversion technologies selected in WP3 and WP4, a number of illustrative logistic chains will be presented in this report. The logistical chains described will cover the supply of biomass to downstream pre-treatment and/or conversion processes.

The concepts will consider different feedstocks, regions and conditions in Europe and different transport and pre-treatment organisation and technology forms (central, decentral, large and small scale, long and short distances, with boat, train, and/or lorry). The logistical concepts and exemplary logistical organisation options presented in this deliverable are important input into WP5 of this project. In WP5 a sub-selection of the logistical concepts to be tested further for specific value chains and in specific case study regions will be made. The sub-selection made in WP5 based on the information presented in this report, will serve as input for the further testing of logistical concepts with the logistical assessment tools in Tasks 2.2 and 2.3 for the selected case study regions. This way it is ensured that the value chains covering a specific sub-selection of logistical concepts that are evaluated in Tasks 2.2 and 2.3 deliver relevant output to WP5 where an integrated sustainability assessment of whole value chains is made.

The development of these entire value chains in WP5 is based on comprehensive data input from work packages 1 to 4. Thus, a coordinated approach for the collection of a consistent and harmonised database is necessary. For this purpose, harmonised data collection sheets have been developed. The collection sheets have been discussed and finalised during the second BECOOL consortium meeting in Athens. The initial value chains compiled and discussed during dedicated workshop sessions in Athens, showed very clearly the different possibilities and technologies of the individual process steps and the corresponding dependencies amongst each other, for example between harvesting technology and the processing process. They also show the data requirements for the description of the logistics chains in WP2, where feedstock characteristics and processing requirements will be matched.

Based on this data and an adapted data collection sheet a number of illustrative logistic chains for the supply of biomass to downstream pre-treatment and/or conversion processes will be developed and described. For that purpose, data regarding different feedstocks, regions and conditions in Europe and

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different transport and pre-treatment organisation and technology forms (for instance large and small scale) are needed. From the large amount of the illustrative logistic chains, a sub-selection of logistical concepts will made based on defined criteria in this report.

The harmonisation of the collected data and the methods involved are crucial for WP5. In BECOOL Deliverable D5.1 the process for data harmonisation and methodological approaches for integrated sustainability assessment in WP5 has been defined. Starting from the compiled initial value chains, the identified connections and dependencies, a methodological approach for data collection, including data harmonisation has been developed. According to the specifications of the standards for conducting an LCA (ISO 14040 and 14044), the workflow for an iterative data collection procedure has been defined. This workflow describes iterative processes for the data collection from the definition and description of the indicators for the assessment, to the data provision for cultivation and conversion processes, the description of the logistic chains and data provision for logistics, to the finalization of the data collection. The selection of exemplary logistical organisation options presented in chapter 5 of this deliverable is therefore crucial input for the integrated sustainability assessment to be performed in WP5.

The sub-selected chain designs will also deliver the basis for the calculation of cost-supply curves for different combinations of biomass feedstock and conversion technologies in the full biomass delivery chains designed and evaluated in Tasks 2.2 and 2.3.

1.2 Feedstock types and conversion technologies considered in BECOOL

Focus in the BECOOL project is on advanced biofuels. More specifically there is already a choice made for specific types of biomass and for specific types of conversion processes. These predefined choices also guide the selection of the illustrative logistical chains to be described in this report.

The BECOOL project will focus on the following selection of **feedstock types** that was made in Work package 1:

- Perennial dedicated lignocellulosic crops in marginal/idle lands
  - giant reed (Arundo donax L.)
  - Miscanthus (Miscanthus x giganteus)
  - Eucalyptus
  - switchgrass (Panicum virgatum L.)

- Annual dedicated lignocellulosic crops in innovative cropping systems:
  - fibre sorghum (Sorghum bicolor L.)
  - sunn hemp (Crotalaria juncea L.)
  - kenaf (Hibiscus cannabinus L.)
  - hemp (Cannabis sativa L.)

- Agricultural, forest and industrial lignocellulosic residues
  - lignin rich residue from the bioethanol conversion processes
  - wood industry
  - olive oil press industry
  - nut hulling industry
  - wine distillation industry

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Since the activities in BECOOL will be closely tuned with the Brazilian BioVALUE project, the research activities on logistics will also involve the application of tools for the design and analysis of biomass delivery chains in Brazil. This involves chains based on typical Brazilian feedstock types, such as sugarcane and energy cane field residues (trash). In this deliverable, these feedstock types will not be addressed in relation to the presentation of the illustrative logistical chains (except for Eucalyptus). However, later in the project in Tasks 2.2 and 2.3 the testing of the logistical concepts and tools in the Brazilian situation will obtain attention.

The three **types of conversion technologies** the BECOOL project will focus on are:

- gasification;
- pyrolysis (fast, intermediate & slow);
- biochemical processing.

These conversion technologies are the topic of Work package 3 (gasification and pyrolysis) and Work package 4 (biochemical processing). Pyrolysis is used as biomass pre-treatment for gasification. The product of interest (from slow, intermediate and fast pyrolysis) are the solid and liquid output from the various processes, either as single products or as combination of products under a single, stable phase (PO/char slurry).

1.3 Selection of relevant value chains in the Athens workshop

In month 8 (January 2018) of the BECOOL project a workshop was held in Athens with participation of all BECOOL project partners. During this workshop the focus was on a further sub-selection of biomass types in combination with conversion technology options (see Figure 1.1). This sub-selection is the basis for the selection of value chains that will be further evaluated in Work package 2 in terms of logistical organisation options of the chains and in Work package 5 for the integrated sustainability assessment of the whole value chains.

The focus of the workshop in Athens was on four types of biomass presented in Figure 1.1, viz. giant reed, fibre sorghum, Eucalyptus and lignin-rich residue. Bagasse was not covered yet. It will be included later in the project as soon as the Brazilian Twinning project BioValue kicks off. In Month 8 during the BECOOL workshop in Athens, this had not happened yet.

In relation to the biomass types, the typical production requirements, the on the field logistics and composition characteristics were presented and discussed during the workshop.

The conversion technologies (Figure 1.1) were particularly evaluated during the workshop in relation to minimal feedstock quality and quantity requirements, technical challenges and possible solutions. The workshop aimed at discussing the conversion technologies in relation to the typical characteristics of feedstock composition, but also options for large-scale cultivation/production in Europe.

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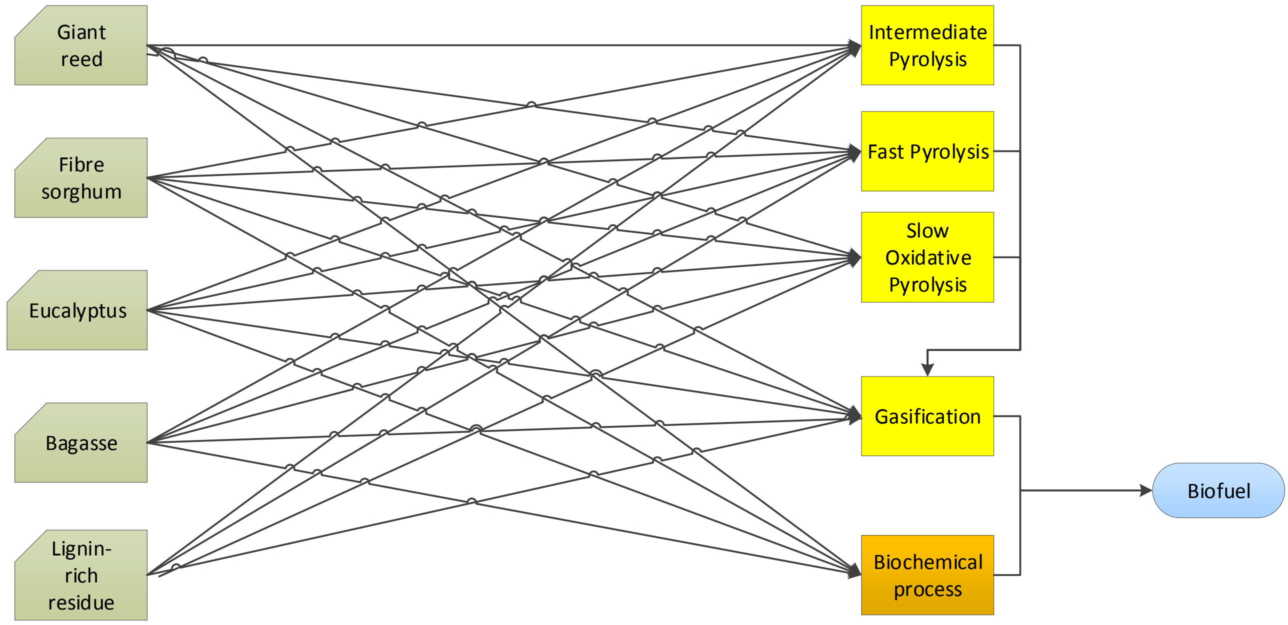

Figure 1.1 Possible combinations of biomass types and conversion technology options to be covered in the BECOOL project.

During the workshop Work package 2 presented an overview of the main logistical concepts in relation to transport, pre-treatment, (spatial) organisation of a logistics chain, typical feedstock characteristics and conversion technology requirements influencing the configuration of the logistics chain. To illustrate all these aspects first examples of designs of logistical chains were presented and it was discussed which specific chains had to be worked out in more detail in this report.

The knowledge obtained at the workshop in Athens forms an important input to this report. The workshop was very useful for establishing the typical feedstock characteristics at the roadside and the conversion technology requirements at the gate of the plant described in Chapter 2 and Chapter 3 respectively, and for the illustrative logistic chain options presented in Chapter 4.

1.4 Former assessments of logistical concepts and biomass value chains

In the BECOOL project we will further elaborate on the results generated in former EU projects. A valuable source of information is the S2BIOM project in which much work was already done on identifying and assessing logistical concepts (Annevelink, 2015). This work involved identifying existing logistical concepts and conceptual designs at both centralised and decentralised scale, incorporating several elements of pre-processing/densification of biomass. In S2BIOM, new logistical concepts and conceptual designs were developed integrating all knowledge and experience on logistics developed in three other large EU-FP7 projects that were started in 2013 and that completely focussed on logistical solutions for different types of feedstock:

- LogistEC (biomass crops);
- EuroPruning (biomass pruning residues) and;
- INFRES (forest residues).

This resulted in several reports (S2BIOM, 2017a) and a knowledge base for the design of the exemplary logistical chains presented in this report.

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1.5 Outline report

Chapter 2 presents an overview of the types of biomass sources on which the selection of biomass delivery chains should be based. The chapter gives and overview of the types of biomass, main cropping characteristics, composition information and field logistics options up to roadside.

Chapter 3 presents the different conversion technologies determining the biomass delivery chains. It specifically explains the general technology characteristics and particularly the minimal biomass characteristics required. An overview is also given of the logistical pre-treatment options that can possibly be integrated with the location where the conversion location is. So all relevant details as from plant gate to the actual conversion process are presented in Chapter 3.

Chapter 4 describes the logistical principles and logistical organisation options between roadside and conversion plant gate. It presents the different options for organisation of the logistical chain that need to be fitted to the different biomass types and conversion technologies.

In Chapter 5 an overview is presented of the different logistical solutions combining the options for biomass production and logistics up to roadside (Chapter 2), the different logistical organisation options described in Chapter 4 and the different specific biomass requirements by the conversion technologies (Chapter 3).

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2. General feedstock characteristics of selected biomass types at roadside

2.1 Introduction

In this chapter, the feedstock characteristics of the selected biomass types at roadside are described. The selected biomass types are giant reed, biomass sorghum, Eucalyptus and lignin-rich residues from the biochemical conversion process that produces bioethanol (see Figure 1.1). The general production and composition characteristics are discussed and options are described for field logistics (covering harvesting, in-field pre-treatment and forwarding to roadside). Most of the information provided on biomass characteristics up to roadside in this chapter is based on input from Work package 1 presented at the Athens workshop in Month 8.

2.2 General feedstock characteristics after harvesting

In the following the main characteristics of the different types of crops that will form the basis of the logistics chain designs is presented. This will cover general characteristics of the crop itself, the biomass feedstock it delivers and the possible logistical handling up to roadside. The description is also illustrated with possible set-ups of the logistical components that lead to delivery of the biomass feedstock at roadside as visualised in Figure 2.1 (Giant Reed), 2.2 (Sorghum) and 2.3 (Eucalyptus). In Table 2.1 a systematic overview is also given of the key biomass characteristics at roadside after harvesting of the four biomass types (giant reed, biomass sorghum and Eucalyptus) and of lignin rich residues. An overview of the main harvesting options is given in Tables 2.2 – 2.5.

2.2.1 Giant reed

Giant reed (Arundo donax L) is a spontaneous C_3 perennial grass originating from the Mediterranean area and Middle East Asia (Saikia et al, 2015). It has wide adaptability to different habitats specially it is well suited for subtropical and warm temperate regions (Saikia, et al., 2015) where it can survive prolonged dry and/or waterlogged periods due to its vigorous root system that penetrates deep into the soil. It has a high lignocellulosic biomass yielding potential. Usually the harvest of giant reed is only once a year (winter season).

For giant reed an average content of 33% (range 26-44%) cellulose, 27% (range 25-28%) hemicellulose and 18% (range 16%-19%) lignin (S2BIOM, 2017b; biomass properties) is common. The ash content is relatively high ranging around 6% and the ash melting temperature is below 1,000 ˚C. The high ash content of this herbaceous feedstock has to be carefully investigated before pyrolysis or gasification processes.

The moisture content in the crop when harvested in winter reaches 50% while when harvested in summer/autumn it is over 70%, although it could be field dried up to 20% in few days. The crop was chosen to be tested in the BECOOL project because it is known to be a low input high yielding perennial grass, which can cope with overall low soil quality circumstances. There are three different harvesting systems tested in the BECOOL work package 1 (see Figure 2.1 and Table 2.1-2.3).

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The first option is to harvest with a forage harvest with Kemper head that cuts, chips and loads the biomass to a tractor-trailer. The tractor drives directly to either the conversion installation or an intermediate collection points where the biomass is pre-treated for further storage and/or conversion processes. Advantages of this harvesting system are:

1. that it can be done in one single pass,
2. it can easily be contracted as already available forage harvesters can be used (see Table 2.2)
3. the harvested product does not touch the ground, which implies that it remains relatively clean.

This system also has many disadvantages. In this harvesting system the moisture content of the biomass is still very high when removed from the field and the immediate further processing in a conversion installation can give problems with fine fractions and clogging (see Table 2.2). Experiments were made by CREA in order to increase the particle size of the chips decreasing the number of knifes in the chipping drum. It is still being evaluated whether this positively affects the possibility to store in piles in which the drying up the material takes place. Other disadvantages are that the forage harvesters are very heavy which can cause compaction and overall machine cost are relatively high.

