Ref. Ares(2018)2956017 - 06/06/2018

Project acronym: BECOOL

Project full title: Brazil-EU Cooperation for Development of Advanced Lignocellulosic Biofuels
Grant Agreement Number: 744821

Project start date: 01.06.2017

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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Reviewers	UNIBO
Date:	18/5/2018 (submission due date 31/5/2018, M12)

Dissemination Level: Public

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

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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 Work package 5 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 WP 5. 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 but 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 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.

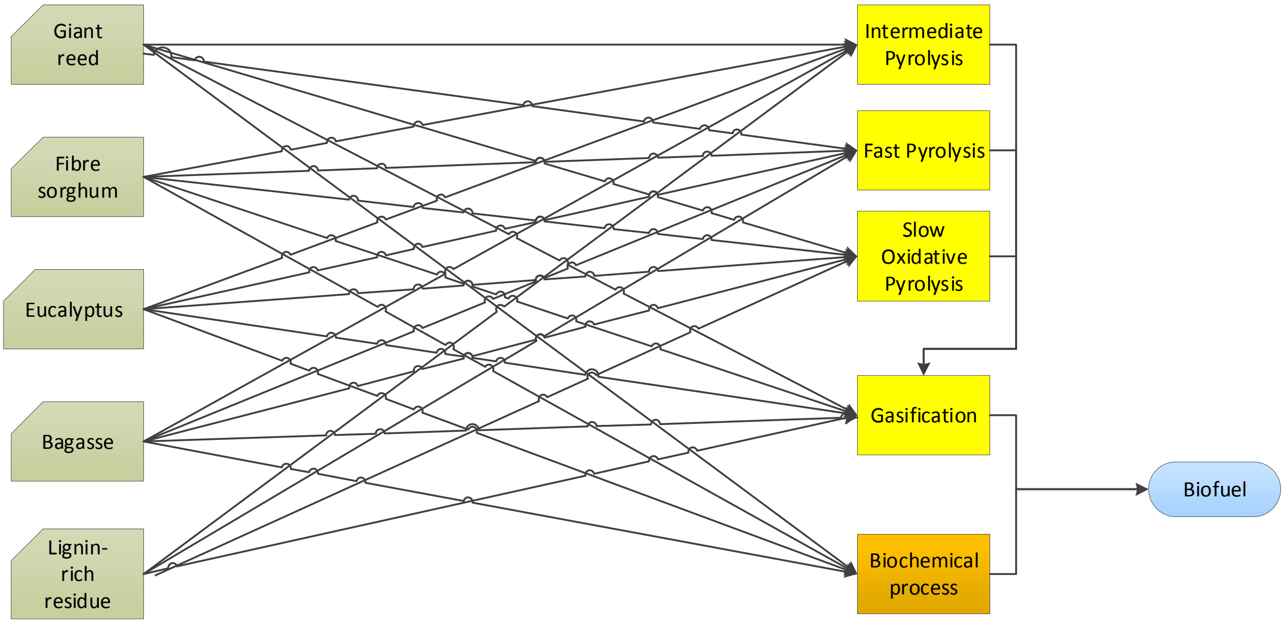

Figure 1.1 Possible combinations of biomass types and conversion technology options to be covered in the BECOOL project.

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[1] and a knowledge base for the design of the exemplary logistical chains presented in this report.

1.5 Outline report

The next chapter 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 road side.

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 treatment options which can possibly be integrated with the location where the conversion location is. So all relevant details as from plant gate to conversion are presented in chapter 3.

Chapter 4 describes the logistical principles and logistical organisation options between road side and conversion plant gate. It presents the different options for organisation of the logistical chain which 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 road side (Chapter 2), the different logistical organisation options described in Chapter 4 and the different specific biomass requirements by the conversion technologies (Chapter 3).

The final chapter 6 presents the main conclusions and further steps in the BECOOL project in relation to logistical chain design and evaluation.

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[1] See: http://s2biom.alterra.wur.nl/web/guest/report-downloads or http://www.s2biom.eu/en/publications-reports/s2biom.html

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 road side 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 road side 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 road side. 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 widely 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 is 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 biomass properties)[2] is common. The ash content is relatively high ranging around 6% and the ash melting temperature is below 1000 ˚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,

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

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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).

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 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 also increase the impurities in the harvested product[3].

After harvest, the giant reed needs to be reduced in size and dried in order to comply to 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).

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[3] 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 (see Assirelli et al., 2018)

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 convert this herbaceous biomass in valuable products which 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 (see Von Cossel et al., 2018)[4]. In BECOOL it will be further reviewed if land is available and accessible that is not attractive (anymore) for food production.

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[4] Von Cossel, M., Iqbal, Y., Scordia, D., Cosentino, S.L., Elbersen, B., Staritsky, I., Van Eupen, M., Mantel, S.d, Prysiazhniuk, O.e, Maliarenko, O., Lewandowski, I. (2018). Deliverable 4.1: Low-input practices for industrial crops on marginal lands. MAGIC project EU Horizon 2020 | MAGIC | GA No 727698

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 (%)[5]**	**Harvesting time**
Giant reed (Arundo donax)	• high WUE • rhizomes (1 year gain) or micro-pragated plants (more economic than rhizoms). Also plantlets are adapted for transplanting machineries • fertilisation 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 fertilisation and harvesting time (in winter lower ash)	Cell: 33% (27% – 44%) Hemi: 27% (26% – 28%) Lign: 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%	• Low • Depends on fertilisation and harvest time • SRC comes with more leaves and bark • Ash: 2%	40 - 50% cellulose and hemicellulose Cell: 43% (9% – 57%) Hemi: 25% (8% – 44%) Lign: 23% (9% – 37%)	• every 2 years (SRC) • every 4 years (MRC) • in southern Europe Dec - Mar
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%) Lign: 9% (6% – 16%)	• September – early October

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

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 (%)[5]**	**Harvesting time**
Residues from Sweet (grain) sorghum	The residues from grain sorghum (straws) 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 pl m-2.	Yields straw are variable depending on soil, cultivars, environ. conditions, etc. In general straw yield in range of 5-7 Mg ha-1.	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	• Harvesting is usually done at the end of august, beginning September.
Lignin rich residue	• from bioethanol plant	140 ton FM/day (at Crecentino plant) (140*0.4=56 ton DM)	50 – 60 55-65 *2	• Ash: 5 – 15 *2	Lignin: 50 – 60 *2 Carbohydr: 30 – 35	• 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 logistic concept.

DM = dry matter; FM = fresh matter

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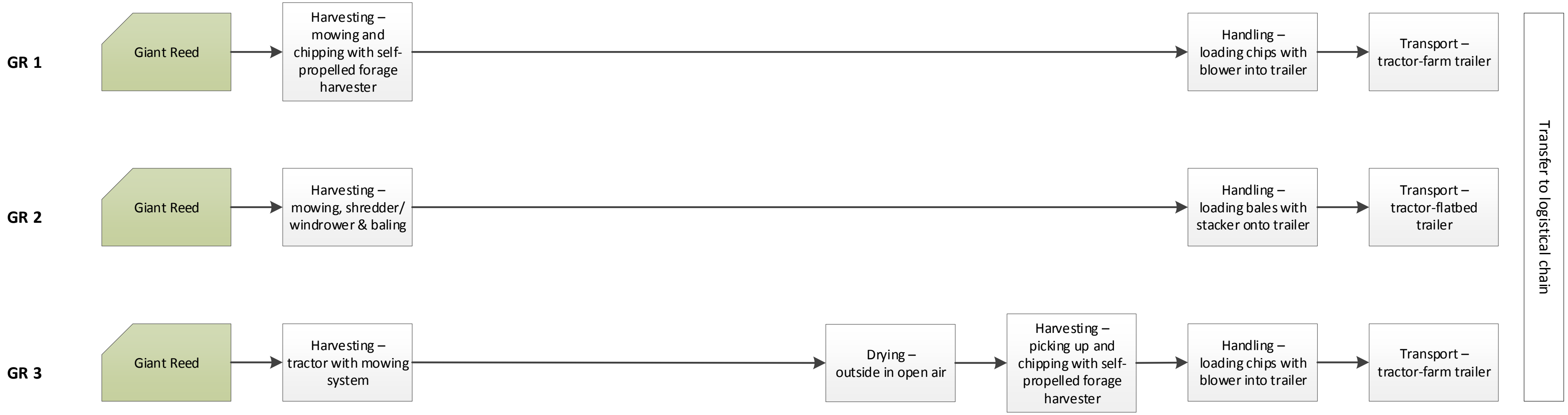

Figure 2.1 Possible harvesting systems for giant reed, up to roadside.