The second option is that the giant reed is shredded and baled in the field and the bales are forwarded for further pre-treatment, including natural drying and chipping. This system requires only one machine pass because the shredder is placed on the front and the baler in the rear part of the tractor. This harvesting system is the cheapest of the three but it results in baled biomass with relatively high impurity levels (adding to ash), and high percentage of product losses (up to 30%). The high impurity levels will cause higher cost for the additional pre-treatments before conversion.

The third harvesting system involves two machine passes in the field. The first involves mowing, after which the biomass is left in the field to dry. The second involves the collection, shredding and loading of the biomass to tractor-trailer. It can then be transported to a conversion installation and/or storage place. The advantage of this system is that the biomass is of low moisture content and in a form ready for conversion and storage. The disadvantages are that this requires two field passes, which makes it more expensive and increases the soil compaction problems and the harvested product contains relatively more impurities (sand) causing more problems in the conversion and/or higher pre-treatment cost. Another problem is related to the possibility that, as the cutting is made in autumn, which is usually the rainy season, this will cause challenges with the dehydration of the biomass and will increase the impurities in the harvested product[1].

After harvest, the giant reed needs to be reduced in size and dried in order to comply with the characteristics of the conversions. These operations can be included in the harvesting schedule or further in the chain (see Figure 2.1 and Table 2.2).

One of the main problems is to convince farmers to grow giant reed. Giant reed is compatible for the conversion methods of gasification and biochemical conversion. Also fast and intermediate pyrolysis can

[1] In the framework of the Optima Project the Enterprise *Spapperi Macchine Agricole* developed together with CREA a prototype for Arundo donax harvesting able of producing longer chips of Arundo, and being an machine attached to the tractor, an acquisition cost acceptable (Assirelli et al., 2018)

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convert this herbaceous biomass in valuable products that can improve the efficiency of the next conversion process (gasification) for advanced biofuels production.

An overall challenge for giant reed is that it is not a common crop and even in some parts of the world (i.e. USA) considered an invasive species. It requires identification of unused lands where this crop can be established. Access to land is a challenge. On the other hand, the crop can still produce acceptable per hectare yields under marginal circumstances, as it is a hardy crop that can cope well with a range of natural constraints mostly occurring in marginal lands in Mediterranean Europe (Von Cossel et al., 2018). In BECOOL it will be further reviewed if land is available and accessible that is not attractive (anymore) for food production.

2.2.2 Eucalyptus

The Eucalyptus family has about 700 species and originates from Australia. Eucalyptus nowadays is cultivated in more than 90 countries and represents about 8% of all planted forests all over the world. The Eucalyptus has the ability to survive adverse climatic conditions and a wide range of environments, such as different soil types and rainfall (Khuspe et al., 1987). Eucalyptus has hundreds of species adapted to a large variety of climatic conditions, so not only one species to survive in very different conditions. The Eucalyptus composition varies highly with different species. The ranges of the biomass properties are 43% (range 9-57%) of cellulose, 25% (range 8-43%) hemicellulose and 23% (range 9-37%) lignin (S2BIOM, 2017b; biomass properties). The ash content is quite low (around 2%) and the ash melting point is around 1,300˚C, which makes it an attractive feedstock particularly for thermochemical conversion.

Eucalyptus is the only woody biomass considered for advanced biofuel production in BECOOL. Generally, slow pyrolysis is used to convert biomass in char in the form of woodchips, so a woody biomass is required. In particular, the slow oxidative pyrolysis unit at RE-CORD has these constraints, so only woody biomass can be converted in char. Herbaceous biomass types are more difficult to standardize in terms of size, at least when not ground at few millimetres.

The average moisture content at harvest is 50%, but wood biomass can usually be dried further easily and cheaply at roadside at the place of harvest. There are two different cropping systems that will be tested in BECOOL: the SRC (short rotation cropping) is the harvest of the trees every 2-3 years and the MRC (medium rotation cropping) is the harvest of the trees every 4-5 years. The SRC and MRC Eucalyptus biomass have different characteristics. The main difference characterizing the harvesting system is the base diameter of the plants when they are harvested: if lower than 15 cm a SRC harvester can be utilised if higher than 15 cm, a forestry system has to be utilized. The site selection of Eucalyptus needs to be carefully chosen as it determines the harvesting methods and cropping systems possible. The pyrolysis oil of Eucalyptus has a lower pH than that of pine forest. It is under investigation how this affects the pyrolysis process. Storing Eucalyptus lowers its volatiles over time. Eucalyptus can be stored at roadside easily.

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Table 2.1 General biomass characteristics at roadside after harvest (Data collected at Athens meeting, unless otherwise specified).

Biomass type	**Characteristics conventional cultivation system/source**	**Average yield level at harvest**	**Average moisture content MC (%) at harvest 4**	**Ash content (%) and melting behaviour & factors in management influencing ash content & composition 4**	**Cellulose, hemicellulose, lignin composition (%)[2]**	**Harvesting time**
Giant reed (Arundo donax)	• high WUE • rhizomes (1 year gain) or micro-propagated plants (more economic than rhizomes). Also plantlets are adapted for transplanting machineries • fertilization 40 – 100 kg N/ha/year	up to 20 – 30 ton DM/ha/year, but on marginal lands much less	50% (in winter harvest) - 70% (in early summer but when left in field to dry it will reach 30% in some days.	• ash: 5% – 6% • ash melting level: 954 ˚C • depends on composition in leaves and stems • depends on fertilization and harvesting time (in winter lower ash)	cell: 33% (27% – 44%) hemi: 27% (26% – 28%) lignin: 18% (17% – 19%)	• single harvest per year • mostly in winter season (avoids damaging new sprouts and allows the cycling of nutrients between shoots and roots, thus fertilization requirements are reduced)
Eucalyptus	• can cope with low quality land • Short Rotation Coppice (SRC) • Medium Rotation Coppice (MRC)	5 – 20 ton DM/ha/year but on marginal lands much less	55 – 60 (30% after 3 months at roadside) Range 35% – 50%	• ash: 2% • depends on fertilization and harvest time • SRC comes with more leaves and bark	40 - 50% cellulose and hemicellulose cell: 43% (9% – 57%) hemi: 25% (8% – 44%) lignin: 23% (9% – 37%)	• every 2 years (SRC) • every 4 years (MRC) • in southern Europe December – March
Biomass sorghum	• high WUE • low fertilisation requirement • 10 – 12 plants/m^2	15 – 30 ton DM/ha/year but on marginal lands much less	70% – 80%	• ash: 4% – 9% • ash melting level: 953˚C • depends on composition in leaves and stems • depends on fertilisation	cell: 40% (29% – 47%) hemi: 25% (18% – 27%) lignin: 9% (6% – 16%)	• September – early October

[2] http://s2biom.alterra.wur.nl/web/guest/biomass-characteristics

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Biomass type	Characteristics conventional cultivation system/source	Average yield level at harvest	Average moisture content MC (%) at harvest 4	Ash content (%) and melting behaviour & factors in management influencing ash content & composition 4	Cellulose, hemicellulose, lignin composition (%)[2]	Harvesting time
Residues from Sweet (grain) sorghum (these have been suggested as an alternative to biomass sorghum)	• grain sorghum has a high WUE • lower fertilization requirements compared to maize • planting density of 20-25 plants/m^2	straw yields are variable depending on soil, cultivars, environmental conditions, etc. in general straw yield in range of 5-7 Mg/ha.	depending on weather, season, and time allowed to dry in the windrow, moisture content of the straws can vary greatly from 50% to 70% right after harvest to about 30% after field drying for some days	• ash content varies in function of the variety and grain production potential • some values are between 4% and 5%	similar composition to biomass sorghum: cell: 40% (29% – 47%) hemi: 25% (18% – 27%) lignin: 9% (6% – 16%)	• harvesting is usually done at the end of August, beginning September
Lignin rich residue	• from bioethanol plant	140 ton DM/day (at Crecentino plant)	50% – 60% 55% – 65%	• Ash: 5% – 15%	Lignin: 50% – 60% Carbohydrates: 30% – 35%	• not harvested, but available at Crecentino plant when it produces bioethanol

DM = dry matter; FM = fresh matter

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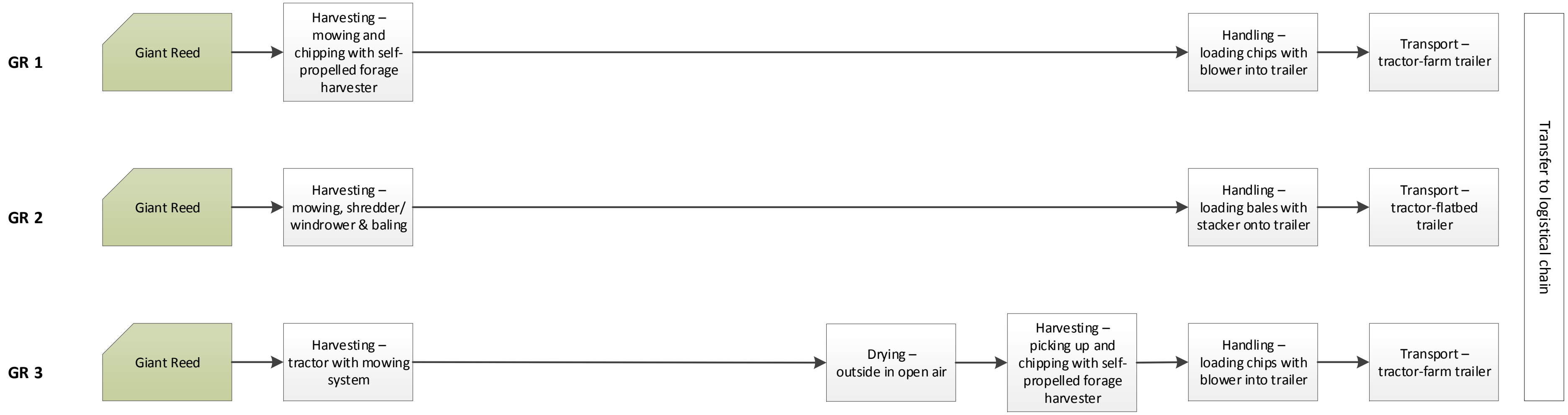

Figure 2.1 Possible harvesting systems for giant reed, up to roadside.

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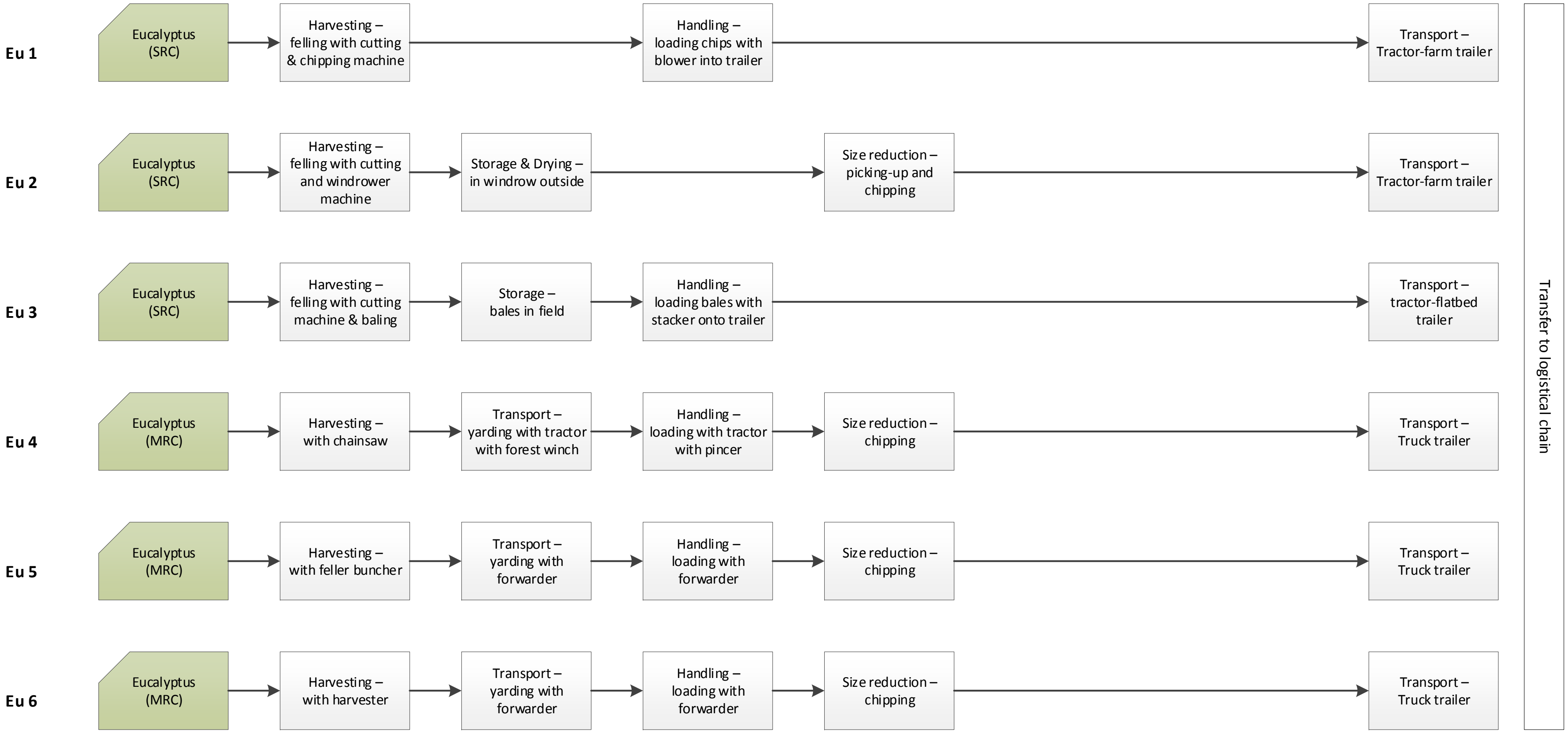

Figure 2.2 Possible harvesting systems for Eucalyptus, up to roadside.

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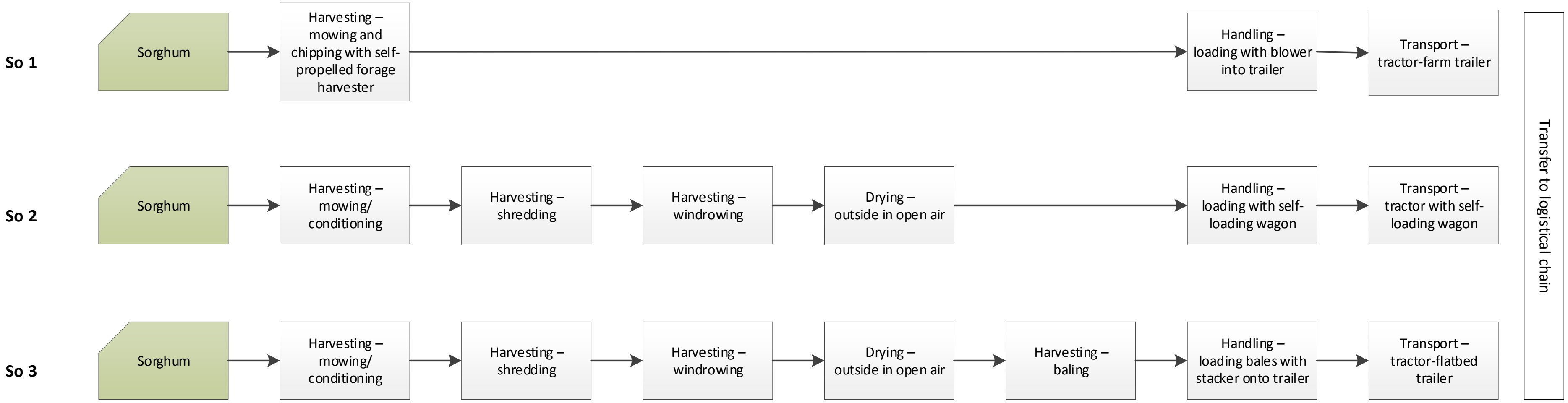

Figure 2.3 Possible harvesting systems for Sorghum, up to roadside.