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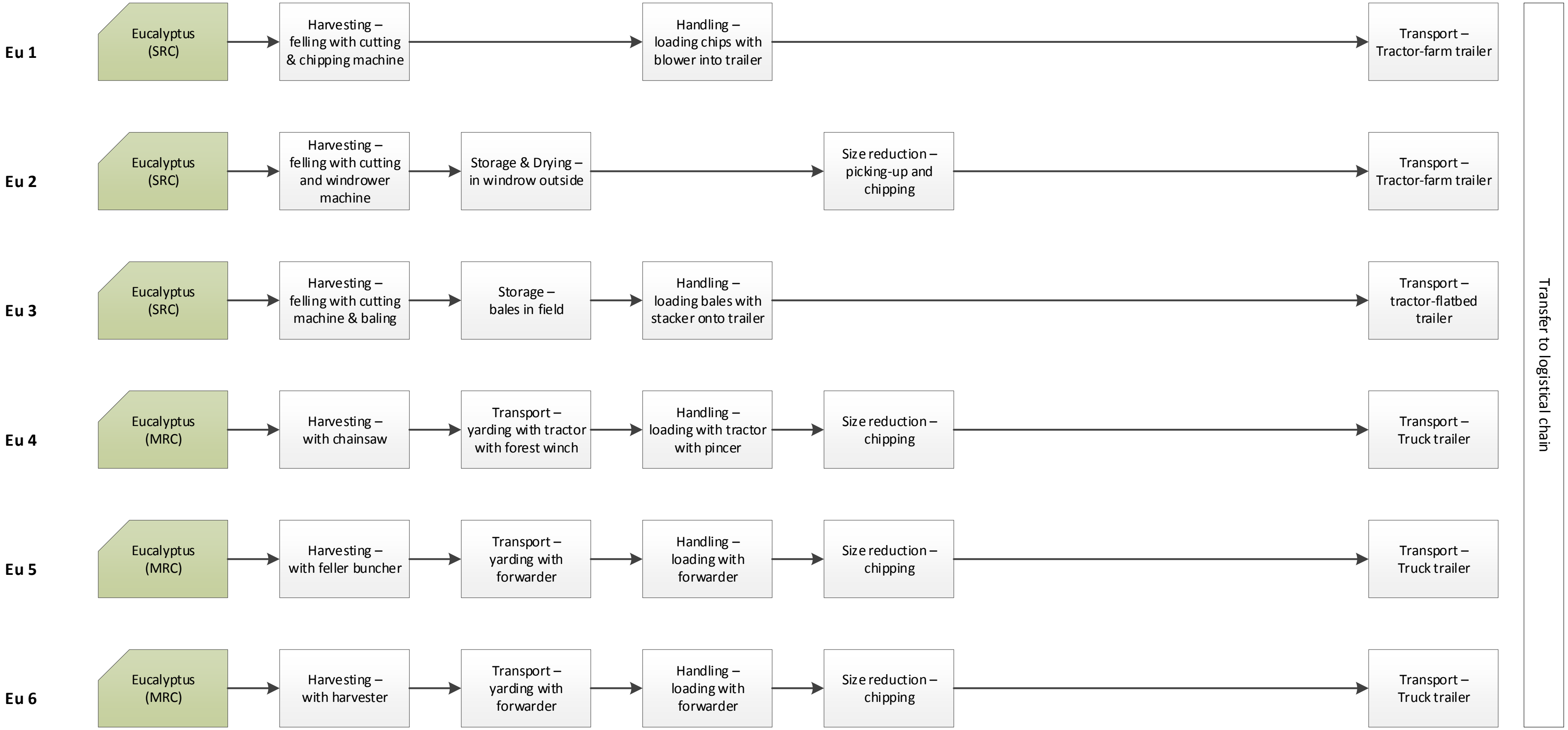

Figure 2.2 Possible harvesting systems for Eucalyptus, up to roadside.