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Table 2.2 Overview of main harvesting and field operation options for giant reed.

Biomass type	**Characteristics of harvesting, pre-treatment and forwarding**	**Logistical components**	**Advantages**	**Disadvantages**
Giant reed – System 1	chipping and loading of the fresh product	• self-propelled forage harvester (SPFH) flanked by tractor-trailer unit • delivered to collection point	• single pass • availability with contractors	• proportion of finest fractions too high • high costs • soil compaction • direct use in power plant gives clogging problems and unconverted materials • Product not ideal for combustion because of size chips
Giant reed – System 2	mulching (shredding) and baling of the fresh biomass	• front part of tractor equipped with shredding/windrower machine & rear part equipped with baler (round or square)	• only single pass • bale collection and storage • most cost efficient	• material needs to be pre-treated before usage (chipped) • presence of impurities (soil) in the biomass
Giant reed – System 3	mowing, pick-up, shredding and loading the dry product	• tractor equipped with mowing system • self-propelled forage harvester (SPFH) equipped with a pick-up system	• good quality material • already low moisture content • ready for conversion • product storable	• two passes in the field • higher harvesting costs • damage to soil structure (compaction) • product not ideal for combustion (size) • presence of impurities (soil) in the biomass
Giant reed – System 3b	test new system to separate stems and leaves	• Sugar cane harvester	• can be done with help of Brazil	• little experience

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Table 2.3 Overview of main harvesting and field operation options for Eucalyptus.

Biomass type	**Characteristics of harvesting, pre-treatment and forwarding**	**Logistical components**	**Advantages**	**Disadvantages**
Eucalyptus Short Rotation Coppice (SRC) – System 1	fresh harvesting (cutting & chipping)	• self-propelled forage harvester (SPFH)	• only one pass • very high field capacity • availability of contractors • direct loading on trailer for easier transport • no presence of impurities (soil) in the biomass	• harvestable diameter < 15 cm • high soil compaction during harvesting (heavy machines) • storage problems due to fine particles that provokes fermentation processes vertical cracks on stumps • presence of leaves in the biomass, increasing ash content and humidity
Eucalyptus Short Rotation Coppice (SRC) – System 2	dry harvesting (cutting, windrowing, drying, picking-up, chipping)	• cutting machine • tractor-chipper coupled with tractor-trailer	• natural drying (thus cheap) in windrow to 20% – 30% moisture content • less problems of soil compaction (light machine) • smaller and cheaper machines are used • dry biomass available for collection	• two passes • presence of leaves (even if they are dry) in the biomass, increasing ash content • more presence of impurities (soil) in the biomass, if windrowed
Eucalyptus Short Rotation Coppice (SRC) – System 3	fresh harvesting (cutting & baling)	• biobaler	• natural drying • easier storage	• harvestable diameter < 15 cm • presence of leaves (even if they are dry) in the biomass, increasing ash content • bales collection • need for pretreatment (chipping)

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Biomass type	Characteristics of harvesting, pre-treatment and forwarding	Logistical components	Advantages	Disadvantages
Eucalyptus Medium Rotation Coppice (MRC) – System 1	traditional (cutting, yarding, loading & comminution)	• chainsaw • tractor with forest winch • tractor with pincer • chipper	• harvestable diameter > 20 cm • biomass drying in the field edge • chipping at 20% – 30% moisture content • larger harvesting period • in medium small size farms the cost are lower respect to systems 2-3	• many passages • requires chainsaw debrunching
Eucalyptus Medium Rotation Coppice (MRC) – System 2	advanced (cutting, yarding, loading & comminution)	• feller buncher • forwarder • chipper	• harvestable diameter > 20 cm • biomass drying in the field edge • chipping at 20-30% moisture content • larger harvesting period	• many passages • high cost of the machines
Eucalyptus Medium Rotation Coppice (MRC) – System 3	very advanced (cutting, yarding, loading & comminution)	• harvester • forwarder • chipper	• harvestable diameter > 20 cm • biomass drying in the field edge • chipping at 20-30% moisture content • larger harvesting period	• many passages • high cost of the machines

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Table 2.4 Overview of main harvesting and field operation options for biomass sorghum.

Biomass type	Characteristics of harvesting, pre-treatment and forwarding	Logistical components	Advantages	Disadvantages
Biomass sorghum – System 1	green biomass harvesting system	• self-propelled forage harvester (SPFH) equipped with head for maize silage • flanked by tractor-trailer unit	• clean product • wide harvesting window (summer & fall) • low ash content	• high costs • soil compaction • product impossible to dry and difficult to store (only fresh silos) • product not ideal for combustion • chips average length of 1 cm with a remarkable presence of fine fractions • high risk of fermentation during storage • limited use of the green comminuted biomass
Biomass sorghum – System 2	dry biomass harvesting system	• conditioner • shredder • windrower • round or square baler or • self-loading wagon	• common machines used for hay-making can be utilized • high bulk density • low moisture content	• cost to collect the bales • low condition effect • ash content • harvest losses • possible harvesting window limits due to crop characteristics (ripening)
Biomass sorghum – System 3	dry biomass harvesting system	• single plant conditioner (Cressoni)	• low moisture content • high bulk density	• cost to collect the bales

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Table 2.5 Overview of logistics operation options for lignin rich residue.

Biomass type	Characteristics of harvesting, pre-treatment and forwarding	Logistical components	Advantages	Disadvantages
Lignin rich residue	available in one location, which is the bioethanol conversion plant	• logistics handling is limited as already available at the bioethanol conversion plant.	• no transport involved if pyrolysis conversion installation it established in same place as bioethanol conversion plant	• the lignin rich residue has high moisture content (~70%) • difficult to move/feed to the next conversion processes • ash content 3%. • availability related to ethanol production times • being a co-product from ethanol production chain, it needs a different logistics concept

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For each of the two cropping systems there are three harvesting options tested in BECOOL (See Figure 2.2 and Table 2.3). For SRC Eucalyptus there are two options with fresh harvesting requiring one machine pass per harvest (system EU1 and system EU3 in Table 2.3). In system EU1, the biomass is chipped in the field and is then immediately transported to the conversion and/or storage place. The advantage is that the harvesting is in one passage. The disadvantages are

1. that the biomass has high moisture content (50%) and appropriate drying and/or storage systems have to be utilized in order to further dry the biomass and prevent quality loss. The storage should be done closer to the production site in order to decrease the transport cost.
2. The machines used in this harvesting system are heavy and may cause compaction.

The other fresh harvest system EU3 involves cutting and baling. The biobaler is a machine developed in Canada that until now has not a wide use in Europe (there are 1-2 machines in Europe). Then the biomass is transported to storage and/or conversion installation. The disadvantages of system EU3 are:

1. that the collection of bales is needed and that a pre-treatment of the bales (chipping) is required before processing;
2. that the biomass has a higher ash content due to the presence of leaves and soil particles.

The system EU2 involves SRC harvesting and then the picking up of the biomass after it has been dried in the field. In a second machine pass, the biomass is picked, chipped and transported by tractors with trailers. This system has more advantages as the biomass is drier when removed from the field leading to easier storage and lower transport cost. Furthermore, the machines used are lighter causing less compaction. In this system, two machine passes are required however and this may lead to higher cost.

For the MRC cropping system there are also three harvesting systems tested (see Table 2.3). The cutting of the trees is operated by manual chainsaw in the system EU4, by a feller-buncher in system EU5 and by a harvester in system EU6. The extraction of the biomass from the field to the field edge is performed by a tractor with a forest winch and tractor with pincer in the system EU4 and by a forwarder in system EU5 and EU6. The three systems have some advantages, which mainly are the ability to harvest plants with a diameter bigger than 20 cm, the natural drying of the biomass at the field edge and the comminution with a forestry chipper when a moisture content level of 20-30 % is reached. The disadvantages are related to the high number of passages required, and concerning system EU5 and EU6 the harvester machines involved are very costly, requiring high investments. In fact, these machines are used only on very large surfaces.

The image of the Eucalyptus in several European regions is that of a non-native species that increases forest fire risks and may lead to depletion of deep fresh water resources, particularly in drought prone areas. Furthermore, like for giant reed and biomass sorghum it will be a challenge to identify land resources that are currently unused. For these reasons, it is likely to be difficult to convince farmers and other landowners in some southern European regions to produce Eucalyptus. On the other hand, Eucalyptus is a hardy crop that can cope well with natural constraints occurring in marginal lands in Mediterranean Europe (Von Cossel et al., 2018).

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2.2.3 Biomass Sorghum

Sorghum has great potential as an annual energy crop. While primarily grown for its grain, sorghum can also be grown for animal feed, sugar, and as a lignocellulosic feedstock. In general sorghum is morphologically diverse, with grain sorghum being of relatively short stature and grown for grain, while biomass sorghum types are tall and grown primarily for their biomass. Currently biomass sorghum types are a promising feedstock since they have a high lignocellulose biomass accumulation potential. The biomass properties of biomass sorghum are presented in Table 2.1. The ash content and ash melting behaviour of biomass sorghum is similar to that of giant reed and thus makes it more suitable for biochemical conversion then for thermochemical. However, if the leaves and stems can be separated in the harvesting process the stem with lower ash content can still go into thermochemical conversion. Intermediate and fast pyrolysis are possible upgrading pathways (towards gasification) for fibre sorghum, but the size and the ash and moisture content of the feedstock have to be carefully evaluated before processing.

As an annual (instead of a perennial) crop with a wide adaptability to different environments, sorghum can be rotated with other annuals such as maize and soybeans or grown in multiple crop rotations. This can diversify production (reducing risk), improve soils and reduce weed and insect control requirements, making sorghum attractive to farmers. Therefore, sorghum is easily integrated in many conventional crop rotations. High level of mechanization of the cultivation is possible (similar to maize) and it is suitable for low input practices. There is a high number of varieties with very different characteristics. N content in leaves is much higher than in the stems. Currently, the seed companies do not have well defined varieties for biomass (fibre) Sorghum production purpose. Currently one can find under the umbrella of biomass sorghum a wide range of varieties with a high level of sucrose also, which may not be ideal for some conversion processes.

Harvesting time is in summer or early fall. At harvest, this crop still has a relatively high moisture content (70-80%) which needs to be addressed before conversion and/or storing. This crop is very sensitive to climate variability which leads to high variability in yield per year (10 to 30 ton DM/ha). This can be corrected through irrigation, but that is costly and leads to worse GHG efficiency (Athens workshop).

The advantage of fibre sorghum over other types of sorghum is that it is not for human consumption and does not interfere with food production when grown on marginal land where food production is abandoned. Biomass sorghum is a hardy crop that can cope well with natural constraints occurring in marginal lands[5].

The two methods of harvesting are visualized in Figure 2.3 and Table 2.4, one being the fresh harvest and the second and third options collecting the sorghum in the field after is has dried. The green biomass harvesting system SO1 utilizing a maize chopper has as advantages, relatively clean biomass and relatively lower ash (as lower in impurities) and a wider harvesting window. Disadvantages are the high cost, higher risk for compaction, high level of impurities and high moisture and therefore more challenges to reach low moisture content that makes it suitable for storage and conversion. The dry biomass harvesting can be obtained both with conventional conditioner for forage SO2 and by a machine developed by *Cressoni Enterprise* SO3 in order to condition the single stem. In fact, the forage conditioner has not the pressure to open the single stem in order to put in contact the pith with the air and perform the dehydration. The Cressoni has as advantages that the biomass is dried in the field in one week after harvesting and therefore

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makes transport and storage easier. However, because it dries in the field it also contains more impurities (soil particles). The machines used are lighter, causing less compaction problems and the handling of the dry bales or of the loose biomass harvested with a self-loading wagon is easier. The bales require more pre-treatment in a later stage to bring in the conversion process however, which comes with extra cost.

The residues from grain sorghum (straws) have been suggested as an alternative to biomass sorghum (even though the yields are low, but the biomass characteristics may be adequate for processing purposes). The advantage is that it is a residue having low indirect effects on food production. One problem, however, could be the availability of such residues, as grain sorghum is not extensively cultivated in most European regions as wheat or barley.

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3 Conversion technology requirements

3.1 Introduction

In this Chapter, a description is given of the minimal feedstock requirements for each of the three conversion technologies in terms of feedstock composition, amount and other factors influencing the biomass delivery chain from field to conversion gate. Most of the information provided on biomass requirements per conversion process in this chapter is based on input from Work package 3 and 4 presented in the Athens workshop in Month 8.

3.2 Main requirements of the conversion processes

An overview of the most important requirements of the conversion processes is given in Table 3.1. Possible set-ups operations of on-site logistical components that prepare the received biomass feedstock for the conversion technology are visualised in Figures 3.1, 3.2 and 3.3. In the following the Table and figures are further explained per conversion technology.

3.2.1 Gasification

Gasification is the heating of carbonaceous material without combustion, with a controlled amount of oxygen and/or steam. Medium temperature gasifiers, as the one used in the project, produce gases from the biomass containing more components, methane, BTX, ethylene, etc. We typically refer to this as product gas. The temperature of medium temperature gasification usually lies between 650-850°C. For woody biomass, this lies at 850 °C and for herbaceous more at 650°C and up. The ash content and ash melting behaviour of the feedstock is therefore important, as the ashes can become sticky and affect the quality of the product (see Table 3.1). Furthermore, ash does not contribute to energy production, it may increase wear of the machinery and it will generally cost money to discard ash. An option in the logistical handling could therefore be to wash out a part of the ash mineral from the biomass, but this is a costly extra pre-treatment step which also needs a drying next step (see option Ga 9 in Figure 3.1). However, probably washing biomass does not make sense. It will remove dirt, which is not a big issue. However, the difficult components are in the feedstock, which can be reduced by having some rain on it before drying. However, really removing difficult ash, would mean higher temperature/pressure washing or using chemicals, which will be too expensive.

As to moisture in biomass, this content should be below 25% when it goes into the conversion process. Since the moisture content when harvested of most biomass types is far above this level, drying should be a key pre-treatment in the logistical chain. Drying is crucial in the logistical chain to prevent degradation. Therefore, it is included in all biomass delivery chains. This can be done in the field already, before the biomass enters the plant gate or in a decentral biomass treatment location (or biomass yard), or within the plant gate of a conversion installation e.g. using solar or solar-biomass hybrid plants for drying in order to save GHG emissions (see Figure 3.1, options Ga 3, 4, 7, 8 and 9).

With herbaceous feedstocks, the risk of agglomeration is higher. Therefore, the gasifier has to operate at lower temperature to prevent this. Corrosion is something you can take into account in material choice.

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The risk of corrosion is directly related to the ash presence and the composition of the ash in relation to chlorine content in thermal conversion. This can be reduced by the presence of sulphur (S). A low Cl/S (Chlorine/sulphur) ratio is therefore required to reduce corrosion in this process. It should be mentioned however that ash in the overall inorganic matter contained in the biomass is not the only limiting factor, the amount of each metal included in the inorganic fraction is also of importance.

The size of the input should be lower than 5 cm. The requirements of the feedstock can be achieved via multiple ways, as can be seen in the Figure 3.1 (Options Ga 5, 6, 7 and 8). For a typical commercial gasification plant there is a need for at least 240 kton biomass DM input per year. This is explained by the fact the project decided on a 100 MW Fischer-Tropsch plant. That means a 200 MW gasifier operated on 40 ton fresh matter per hour, which equals 30 ton DM of biomass per hour. With 8,000 operation hours, we this results in 240 kton. A possible option for most biomass feedstock is to carry out an initial pyrolysis step in order to increase the energy density of the feedstock and to improve the gasification process yield. Pyrolysis products such as bio-oil, or a combination of bio-oil and char (slurry) can be used as intermediate carriers for the gasifier (Option Ga 10 in Figure 3.1). The question is of course if the intermediate carrier's production costs and GHG emissions can be compensated by the improved gasification efficiency, and eventually the reduced storage and transport costs?

The large biomass demand makes good storage facilities for the biomass within or near the plant gate important to ensure security of supply of biomass that usually has a seasonal harvest cycle. The option Ga 1 (in Figure 3.1) is therefore not the most likely, unless the plant is sourced from a biomass yard located in the near distance of the plant. The use of feedstocks collected in different periods of the year will contribute to reduce the storage problem.

Finally, it is preferred to use biomass with a low nitrogen content in gasification. This is not because nitrogen inhibits the conversion process itself, but leads to higher emissions. The medium temperature gasifier produces HCN and NH3 typically. Internally we produce char containing Nitrogen. This is combusted and produces NOx but that is something we can control.

Overall, in terms of feedstock it is therefore easier to use Eucalyptus in this process. Sorghum and giant reed are typically having higher ash, chlorine and nitrogen content and need to lose more moisture in the logistical delivery chain before being fed to the gasification process than Eucalyptus. Maybe even more important is the gas clean-up for these higher ash materials. ECN has seen sulphur being much higher than in woody biomass, which will result in larger reactors to convert and capture it and in higher OPEX.

3.2.2 Pyrolysis

Pyrolysis process consists in heating an organic matter without the presence of air (free or lean of oxygen) to convert the feedstock in gaseous, liquid and solid products. Depending on the process conditions as pyrolysis vapours residence time, heating rate and temperature, the outputs are different quantities of these products. BECOOL investigates mainly the liquid and the solid products from slow, intermediate and fast pyrolysis of the lignocellulosic material: the liquid product, pyrolysis oil, is also called bio-oil, while the solid product is char. Generally, the temperature of these pyrolysis pathways usually lies around 500°C, thus the main difference is the heating time. The condensed product is the bio-oil, which is produced in a large fraction in the fast pyrolysis process. The non-condensable gases are generally adopted to provide heat to the process, or for biomass drying. The residual product, char, is the solid fraction, which is

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maximized in the slow pyrolysis process. The pyrolysis should function as a method of increasing the bulk (energy) density of the feedstock. This leads to cheaper transport and increases the efficiency of the next gasification process. The ash content of the feedstock is rather important for the pyrolysis process: it should be below 5% because has a catalytic effect that affects the oil yield.

Depending on the type of pyrolysis process, the moisture and the size of the initial biomass can vary (as shown in Table 3.1). For example, the moisture content at the input of the slow pyrolysis plant should be below 20%, while intermediate and fast pyrolysis require a limit below 8%. In order to maximize the heating rate of the process, the size of the biomass is particularly small for fast pyrolysis, and it should be within 3 mm. On the contrary, slow pyrolysis has higher tolerability in terms of dimensions (3-8 cm), or rather the common dimension of the wood chips. The options for BECOOL include the evaluation of all pyrolysis pathways: slow oxidative, intermediate and fast. Thus the dimension and the moisture content of the initial biomass have to be adapted prior of each pathway. In the BECOOL project, the decision of decentralized pyrolysis plants has been made. Currently it is estimated that such a plant needs at least 4-5 ton DM/h, which amounts to around 35,000 ton DM/year.

In terms of feedstock type, it is easier to use Eucalyptus. Sorghum and giant reed are typically having higher ash and chlorine content and need to lose more moisture in the logistical delivery chain before being fed to the gasification process than Eucalyptus.

There are different types of set-up for the logistical handling of the biomass foreseen after in enters the plant gate of the conversion plant (see Figure 3.2). The logistical handling will be similar for fast, intermediate and oxidative/slow pyrolysis. Biomass can enter the gate and fits exactly the requirements to feed it directly into the conversion process. Usually, this is not the case. What is more likely is that the biomass needs further drying in order to make it fit the requirements for storage and conversion process. The same applies to a further size reduction step which is usually needed to fit with the conversion technology requirements and could also be a necessary step for proper storage. Storage within or near the plant gate is likely to be a necessary step for all conversion installations as these need whole year feedstock security and biomass harvesting/collection is usually bound to certain periods in the year.

In case the pyrolysis oil will be used as input for gasification, an additional pumping step is needed after pyrolysis.

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Table 3.1 Overview of main conversion technologies requirements influencing logistical chain configuration (fundamental and physical). The contents of this table is based on work package 3 and 4 information presented during Athens BECOOL workshop and on S2BIOM (Elbersen et al., 2016).

Conversion technology	**Minimal feedstock requirement (ton dm/year)**	**Ash & Ash melting point**	**Chlorine**	**Nitrogen/ phosphates other minerals**	**Other fundamental requirements for feedstock**	**Moisture content (%)**	**Particle size & bulk density**	**Mixed & impure feedstock**	**Other physical requirements for feedstock**
Gasification (650 – 850°C)	240,000 (30 ton DM/h at 200 MW)	important for design and operation, preference for low ash content (<5%)	low (low Cl/S ratio to reduce corrosion)	less low than for pyrolysis	-	medium dry < 25%	< 5 cm	possible	
Pyrolysis (fast, intermediate & oxidative) (500°C)	35,000 (4 – 5 ton DM/h at 20 MW)	preference for low ash content (<5%) (separate low and high ash content biomass before processing)	low	low nitrogen content is preferred as it leads to lower NOx emissions	some metal contained in the ashes can have a catalytic effect during the process	dry < 20% (slow pyrolysis) < 8% (intermediate and fast pyrolysis)	3 - 8 cm (slow pyrolysis) < 3 mm (intermediate and fast pyrolysis)	not always possible	
Biochemical conversion to advanced bioethanol	150,000 – 200,00 (500 ton FM/day)	preference is for low/medium low ash levels to keep conversion cost low, but technically it can handle higher levels < 7%	medium/high	low/medium as influences ash content and this causes high cost in conversion (waste water cleaning)	low lignin content in biomass	dry, wet material is OK, when storage as silage dry < 20%	< 2 cm	possible	cell >30% hemi >20% lignin <25%

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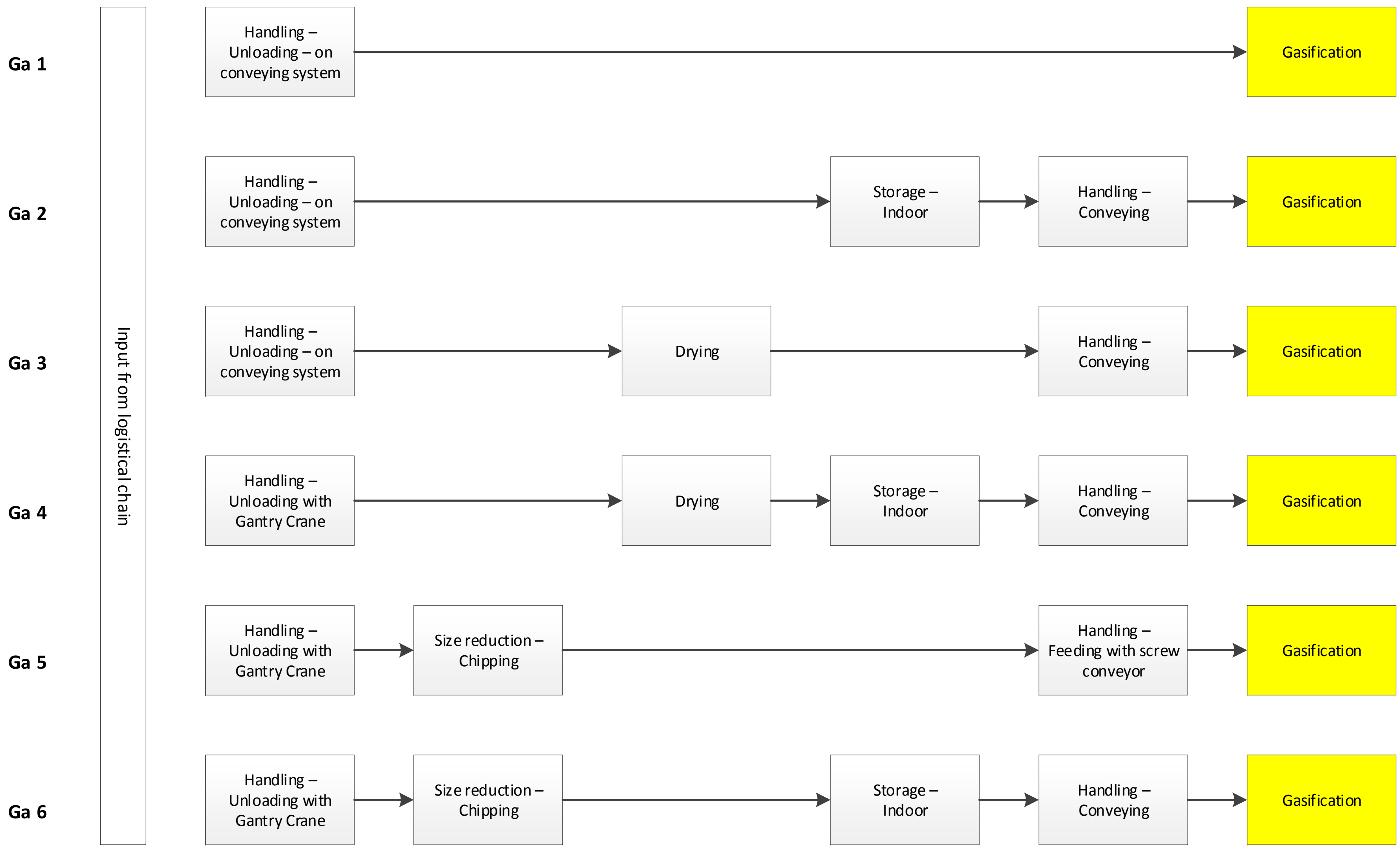

Figure 3.1a possible set-ups of on-site operations of gasification conversion technology.

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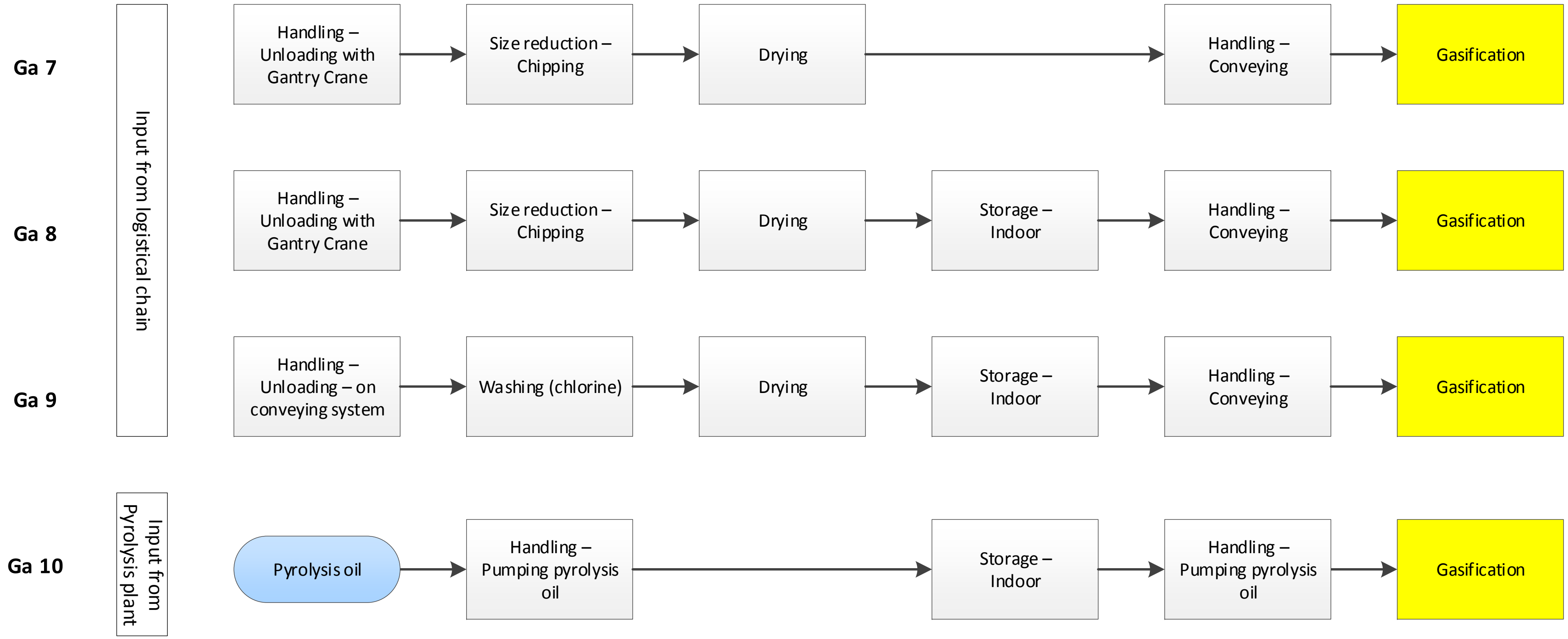

Figure 3.1b Possible set-ups of on-site operations of gasification conversion technology (continued).