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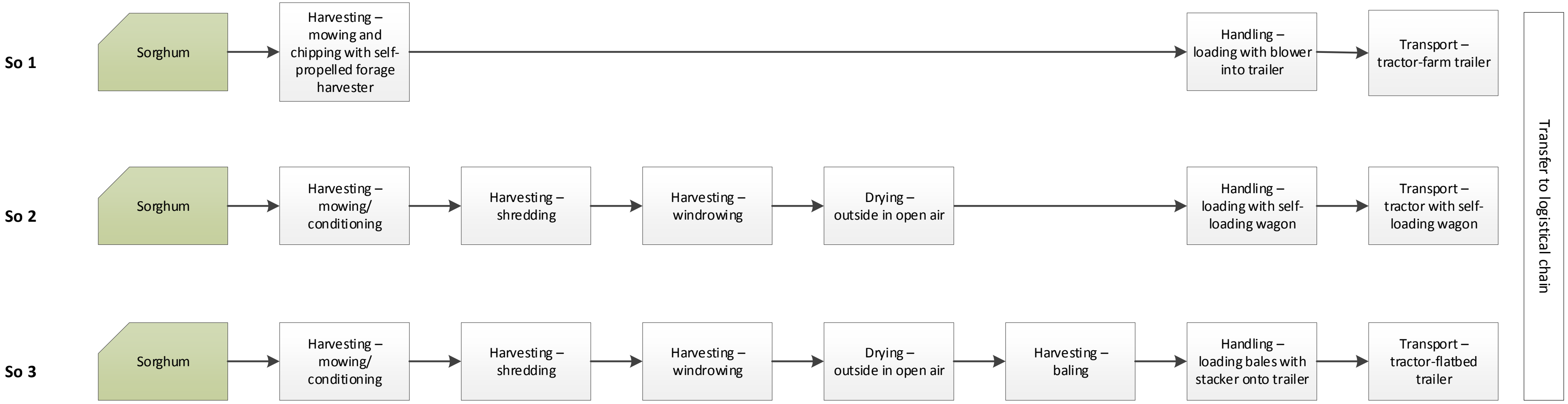

Figure 2.3 Possible harvesting systems for Sorghum, up to roadside.

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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	• proporton 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 (so 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 avarage length of 1 cm with a remarkable pressence 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	• single plant conditioner (Cressoni)	• low moisture content • high bulk density	• cost to collect the bales

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 biothanol conversion plant	• Logistical 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	• None

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2.2.2 Eucalyptus

The eucalyptus ranges from 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 rain fall (Khuspe et al, 1987). The eucalypts 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 biomass properties)[6]. The ash content is quite low (around 2%) and the ash melting point is around 1330 ˚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, our slow oxidative pyrolysis unit has this 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 equals 50%, but wood biomass can usually be dried further easily and cheaply at road side at the place of harvest. There are two different cropping system which will be tested in BECOOL: the SRC (short rotation cropping) is the harvest of the trees for every 2-3 years and the MRC (medium rotation cropping) is the harvest of the trees for every 4-5 years. The SRC and MRC biomass have different characteristics. The main difference characterizing the harvesting system is the base diameter of the plants when harvested , if lower than 15 cm an SRC harvester can be utilised if higher than 15 cm a forestry system have 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, which is under investigation how this affects the pyrolysis. Storing eucalyptus lowers its volatiles over time and can be stored at roadside easily.

For each cropping system 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 1 and system 3 in Table 2.3). In system 1, the biomass is chipped in the field which 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 up 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 3 involves cutting and baling. The Biobaler is a machine developed in Canada that untill now has not a wide use in Europe (there are 1-2 machines in Europe). The biomass is then transported to storage en/or conversion installation. The disadvantages of system 3 are:

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

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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 an higher ash content due to the presence of leaves and soil particles.

The system 2 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 the system two machine passes are required however and this may lead to higher cost.

For the MRC cropping system there are also 3 harvesting systems tested (see Table 2.3). The cutting of the trees is operated by manual chainsaw in the system 1, by a feller buncher in system 2 and by a harvester in system 3. 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 1 and by a forwarder in system 2 and 3. The three systems have some advantages which manly 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 2 and 3 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 land owners 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[7].