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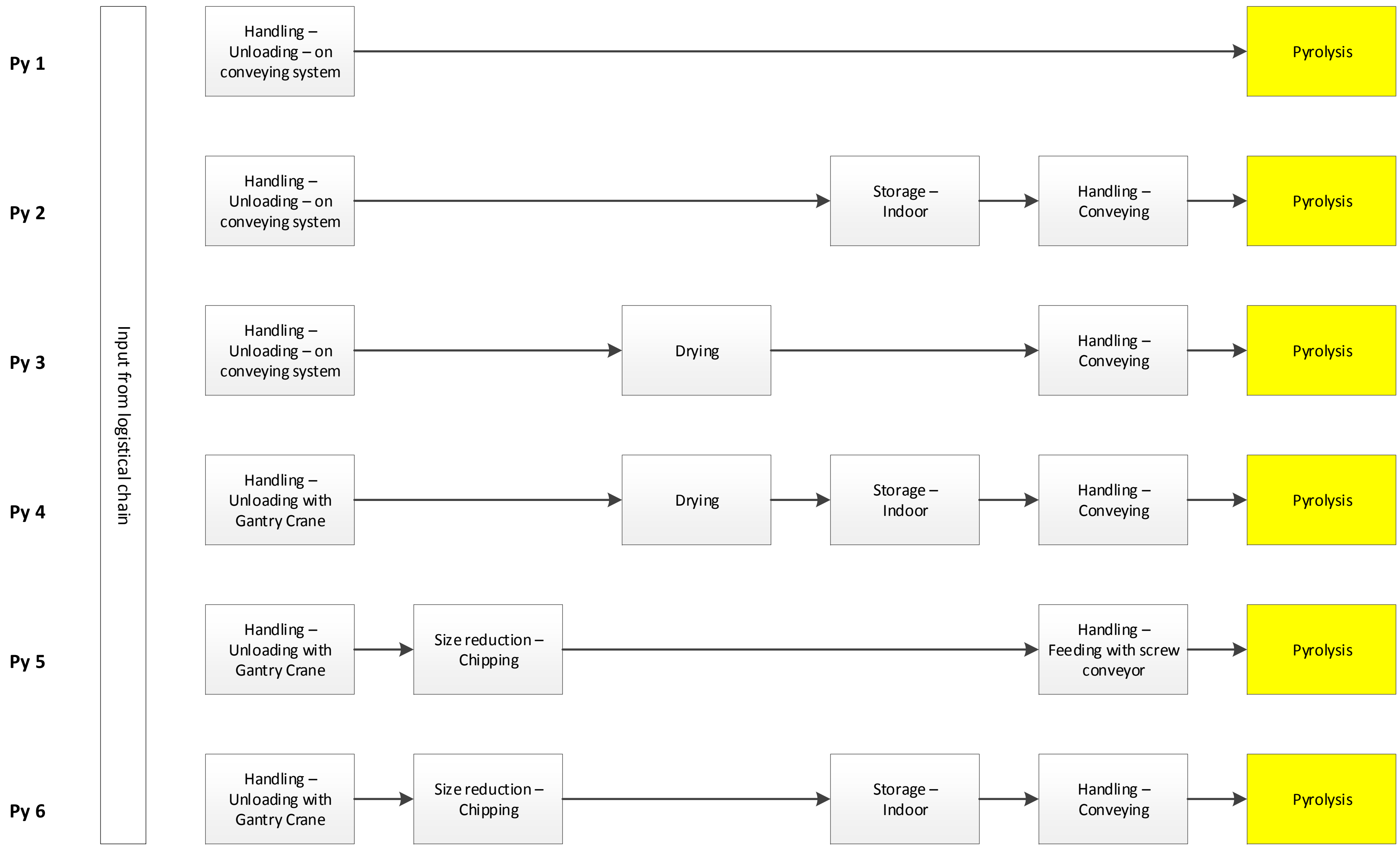

Figure 3.2a Possible set-ups of on-site operations of pyrolysis conversion technology. Is it envisaged to produce pyrolysis oil in small plants with local biomass, and then transport the pyrolysis oil to the large-scale gasification plant.

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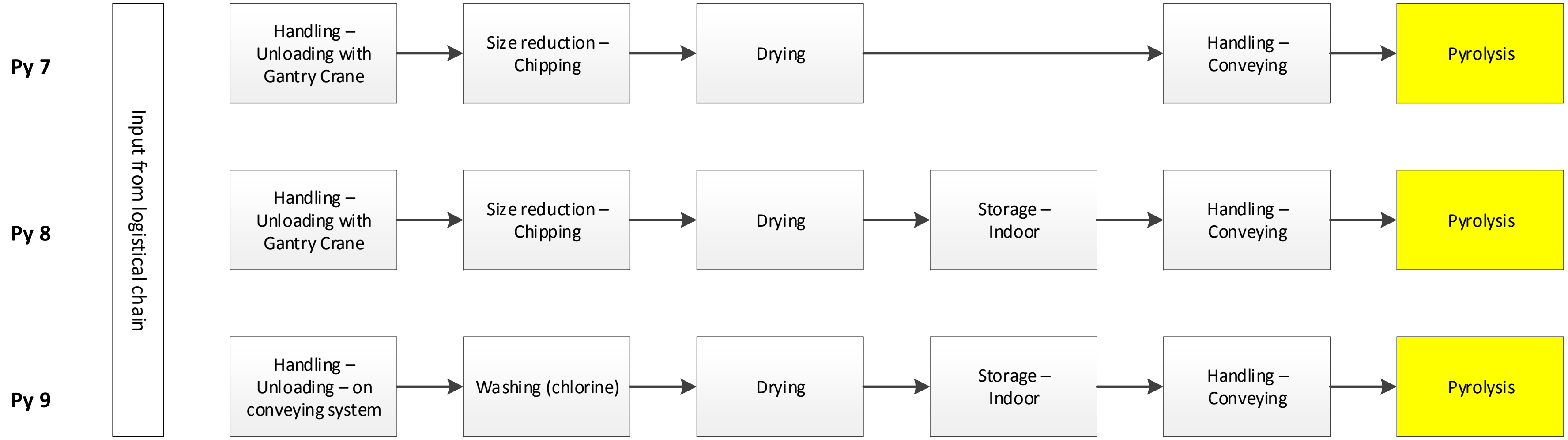

Figure 3.2b Possible set-ups of on-site operations of pyrolysis conversion technology (continued).

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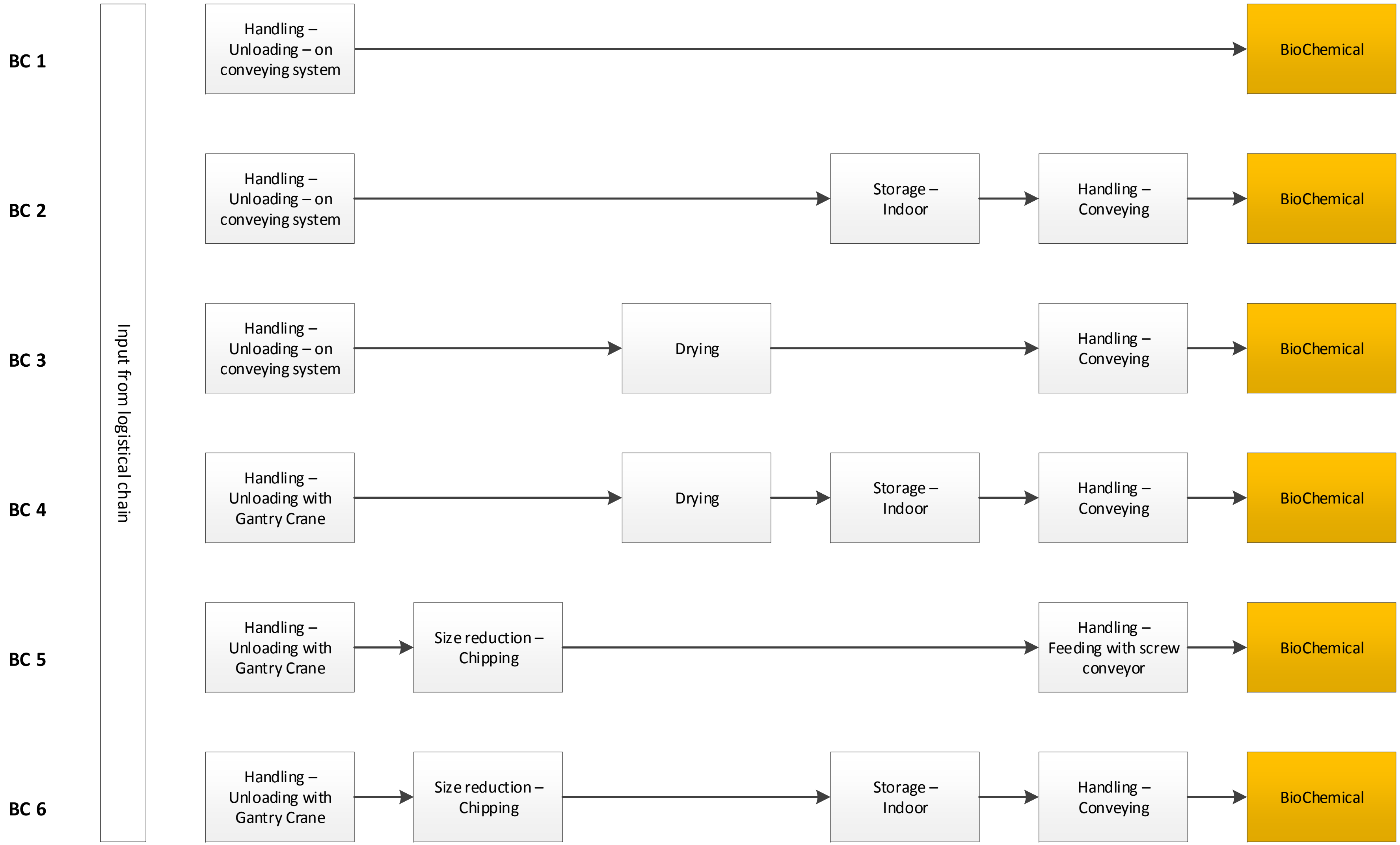

Figure 3.3a Possible set-up of on-site operations of biochemical conversion technology.

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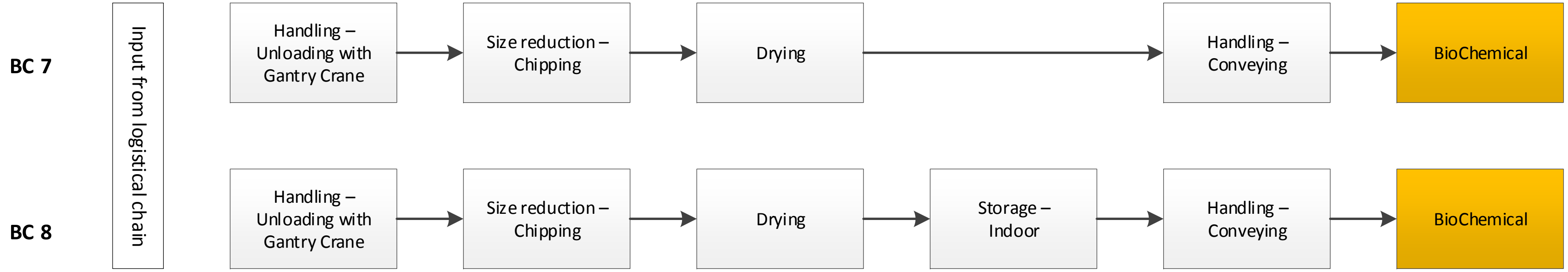

Figure 3.3b Possible set-up of on-site operations of biochemical conversion technology (continued).

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3.2.3 Biochemical conversion to advanced bioethanol

The biochemical process is the processing of lignocellulosic biomass to ethanol. First, the biomass is cooked at alkaline or acidic conditions to separate polymeric constituents like cellulose, hemicellulose and lignin, and in order to increase accessibility of the polysaccharides. In a next stage, the polysaccharide polymers are hydrolysed, often done by adding enzymes. Afterwards microorganisms are added for the fermentation into ethanol (Figure 3.4). By distilling, the ethanol is purified. The by-product is a lignin rich residue. The lignin rich residue is investigated for an energy application via pyrolysis or gasification.

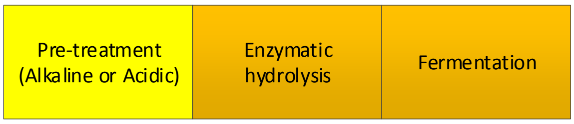

Figure 3.4 Scheme of subsequent steps in biochemical conversion technology.

In this biochemical process there is a preference for high carbohydrate biomass, specifically cellulose and hemicellulose as these can be converted into sugars, and the final conversion step in the biochemical process is based on sugars. The higher the cellulose and hemicellulose content the more suitable the biomass type is for biochemical conversion.

On the other hand, it is also preferable to have a low lignin content biomass in this process as lignin can hardly be degraded by enzymes and microorganisms. Furthermore, as explained by Elbersen et al. (2016), lignin acts as a shield that prohibits the bioconversion of cellulose and hemicellulose. This also explains the lignin-rich residue in this process. The higher the lignin content in the feedstock, the more difficult it is to use lignocellulose in biochemical conversion processes.

As with the other two conversion methods, ash or inorganic material cannot be converted within biochemical processes and generally adds to the costs of conversion. On the other hand, in the biochemical conversion, the ash content is not particularly problematic. It remains in the co-product, the lignin-rich residue. However, this implies that when this lignin-rich residue is used further as pyrolysis feedstock, it requires special precautions. The ash content, but in particular the quantity of some metal, can affect the gasification and the pyrolysis process. For this reason, each type of biomass has to be evaluated individually.

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4. Logistics and designing logistical chains

4.1 Introduction

In Section 4.2 it will first be explained how in theory a biomass feedstock matches with a conversion technology and the way this match can be influenced by logistical components. The S2BIOM project has delivered a specific biomass-matching tool that facilitates assessment of the suitability of lignocellulosic biomass feedstocks for various conversion technologies (Elbersen et al., 2016; Lammens et al., 2016). In Section 4.3 the logistical components will be discussed which can potentially be used to design a biomass delivery chain. Furthermore, a general explanation is given of logistical concepts, which can be applied to design options for the biomass value chains in the BECOOL project that will be presented in Chapter 5 of this report. In Section 4.4, the logistical chain options are visualised to connect feedstock at roadside with the gate of the conversion plant.

4.2 Matching biomass feedstock to conversion technology with logistical components

In BECOOL, the focus is on designing and evaluating biomass delivery chains for three main conversion technologies into advanced biofuels. The possible biomass feedstock - technology combinations to be tested further in BECOOL were already presented in Chapter 1 in Figure 1.1. The biomass feedstock needs to be matched with various conversion technologies that are visualised in Figure 4.1.