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 (biomass types). 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 high lignocellulose biomass accumulation potential. The biomass properties of the 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 therefore makes it more suitable for biochemical conversion then for thermochemical. However, if the leaves and stems can be separated in the harvest process the stem with lower ash content can still go into thermochemical conversion. The 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.

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[7] Von Cossel, M., Iqbal, Y., Scordia, D., Cosentino, S.L., Elbersen, B., Staritsky, I., Van Eupen, M., Mantel, S.d, Prysiazhniuk, O.e, Maliarenko, O., Lewandowski, I. (2018). Deliverable 4.1: Low-input practices for industrial crops on marginal lands. MAGIC project EU Horizon 2020 | MAGIC | GA No 727698

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, which 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 cultivation is possible (similar to maize) and it is suitable for low input practices. High number of varieties with very different characteristics and N content in leaves is much higher than in the stems. Currently, the seed companies do not have well defined varieties for biomass (fibber) surghum production purpose. Currently one can find under the umbrella of biomass sorghum a wide range of varieties with high level of sucrose also, which may not be ideal for some conversion processes.

Harvest 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 this is costly and leads to worse GHG efficiency (Athens workshop).

The advantage of fibre sorghum over other types of sorghum is that they are not for human consumption and doesn't 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 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 and by a machine developed by *Cressoni Enterprise* in order to conditioning 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 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.

Alternatively 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.

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 and 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 is 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. This procedure will release gasses (syngas) from the biomass. The temperature of gasification usually lies between 800-1000°C. 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).

As to moisture in biomass, this content should be below 25% when it goes into the conversion process. Since moisture content from most biomass when harvested is far above this level, drying should be a key pre-treatment in the logistical chain, included therefore in all biomass delivery chains, but can be done in the field already, before the biomass enters the plant gate in a decentral biomass treatment location (or biomass yard) or within the plant gate of a conversion installation (see Figure 3.1, options Ga 3, 4, 7, 8 and 9).

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 between 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 200 Kton dm input per year. A possible option for most biomass feedstock is to carry out an initial pyrolysis stepin order to increase the energy density of the

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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 feedstock for the gasifier (Option Ga 10 in Figure 3.1).

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 most likely unless the plant is sourced from a biomass yard located in the near distance of the plant.

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 NOx emissions. This may lead to high emission reduction measures and will make the conversion technology more expensive.

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.

3.2.2 Pyrolysis

Pyrolysis process consists in heating an organic matter without the presence of air (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 output are different quantities of these product. 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 consists in the hot vapour residence time. The condensed product is the bio-oil, which is produced in 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 maximized in the slow pyrolysis process. The pyrolysis should function as a method of increasing the bulk (energy) density of the feedstock for cheaper transport and to increase 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 which 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 within 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 20 t/h which amounts to around 35.000 ton DM/year.

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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.