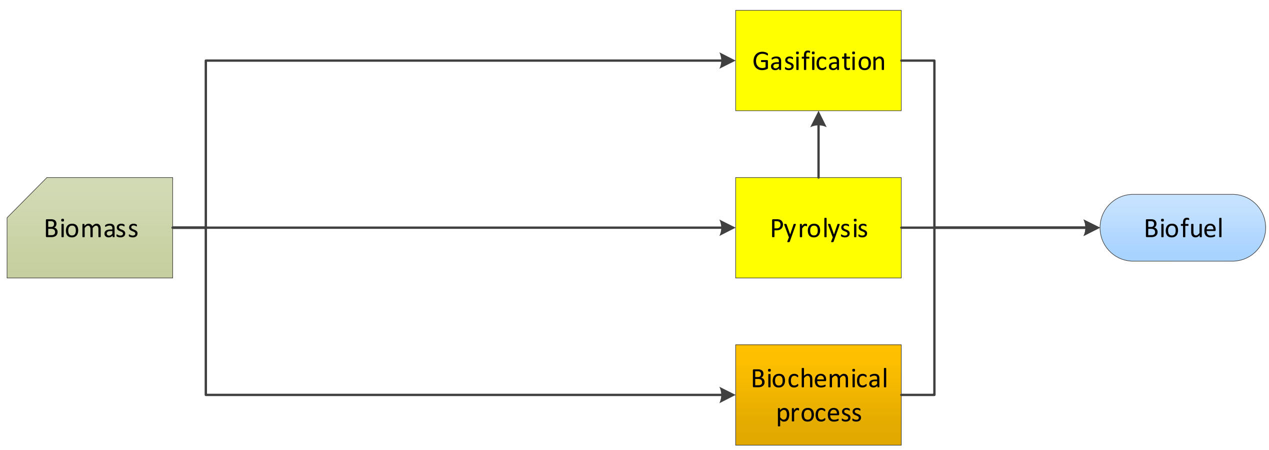

Figure 4.1 General biomass value chain options.

Some of the feedstock characteristics can be influenced by the configuration of the logistical chain that connects the roadside to the gate of the conversion plant like:

- moisture content by drying;
- particle size by size reduction;
- bulk density by densification;
- mixed or impure feedstocks by sorting/sieving/washing/etc.;
- Chlorine content by washing.

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However, many other feedstock characteristics are much more challenging to influence by the logistic chain. The final conversion technology will still need to address characteristics like:

- ash deformation temperature;
- ash content;
- Nitrogen content.

Some other feedstock characteristics are not related to the conversion technology, but they can be influenced by the logistic chain like:

- spatial distribution which implies collection and transport from a certain area;
- seasonal availability patterns (peaks in supply) which can be overcome by storage.

So logistical components can be used to change some of the characteristics of the biomass type. The main categories of logistical components that can be present in a biomass chain are:

1. comminution (size reduction);
2. compaction/densification;
3. drying;
4. feedstock handling;
5. other pre-treatments that influence feedstock quality;
6. storage;
7. transportation technologies.

The subcategories of these main logistical components are given in Annex A based on the work in the S2BIOM project, and more specifically on Deliverable D3.1 ‘Review of the main logistical components’ (Annevelink et al., 2014).

4.3 Logistical concepts & chain design options

'A biomass value chain connects the available biomass types with the final conversion process through various logistical components. A logistical concept is broader and more general than a specific biomass value chain. A logistical concept always still needs to be further specified and translated in order to obtain a specific biomass value chain (specify all the components). Often several possible biomass value chains fit within that general logistical concept' (Annevelink et al., 2016). The S2BIOM project has described several general logistical concepts (see Table 4.1) that could be applied to design the biomass value chains in the BECOOL project in Chapter 5.

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Table 4.1. General logistical concepts as defined in the S2Biom project (Annevelink et al., 2016).

	Variant 1	Variant 2
Pre-treatment	Integrated with harvesting/collecting	Stand-alone, later on in the biomass chain
Supply	Indirect through intermediate collection points (biomass yards) to the final conversion location	Direct from the road-side to the final conversion location
Transportation	Multi-modal (combination of different types)	Only one modality (road, water or rail)
Form	Standardized biocommodities (e.g. wood pellets, ethanol, pyrolysis oil)	'Raw' biomass (e.g. wood chips, bales)
Scale	Many small-scale conversion plants	One large-scale conversion plant

The design of logistical biomass chains from the edge of the field (roadside) to the gate of the conversion plant can vary according to a wide range of issues. The most important are listed as follows:

- what is the location and scale of conversion plant (central large-scale conversion versus decentral small-scale conversion);
- is the biomass available at a short distance around the conversion plant or at (very) long distance;
- which transport means (truck, train or boat) are chosen for each transport arc type (e.g. a certain transport means from roadside to intermediate collection point and a different type from there to the conversion plant);
- are intermediate collection points or biomass yards included in the chain;
- which pre-treatments are needed to achieve the required quality for storage and for conversion (e.g. size reduction or drying), and where in the value chain are these performed (e.g. at an intermediate collection point or at the conversion plant);
- what is the storage location (field, intermediate collection point, biomass yard or conversion plant) and what pre-treatments can be applied there too;
- is small-scale conversion of biomass to pyrolysis oil (e.g. at intermediate collection points) incorporated in the chain before large-scale conversion through gasification;

In order to ensure that all relevant issues are taken into account it is advisable to systematically cover the main factors in the design of a biomass delivery chain:

a) Physical quality of the biomass feedstock – Pre-treatment

The characteristics at roadside could already match the required specifications of the conversion plant. In that case, the biomass does not need any further pre-treatments (like size reduction, drying etc.). It can be transported directly to the location of the conversion plant. The choice of the transport device is determined during the harvesting operation. However, when the characteristics at roadside do not meet the required specifications, which is the most likely situation, some or several pre-treatments are needed at a certain position in the value chain. This location in the chain can be at roadside, at an intermediate collection point or at the conversion plant.

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b) Geographical dispersion of the biomass feedstock – Intermediate collection, transportation means

When a sufficient amount of biomass is available at close range of the conversion plant (short distances) direct transport from roadside to the conversion site is an option. When the biomass is spread over a large area than more transport kilometres are needed. This will influence the choice of the transport means and may be favourable for choosing a set-up with intermediate collection points or biomass yards beyond a certain distance to the plant. In the intermediate collection points, biomass from the region can be pre-treated, particularly dried and densified, and stored and as soon as the conversion installation needs the biomass, it is transported further.

c) Time period of availability - Storage

Often the biomass harvesting period is limited to a few months. Therefore, storage is inevitable when biomass is needed year-round. The location where this storage is to be done needs to be selected: at roadside, at an intermediate collection point or at the site of the conversion plant. Before storing the biomass, it is of utmost importance that the biomass does not lose any of its quality. Pre-treatments of the biomass such as drying, chipping, pelletizing, conversion to pyrolysis oil, comminution, etc. are then required to ensure long- term quality stabilisation.

d) *Location of conversion plant – Near rail, water, near city/market for end-product or residues (heat) or as close as possible to the origin of the biomass*

Choosing a specific location for a conversion plant can be driven by several factors. Ideally the location should be chosen where biomass delivery cost and cost to transport the final or intermediate products remain as low as possible. If a conversion installation needs to be sourced from both local and imported biomass to ensure security of supply, a location near a transport node such as a train station or harbour is advisable. Delivery of the energy and residual heat to users sometimes also requires a physical close proximity to the consumers. This could have a higher priority for making a business case really work then being close the origin of the biomass. This implies that biomass pre-treatments near the biomass sources are crucial to bring down the cost of transport that is needed to supply a power plant over larger distances. Cheaper transport options like by boat or train can bring cost down significantly as compared to road transport by truck.

4.4 Visualization of logistical chain options

This section presents an overview of visual designs for the chosen biomass feedstock-conversion technology combinations in BECOOL taking account of the logistical concepts and principles discussed in the former sections. Each logistical chain option is described in a *visio*-scheme to visualize the design (see a schematic example in Figure 4.1). In this visualisation of a logistic chain also the locations should be specified where different operations (transport, pre-treatment, storage, etc.) occur. A biomass logistical chain can include one or more of the following logistical components:

- field/roadside;
- transport;
- intermediate collection point with handling, pre-treatments, storage and drying (optional);
- transport (optional);
- intermediate conversion by pyrolysis with handling and storage, possibly connected with the intermediate collection point (optional);
- transport (optional);
- final conversion.

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Figure 4.1. Potential components of a logistic chain description; exact components depend on biomass quality delivered at roadside and logistical components available at the conversion site.

In Figures 4.2, eight types of logistical chains that can connect the biomass feedstock at roadside with the gate of the conversion plant are visualised:

- direct transport (Figure 4.2, Lo 1);
- intermediate collection point including pre-treatments for one or more different types of biomass sourced from the surrounding region (Figure 4.2, Lo 2 – 8);

Direct transportation (Figure 4.2, Lo 1) is possible when sufficient biomass can be sourced from the local region at low cost. This can either work because the amount of biomass needed is relatively small and/or the spatial concentration of accessible biomass is high.

Intermediate collection points are interesting to use (see examples Lo 2 – Lo 8 in Figure 4.2) if the biomass is further away from the conversion installation and/or if it is more spatially dispersed over a larger region. If there is a simple pre-treatment included in the intermediate collection point the biomass characteristics will change according to that pre-treatment. Pyrolysis can also be seen as a (more complex) pre-treatment option as it changes the biomass into bio-oils, and these bio-oils will be further processed in the gasifier (option Ga 10 in Table 3.1b).

As a variation to a simple intermediate collection point, the more sophisticated biomass yard concept may be used. A biomass yard usually involves a more complex logistical handling with larger variations in pre-treatments options of biomass and pre-treating many different types and origins of biomass at the same time. A biomass yard can be supplied by local, regional and long distance biomass of different types at the same time. Moreover, the biomass yard can supply one or more conversion installations in the wider local region or further away region with a mix of feedstocks.

Multi-feedstock with local sourcing or local sourcing and point sourcing (harbor and or train station) is represented in Figure 4.3.

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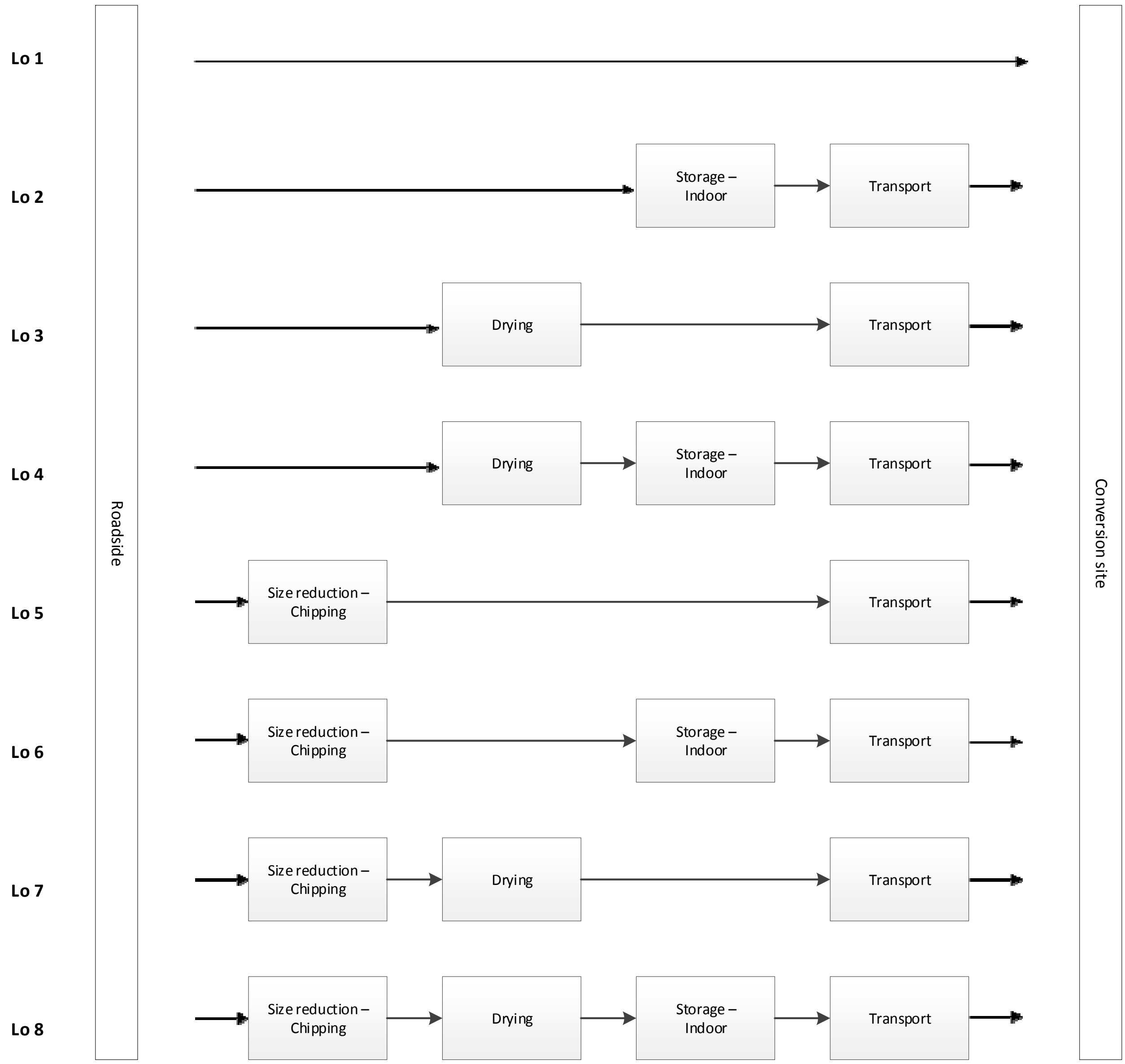

Figure 4.2. Possible set-ups of logistical chain from roadside to conversion plant gate.