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 (800 – 1000°C)	200,000 (10/20 ton/h at 50 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	Low nitrogen content is preferred as leads to lower NOx emissions
Pyrolysis (fast, intermediate & oxidative) (500°C)	35,000 (4 ton/h at 20 MW)	Preference for low ash content (<5%) (separate low and high ash content biomass before	Low	Low	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	Low nitrogen content is preferred as leads to lower NOx emissions
Biochemical conversion to advanced bio-ethanol	100,000	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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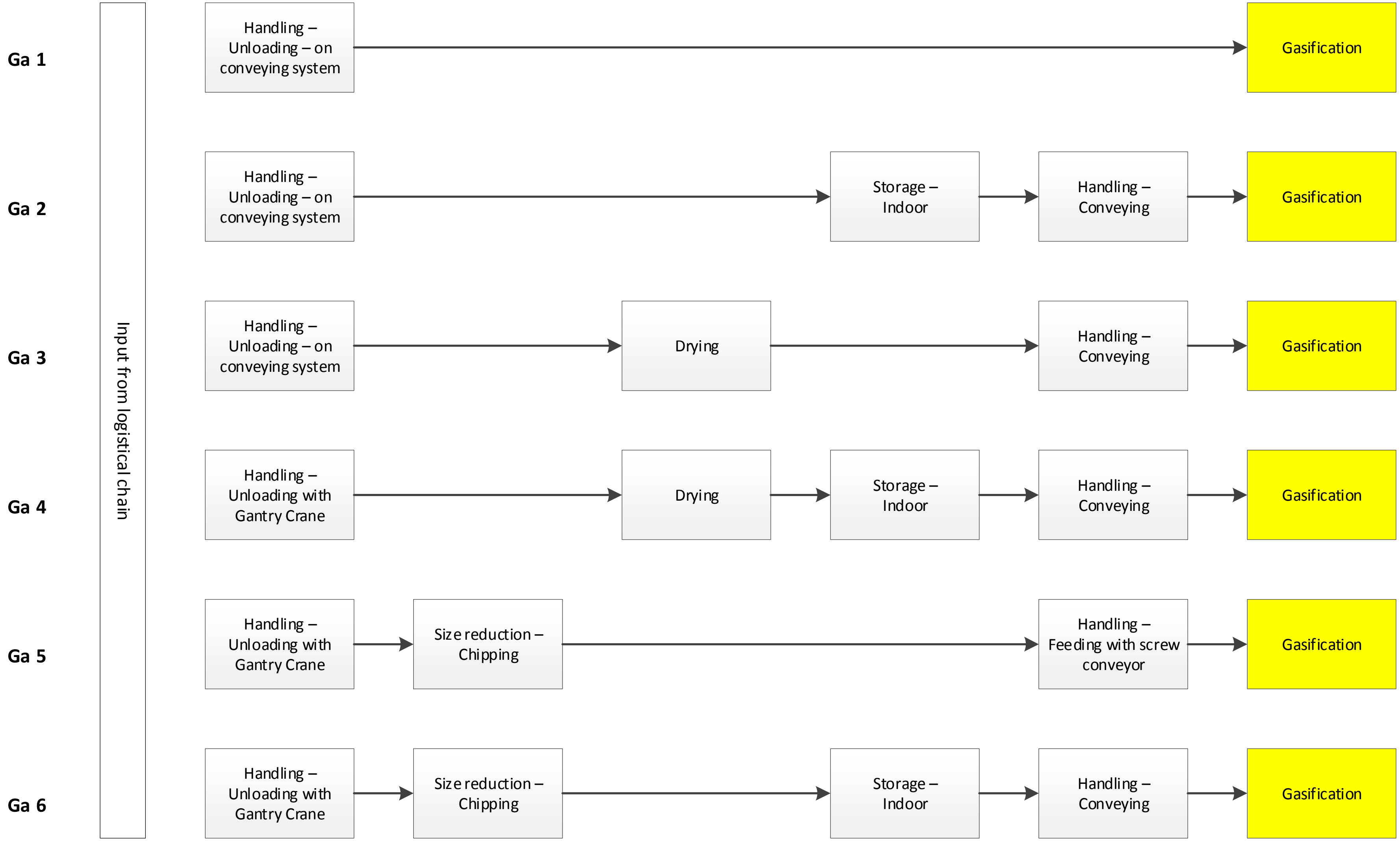

Figure 3.1a Possible set-ups of on-site operations of gasification conversion technology.

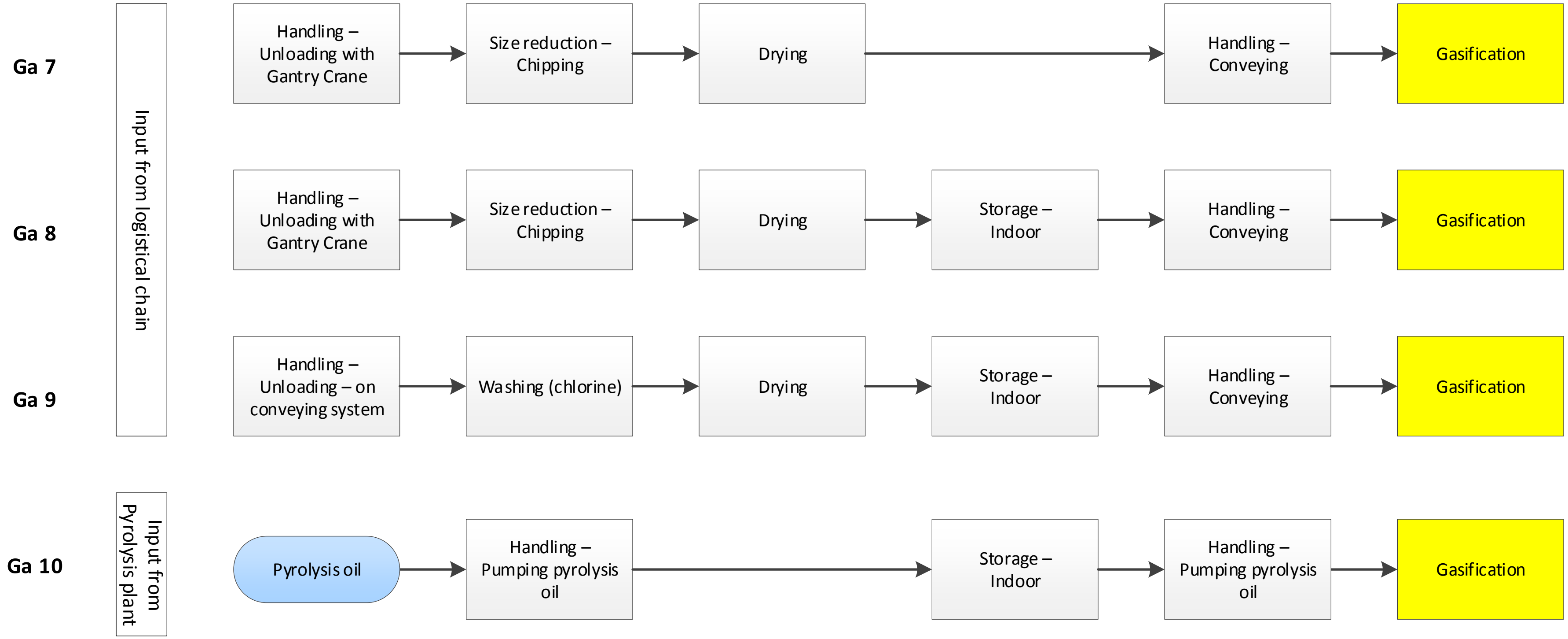

Figure 3.1b Possible set-ups of on-site operations of gasification conversion technology (continued).