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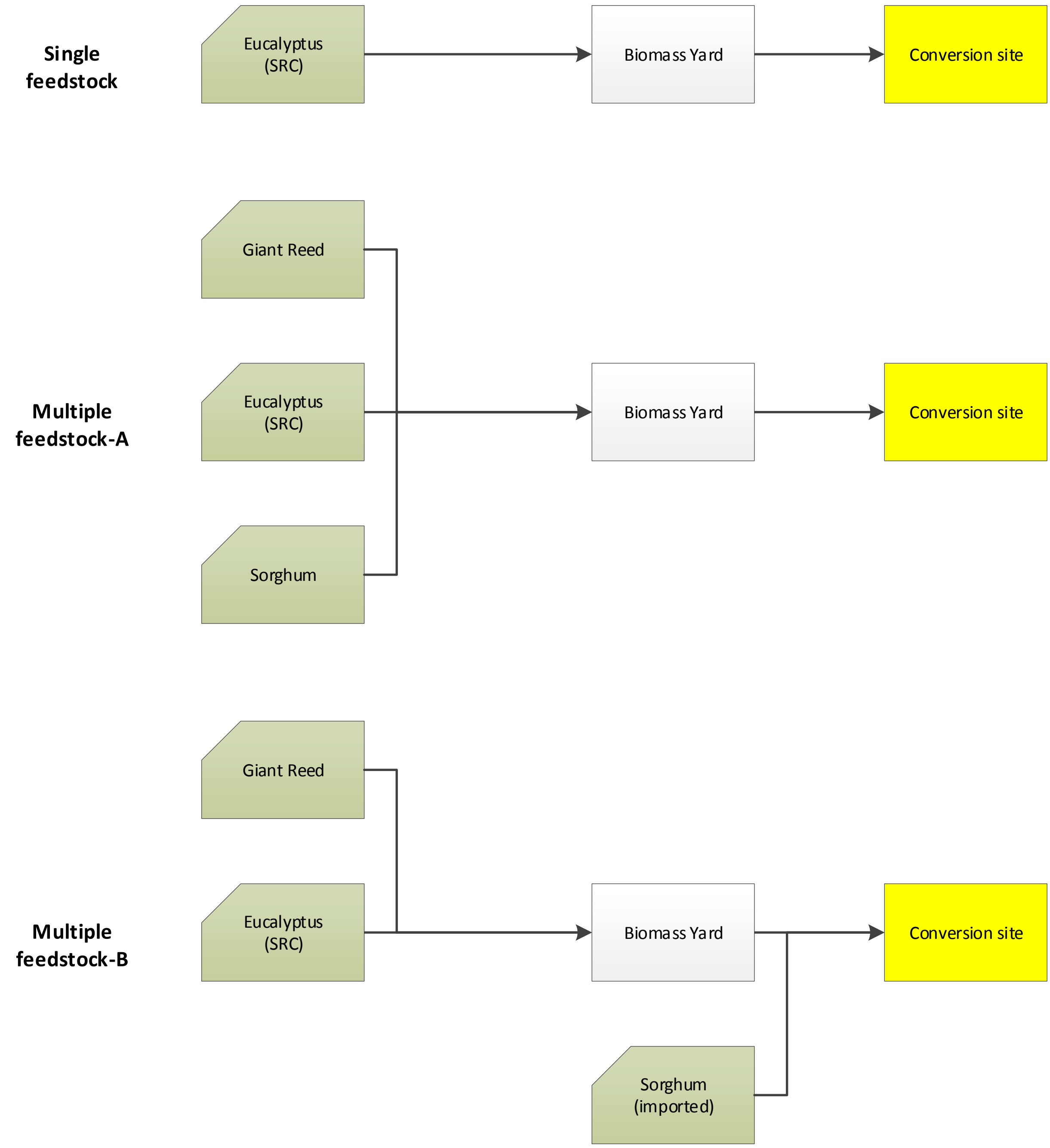

Figure 4.3 Schematic impression of a multi-feedstock system with local sourcing of different types of biomass produced in the region (A) and point sourcing of imported biomass e.g. at a harbour (B).

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5. Selection of logistic chains for sustainability assessment and case studies

5.1 Introduction

In the former chapters, all aspects are mentioned that need to be taken into account for the selection of logistical chain designs to test in case studies in the BECOOL project. These aspects can be summarized as follows:

1) All four biomass types (giant reed, biomass sorghum, Eucalyptus and lignin rich residue from the bioethanol plant) combined with the three conversion technology combinations need to be tested in one or more European case studies. This implies that case regions need to be selected where sourcing options with the four feedstock types are realistic in the near future.
2) Variation in case study selection in order to be able to test all types of harvesting options per feedstock type selected in WP1.
3) Variation of cases according to different spatial dispersion situations for biomass: low density dispersed versus high spatial concentration.
4) Mono-feedstock sources versus multi-feedstock sourcing.
5) Variation of cases according to central and decentral biomass value chain organization with intermediate collection points/biomass yards sourced locally by single and multi-feedstock types.
6) Variation of cases according to central and decentral chain organization with intermediate collection point or yard sourced from local and long-distance biomass.
7) Variations in logistical chain organization with most logistical pre-treatments and storage at field, all pre-treatments and storage at intermediate collection points or biomass yards, or all pre-treatments and storage in conversion installation point.

5.2 Possible biomass value chains

In Table 5.1, the possible combinations of the four biomass types with the three conversion technologies are presented and alternative logistical options are given for connecting them. In theory, all possible combinations presented in this table could be tested in case studies. However, in practice a choice will have to be made for a limited number of options that are more likely to be implemented. This will be done in Section 5.3, but in this section, it will also be discussed which combinations are not logical from the start and can thus be excluded directly.

A few specifics applied when constructing Table 5.1:

- Transportation between roadside, possible intermediate collection point and conversion site is required for all biomass value chain combinations. In order to keep the overview in Table 5.1 as simple as possible, the transportation component has been omitted.
- Some combinations of feedstock quality at roadside – logistic operations at the conversion plant are not relevant because they include doubling of operations (e.g. double chipping). Those combinations have been omitted in the table. An overview of these combinations is presented in Table 5.2.
- *1 - Storage of fresh giant reed and sorghum may be done as silage when it is used as feedstock for biochemical conversion. In that case, silage replaces the “drying + storage” operations at an

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intermediate collection point (Lo 4) or at the conversion plant (BC 4). These combinations are marked with *[1] in Table 5.1.

- *2 - Storage for a longer period (not being silaged) of undried biomass may lead to heating or unwanted microbial attack. This implies that some combinations including storage of undried biomass feedstock at the intermediate collection point are less relevant. These combinations are marked with *[2] in Table 5.1.
- *3 - Drying of bales is very inefficient. Otherwise, unbaling prior to drying and subsequent re-baling or transportation of unbaled voluminous biomass is inefficient as well. These less relevant combinations are marked with *[3] in Table 5.1.
- *4 - When biomass feedstock will be washed, dried and stored at the conversion plant, it does not make sense to dry the biomass in a previous step. These less relevant combinations are marked with *[4] in Table 5.1.
- Transportation of wet feedstock to conversion plants increases costs and may therefore be less favourable (except maybe for the washing option at the conversion site).
- For intermediate and fast pyrolysis, particle size should be smaller than 3 mm. As required size reduction and handling/transportation equipment is usually not available at primary feedstock production locations, such (additional) size reduction likely will have to be achieved at the intermediate collection point, or at the conversion site.
- Size reduction (chipping) as a single operation at the intermediate collection point is not likely to be efficient as it implies two times biomass uploading, two times downloading and twice transporting of which the first involves very bulky biomass. Therefore, these options have not been included in Table 5.1.

The value chain options in Table 5.1 and 5.2 are marked with one of the following colours indicating their probable suitability:

Colour	Meaning
Dark green	Possible value chain combination
Light green	Less likely value chain combination
Orange	Unlikely value chain combination
Red	Impossible value chain combination

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Table 5.1. Overview of all combinations of feedstock at the roadside connected by logistics to a receiving conversion plant. At each of these three stages of the chain, the applied logistical components are mentioned. Each logistics option involves at least one transport operation and most of the times also handling (loading/unloading) at the biomass yard. However, these are left out of this table for clarity. The '-' sign means direct transport without any other logistical components.

Feedstock at roadside (Chapter 2)		Logistics direct or at intermediate collection point/ biomass yard (Chapter 4)		Conversion plant (Chapter 3)	
GR 1	Chipping	Lo 4	Drying, Storage	Ga 1	-
		Lo 3	Drying	Ga 2	Storage
		Lo 2	Storage *[2]	Ga 3	Drying
		Lo 1	-	Ga 4	Drying, Storage
		Lo 1	-	Ga 9	Washing, Drying, Storage
		Lo 4	Drying, Storage	Py 1	-
		Lo 3	Drying	Py 2	Storage
		Lo 2	Storage *[2]	Py 3	Drying
		Lo 1	-	Py 4	Drying, Storage
		Lo 1	-	Py 9	Washing, Drying, Storage
		Lo 4	Drying, Storage *[1]	BC 1	-
		Lo 3	Drying	BC 2	Storage
		Lo 2	Storage *[2]	BC 3	Drying
		Lo 1	-	BC 4	Drying, Storage *[1]
GR 2	Baling	Lo 8	Chipping, Drying, Storage	Ga 1	-
		Lo 7	Chipping, Drying	Ga 2	Storage
		Lo 6	Chipping, Storage *[2]	Ga 3	Drying
		Lo 5	Chipping	Ga 4	Drying, Storage
		Lo 4	Drying, Storage *[3]	Ga 5	Chipping
		Lo 3	Drying *[3]	Ga 6	Chipping, Storage
		Lo 2	Storage *[2]	Ga 7	Chipping, Drying
		Lo 1	-	Ga 8	Chipping, Drying, Storage
		Lo 5	Chipping	Ga 9	Washing, Drying, Storage

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Feedstock at roadside (Chapter 2)		Logistics and biomass yard (Chapter 4)		Conversion plant (Chapter 3)	
GR2 (continued)	Baling (continued)	Lo 8	Chipping, Drying, Storage	Py 1	-
		Lo 7	Chipping, Drying	Py 2	Storage
		Lo 6	Chipping, Storage *2	Py 3	Drying
		Lo 5	Chipping	Py 4	Drying, Storage
		Lo 4	Drying, Storage *3	Py 5	Chipping
		Lo 3	Drying *3	Py 6	Chipping, Storage
		Lo 2	Storage *2	Py 7	Chipping, Drying
		Lo 1	-	Py 8	Chipping, Drying, Storage
		Lo 8	Chipping, Drying, Storage	BC 1	-
		Lo 7	Chipping, Drying	BC 2	Storage
		Lo 6	Chipping, Storage *2	BC 3	Drying
		Lo 5	Chipping	BC 4	Drying, Storage *1
		Lo 4	Drying, Storage *3	BC 5	Chipping
		Lo 3	Drying *3	BC 6	Chipping, Storage
		Lo 2	Storage *2	BC 7	Chipping, Drying
		Lo 1	-	BC 8	Chipping, Drying, Storage
GR 3	Drying, Chipping	Lo 2	Storage	Ga 1	-
		Lo 1	-	Ga 2	Storage
		Lo 1	-	Ga 9	Washing, Drying, Storage *4
		Lo 2	Storage	Py 1	-
		Lo 1	-	Py 2	Storage
		Lo 1	-	Py 9	Washing, Drying, Storage *4
		Lo 2	Storage	BC 1	-
		Lo 1	-	BC 2	Storage

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Feedstock at roadside (Chapter 2)		Logistics and biomass yard (Chapter 4)		Conversion plant (Chapter 3)	
Eu 1, Eu 4, Eu 5, Eu 6	Chipping	Lo 4	Drying, Storage	Ga 1	-
		Lo 3	Drying	Ga 2	Storage
		Lo 2	Storage *2	Ga 3	Drying
		Lo 1	-	Ga 4	Drying, Storage
		Lo 1	-	Ga 9	Washing, Drying, Storage
		Lo 4	Drying, Storage	Py 1	-
		Lo 3	Drying	Py 2	Storage
		Lo 2	Storage *2	Py 3	Drying
		Lo 1	-	Py 4	Drying, Storage
		Lo 1	-	Py 9	Washing, Drying, Storage
		Lo 4	Drying, Storage *1	BC 1	-
		Lo 3	Drying	BC 2	Storage
		Lo 2	Storage *2	BC 3	Drying
		Lo 1	-	BC 4	Drying, Storage *1
Eu 2	Drying, Chipping	Lo 2	Storage	Ga 1	-
		Lo 1	-	Ga 2	Storage
		Lo 1	-	Ga 9	Washing, Drying, Storage *4
		Lo 2	Storage	Py 1	-
		Lo 1	-	Py 2	Storage
		Lo 1	-	Py 9	Washing, Drying, Storage *4
		Lo 2	Storage	BC 1	-
		Lo 1	-	BC 2	Storage
Eu 3	Baling, Storage	Lo 7	Chipping, Drying	Ga 1	-
		Lo 5	Chipping	Ga 3	Drying
		Lo 3	Drying	Ga 5	Chipping
		Lo 1	-	Ga 7	Chipping, Drying
		Lo 5	Chipping	Ga 9	Washing, Drying, Storage

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Feedstock at roadside (Chapter 2)		Logistics and biomass yard (Chapter 4)		Conversion plant (Chapter 3)	
Eu 3 (continued)	Baling, Storage (continued)	Lo 7	Chipping, Drying	Py 1	-
		Lo 5	Chipping	Py 3	Drying
		Lo 3	Drying	Py 5	Chipping
		Lo 1	-	Py 7	Chipping, Drying
		Lo 5	Chipping	Py 9	Washing, Drying, Storage
		Lo 7	Chipping, Drying	BC 1	-
		Lo 5	Chipping	BC 3	Drying
		Lo 3	Drying	BC 5	Chipping
		Lo 1	-	BC 7	Chipping, Drying
So 1	Chipping	Lo 4	Drying, Storage	Ga 1	-
		Lo 3	Drying	Ga 2	Storage
		Lo 2	Storage *2	Ga 3	Drying
		Lo 1	-	Ga 4	Drying, Storage
		Lo 1	-	Ga 9	Washing, Drying, Storage
		Lo 4	Drying, Storage	Py 1	-
		Lo 3	Drying	Py 2	Storage
		Lo 2	Storage *2	Py 3	Drying
		Lo 1	-	Py 4	Drying, Storage
		Lo 1	-	Py 9	Washing, Drying, Storage
		Lo 4	Drying, Storage *1	BC 1	-
		Lo 3	Drying	BC 2	Storage
		Lo 2	Storage *2	BC 3	Drying
		Lo 1	-	BC 4	Drying, Storage *1
So 2	Drying	Lo 6	Chipping, Storage	Ga 1	-
		Lo 5	Chipping	Ga 2	Storage
		Lo 2	Storage	Ga 5	Chipping
		Lo 1	-	Ga 6	Chipping, Storage
		Lo 5	Chipping	Ga 9	Washing, Drying, Storage *4

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Feedstock at roadside (Chapter 2)		Logistics and biomass yard (Chapter 4)		Conversion plant (Chapter 3)	
So 2 (continued)	Drying (continued)	Lo 6	Chipping, Storage	Py 1	-
		Lo 5	Chipping	Py 2	Storage
		Lo 2	Storage	Py 5	Chipping
		Lo 1	-	Py 6	Chipping, Storage
		Lo 5	Chipping	Py 9	Washing, Drying, Storage *4
		Lo 6	Chipping, Storage	BC 1	-
		Lo 5	Chipping	BC 2	Storage
		Lo 2	Storage	BC 5	Chipping
		Lo 1	-	BC 6	Chipping, Storage
So 3	Drying, Baling	Lo 6	Chipping, Storage	Ga 1	-
		Lo 5	Chipping	Ga 2	Storage
		Lo 2	Storage	Ga 5	Chipping
		Lo 1	-	Ga 6	Chipping, Storage
		Lo 5	Chipping	Ga 9	Washing, Drying, Storage *4
		Lo 6	Chipping, Storage	Py 1	-
		Lo 5	Chipping	Py 2	Storage
		Lo 2	Storage	Py 5	Chipping
		Lo 1	-	Py 6	Chipping, Storage
		Lo 5	Chipping	Py 9	Washing, Drying, Storage *4
		Lo 6	Chipping, Storage	BC 1	-
		Lo 5	Chipping	BC 2	Storage
		Lo 2	Storage	BC 5	Chipping
		Lo 1	-	BC 6	Chipping, Storage
Pyrolysis oil	-	Lo 1	-	Ga 10	Storage

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Table 5.2. Overview of all combinations of feedstock quality at roadside and logistic operations at the conversion plant which comprise doubling of operations, and which are therefore not relevant for further consideration.

Feedstock at roadside (Chapter 2)		Logistics and biomass yard (Chapter 4)		Conversion plant (Chapter 3)	
GR 1 So 1 Eu 1, 4-6	Chipping			Ga 5 – 8 Py 5 – 8 BC 5 – 8	Options including Chipping
GR 3	Drying, Chipping			Ga 3 – 8 Py 3 – 8 BC 3 – 8	Drying and/or Chipping
So 2	Drying			Ga/Py/BC 3, 4, 7, 8	Options including Drying
So 3	Drying, Baling			Ga/Py/BC 3, 4, 7, 8	Options including Drying
Eu 2	Drying, Chipping			Ga 3 – 8 Py 3 – 8 BC 3 – 8	Drying and/or Chipping
Eu 3	Baling, Storage			Ga/Py/BC 2, 4, 6, 8	Chipping, Drying, Storage

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5.3 Selected chains

From the former it became clear that a biomass logistical chain could be very simple in some cases because most of the pre-treatments, drying and storage are either done at the field/road side or after the gate of the conversion plant. In this case, only transport is part of the logistical chain. However, a logistical chain can also be more complex when it involves all possible activities of pre-treatments, drying, storage, handling and transport. Such a more complex logistical chain occurs when the on-field biomass pre-treatment is minimized to only harvesting and when the conversion plant concentrates entirely on the direct conversion of the pre-treated biomass when it enters the gate. In that case, a logistical chain will need to include an intermediate biomass collection point/biomass yard where biomass pre-treatment and storage can be organised.

Another important reason to work with an intermediate biomass collection point/biomass yard is when multiple biomass feedstocks have to be handled in a chain in order to create more security of supply of biomass at an acceptable price. Multiple-feedstocks are needed when there is not enough biomass of one type in the near distance to reach the minimal demand of the conversion plant. Whether a conversion process can handle multiple-feedstocks, needs to be evaluated in the conversion process experiments, but it also needs to be evaluated whether it is an efficient choice in a chain organisation. Biomass pre-treatment could be an option to create more uniform quality in the feedstock in spite of the multiple biomass feedstocks.

The optimal organisation of the chain, especially in relation to the distribution of activities in the three parts of the biomass delivery chain, is something that needs to be tested in the case studies of BECOOL. These case studies need to be areas where at least one of the four biomass types studied in BECOOL will be available at large enough quantities in the near future.

For the testing of the logistical chains is case studies the following situations will need to be covered in combination or as single factors in one or more case studies (see Table 5.3):

1) Variation of biomass types: the four different biomass types;
2) Variation of available biomass quantities due to the regional spatial dispersion situations of the biomass: low biomass availability because of spatially very dispersed biomass versus high biomass availability due to spatial concentration of the biomass;
3) Variation of conversion processes: the three different types;
4) Variation of the biomass value chain organization: either direct transport from the field to the conversion installation (with most pre-treatments and storage at field or at the conversion installation point) or passing through an intermediate collection points/biomass yard (where all pre-treatments and storage are done);
5) Mono-feedstock sources versus multiple feedstock sourcing.

In Table 5.3 an overview is presented of possible variations in combinations of these factors that could be tested in case studies.

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Table 5.3 Logistics chain options and case selection options

Biomass type (1)	**Available quantity (within 100 km radius) (2)**	**Type conversion process and minimal biomass need (ton DM/year) (3)**	**Biomass value chain organisation - Direct transport field to conversion or with intermediate collection point/biomass yard (4)**	**Mono-feedstock or multi-feedstock possibly combined with feedstock from point source (5)**
Giant reed (Arundo donax)	Low availability – High spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Gasification (minimal 200,000 ton dm/y)	Direct transport from field to conversion installation	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Agricultural lignocellulosic residues (straw, stubbles from arable crops as second feedstock • Biomass sorghum as a additional crop on existing arable land
Giant reed (Arundo donax)	Low availability – High spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Gasification (minimal 200,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Additional point source feedstock (from EU and overseas)
Giant reed (Arundo donax)	Low availability – High spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Pyrolysis (35,000 ton dm/y)	Direct transport from field to conversion installation	• Mono-feedstock
Giant reed (Arundo donax)	Low availability – High spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Pyrolysis (35,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multi-feedstock
Giant reed (Arundo donax)	Low availability – High spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Biochemical conversion into biofuel (minimal 100,000 ton dm/y)	Direct transport from field to conversion installation	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Agricultural lignocellulosic residues (straw, stubbles from arable crops as second feedstock • Biomass sorghum as a additional crop on existing arable land

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Biomass type (1)	**Available quantity (within 100 km radius) (2)**	**Type conversion process and minimal biomass need (ton DM/year) (3)**	**Biomass value chain organisation - Direct transport field to conversion or with intermediate collection point/biomass yard (4)**	**Mono-feedstock or multi-feedstock possibly combined with feedstock from point source (5)**
Giant reed (Arundo donax)	Low availability – High spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Biochemical conversion into biofuel (minimal 100,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Additional point source feedstock (from EU and overseas)
Giant reed (Arundo donax)	Medium availability – Intermediate spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Gasification (minimal 200,000 ton dm/y) or Pyrolysis (35,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Additional point source feedstock (from EU and overseas)
Giant reed (Arundo donax)	Medium availability – Intermediate spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Pyrolysis (35,000 ton dm/y)	Direct transport from field to conversion installation	• Mono-feedstock
Giant reed (Arundo donax)	Medium availability – Intermediate spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Biochemical conversion into biofuel (minimal 100,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Additional point source feedstock (from EU and overseas)
Eucalyptus SRC or MRC	Medium availability – Intermediate spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Gasification (minimal 200,000 ton dm/y) or Pyrolysis (35,000 ton dm/y)	Direct transport from field to conversion installation	• Mono-feedstock • Only Eucalyptus (SRC or MRC)
Eucalyptus SRC or MRC	Medium availability – Intermediate spatial dispersion on marginal lands (agricultural-abandoned/ forest-abandoned)	Pyrolysis (35,000 ton dm/y)	Direct transport from field to conversion installation	• Mono-feedstock • Only Eucalyptus (SRC or MRC)
Eucalyptus SRC or MRC	Medium availability – Intermediate spatial dispersion on marginal lands (agricultural-	Biochemical conversion into biofuel (minimal	Direct transport from field to conversion installation	• Mono-feedstock • Only Eucalyptus (SRC or MRC)

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Biomass type (1)	Available quantity (within 100 km radius) (2)	Type conversion process and minimal biomass need (ton DM/year) (3)	Biomass value chain organisation - Direct transport field to conversion or with intermediate collection point/biomass yard (4)	Mono-feedstock or multi-feedstock possibly combined with feedstock from point source (5)
	abandoned/ forest-abandoned)	100,000 ton dm/y)		
Eucalyptus SRC or MRC	Medium availability – Intermediate spatial dispersion on marginal lands (agricultural-abandoned/ forest-abandoned)	Biochemical conversion into biofuel (minimal 100,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multi-feedstock • Also other woody residues in region • Imported wood residue chips
Eucalyptus SRC or MRC	High availability – High concentration on marginal/ forest land	Gasification (minimal 200,000 ton dm/y)	Direct transport from field to conversion installation	• Mono-feedstock • Only Eucalyptus (SRC or MRC)
Eucalyptus SRC or MRC	High availability – High concentration on marginal/ forest land	Gasification (minimal 200,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multi-feedstock • Also other woody residues in region • Imported wood residue chips
Biomass sorghum	Medium availability – High-intermediate spatial dispersion (on marginal-unused/ abandoned lands) with low per ha yield	Gasification (minimal 200,000 ton dm/y) or Pyrolysis (35,000 ton dm/y)	Direct transport from field to conversion installation	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Agricultural lignocellulosic residues (straw, stubbles from arable crops as second feedstock
Biomass sorghum	High availability – High concentration on marginal land	Gasification (minimal 200,000 ton dm/y)	Direct transport from field to conversion installation	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Agricultural lignocellulosic residues (straw, stubbles from arable crops as second feedstock
Biomass sorghum	High availability – High concentration on marginal land	Gasification (minimal 200,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Agricultural lignocellulosic residues (straw, stubbles from arable crops as second feedstock

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Biomass type (1)	**Available quantity (within 100 km radius) (2)**	**Type conversion process and minimal biomass need (ton DM/year) (3)**	**Biomass value chain organisation - Direct transport field to conversion or with intermediate collection point/biomass yard (4)**	**Mono-feedstock or multi-feedstock possibly combined with feedstock from point source (5)**
Biomass sorghum	Medium availability – Intermediate spatial dispersion on marginal lands (agricultural-abandoned/ forest-abandoned)	Biochemical conversion into biofuel (minimal 100,000 ton dm/y)	Direct transport from field to conversion installation	• Multi-feedstock • Security of feedstock supply cannot be expected from new crop on abandoned lands • Agricultural lignocellulosic residues (straw, stubbles from arable crops as second feedstock
Biomass sorghum	Medium availability – Intermediate spatial dispersion on marginal lands (agricultural-abandoned/ forest-abandoned)	Biochemical conversion into biofuel (minimal 100,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multi-feedstock • Ssecurity of feedstock supply cannot be expected from new crop on abandoned lands • Agricultural lignocellulosic residues (straw, stubbles from arable crops as second feedstock
Biomass sorghum	Medium availability – Intermediate spatial dispersion on marginal lands (agricultural-abandoned/ forest-abandoned)	Pyrolysis (35,000 ton dm/y)	Direct transport from field to conversion installation	• Mono-feedstock
Lignin rich residue	High availability – High volume at point source	Gasification (minimal 200,000 ton dm/y)	Direct transport from site of biochemical conversion to next conversion installation	• Mono-feedstock
Lignin rich residue	High availability – High volume at point source	Pyrolysis (35,000 ton dm/y)	Direct transport from site of biochemical conversion to next conversion installation	• Mono-feedstock

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Further point to take into account during the final case study selection are:

- Choose regions with a high share of abandoned marginal lands where the chosen crops (Giant reed, Eucalyptus and Biomass Sorghum) can be grown;
- Choose regions with available residues from agriculture or forestry;
- Choose regions with the possibility to use biomass from point sources like harbours (imports) or food processing industries (residues).

Although the three chosen biomass crop types are especially suitable for southern European countries like Spain, Italy and Greece, they can also be representative for a larger part of Europe than Mediterranean only. For example, in the S2Biom project it was shown that Giant Reed and Eucalyptus (and also Sorghum) can be grown even in central Europe although they might reach lower biomass yields there. However, this is common to most crops outside their preferred climatic zone. In the BECOOL project there will also be two case studies (according to GA) focusing on conversion plants in Finland (VTT) and the Netherlands (BTG). Furthermore, the last two BECOOL feedstocks (and value chains) are lignin rich and bagasse (sugar cane) which can obviously be replicated in all parts of Europe as they are residues and not geographically dependent crops. Apart from the biomass type, the logistical concepts should have the possibility to be easily extended to other regions of Europe when similar type biomass are used, or when large amounts of biomass produced in central/southern Europe are transported to plants located in North Europe. So the studied value chains can be replicated not only in Italy, Spain or southern EU countries but also in many other parts of Europe.

5.4 Further steps

From the large amount of logistical chain options presented in this chapter WP5 (Task 5.1) will make a sub selection of chains to be tested in case study regions. This sub-selection of biomass logistical chains will also serve as input for the further testing of logistical concepts with the logistical assessment tools in tasks 2.2 and 2.3 in the case study regions.

In Task 2.2, the existing logistical assessment tools BeWhere, LocaGIStics and Bioloco will be further adapted in order to evaluate at least the sub-selection of logistical chains made and presented in this report.

In Task 2.3, the sub-selection of the logistical chains presented in this report will be evaluated in the selected case study regions with the adapted logistical assessment tools further adapted in Task 2.2.

It has to be ensured that the value chains covering a specific sub-selection of logistical concepts that are evaluated in tasks 2.2 and 2.3 deliver relevant output on the logistical chains to WP5 where the integrated sustainability assessment of whole value chains is made. The sub-selected chain designs presented in this report will also deliver the basis for the calculation of cost-supply curves for different combinations of biomass feedstock and conversion technologies in the full biomass delivery chains designed and evaluated in tasks 2.2 and 2.3.

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Annex A. Logistical components

1. Comminution (size reduction)

- chipping
  - disk chippers
  - drum chippers
  - screw chippers
- chunking
- crushing
- debarking
- grinding
  - hammer mill
  - horizontal grinder
  - tub grinder
- milling
- screening
  - disk screen
  - drum screen
  - flip-flow screen
  - star screen
- shredding

2. Compaction/densification

- briquetting
- centrifugation
- pelletizing
- bundling

3. Drying

- active/forced drying (artificial)
  - belt dryer
  - dryer equipment
  - heating with residual heat
  - rotary drum dryer
  - ventilation with fans or blowers
- passive drying (natural)
  - inside in barn
  - outside covered
  - outside in open air and sun

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4. Feedstock handling

- bucket grab
- conveyor
  - belt
  - bucket
  - chain
  - screw
- crane
  - wood crane
- front loader
- gravity feed
- intake system
- loading/unloading system
  - ship
  - train
  - truck
- pneumatic blower
- pumped flow
- screw type auger feed
- shovel
- squeeze loader
- stacker
- telehandler
- tipping platform (raising front of trailer)

5. Other pre-treatments that influence feedstock quality

- biological pre-treatments (fungi)
- blending
- conservation (e.g. silage)
- de-watering
- separation (e.g. S/L)
- sieving
- sorting out metal with a magnet
- ultrasonic pre-treatment
- washing

6. Storage (a combination of several characteristics below)

- indoors versus outdoors
- covered versus uncovered
- base type: asphalt, bare soil, bearers or concrete floor
- permanent storage structure type: bunker, container, silo or tank
- temporary bulk form type: big bag, ensiled, pile or stack

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7. Transportation technologies

- Inland waterway
  - deck barge
  - dry bulk cargo barge
  - hopper barge
  - tug-boat
- Maritime
  - handymax bulk carrier
  - handysize bulk carrier
  - Panamax bulk carrier
- Rail
  - closed bulk wagon
  - closed wagon with rolling roof
  - open bulk wagon
  - open wagon
  - wagon suitable for 3 TEU containers
  - wagon suitable for WoodTainersystem
- Road
  - bulk van/chip van
  - farm trailer
  - flatbed trailer
  - log trailer
  - open-end bulk van
  - removable cargo container lorry/trailer
  - tanker, grain or animal feed vehicle
  - timber haulage wagon
  - tipper trailer or truck
  - walking floor trailer/self-unloading floor/live floor

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