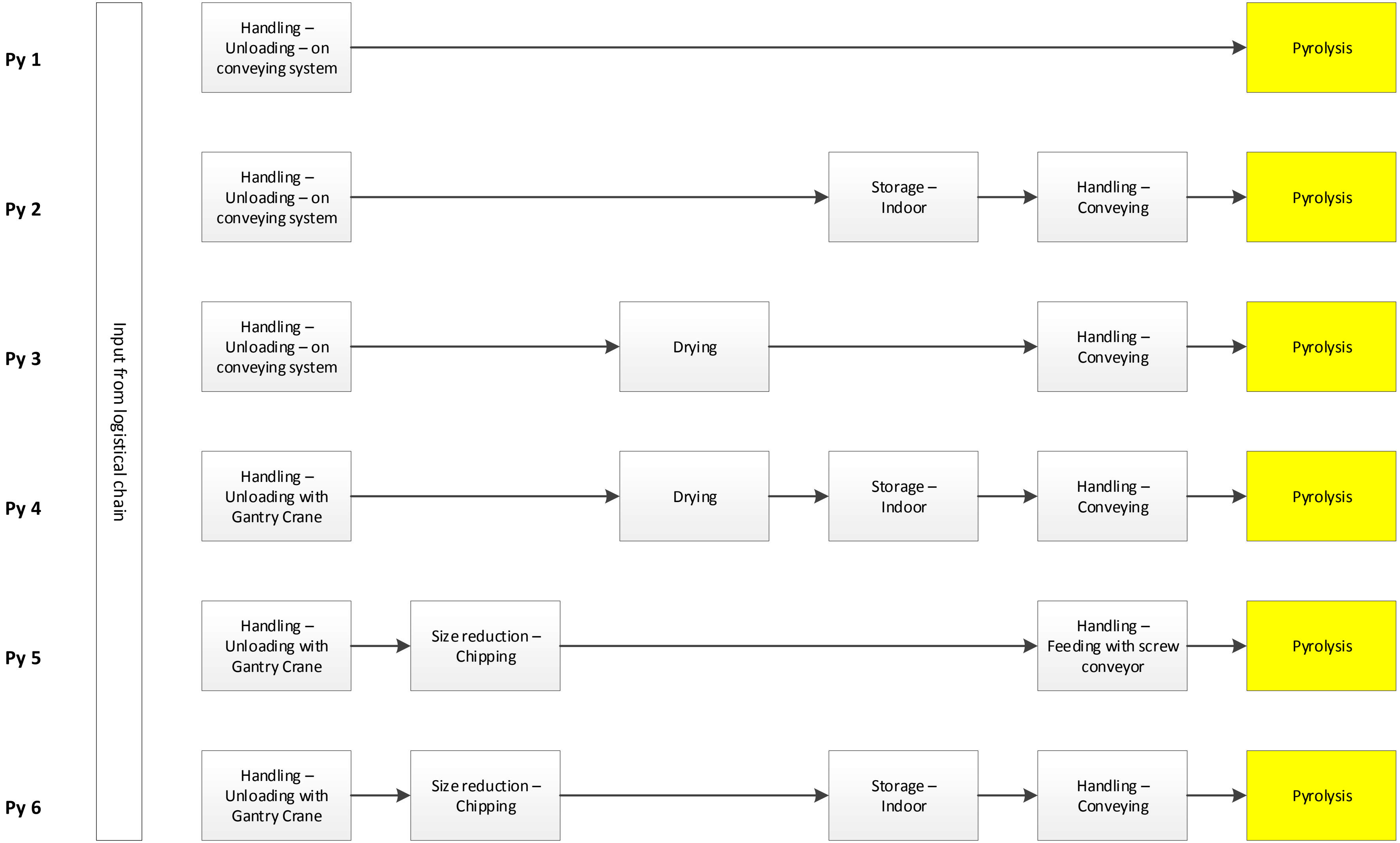

Figure 3.2a Possible set-ups of on-site operations of pyrolysis conversion technology.

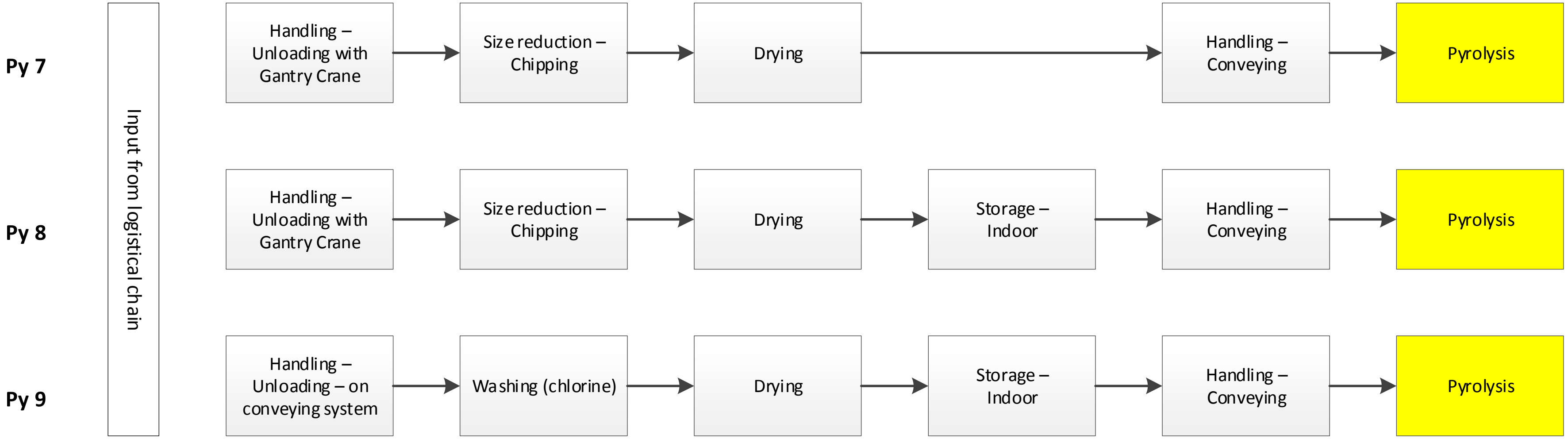

Figure 3.2b Possible set-ups of on-site operations of pyrolysis conversion technology (continued).

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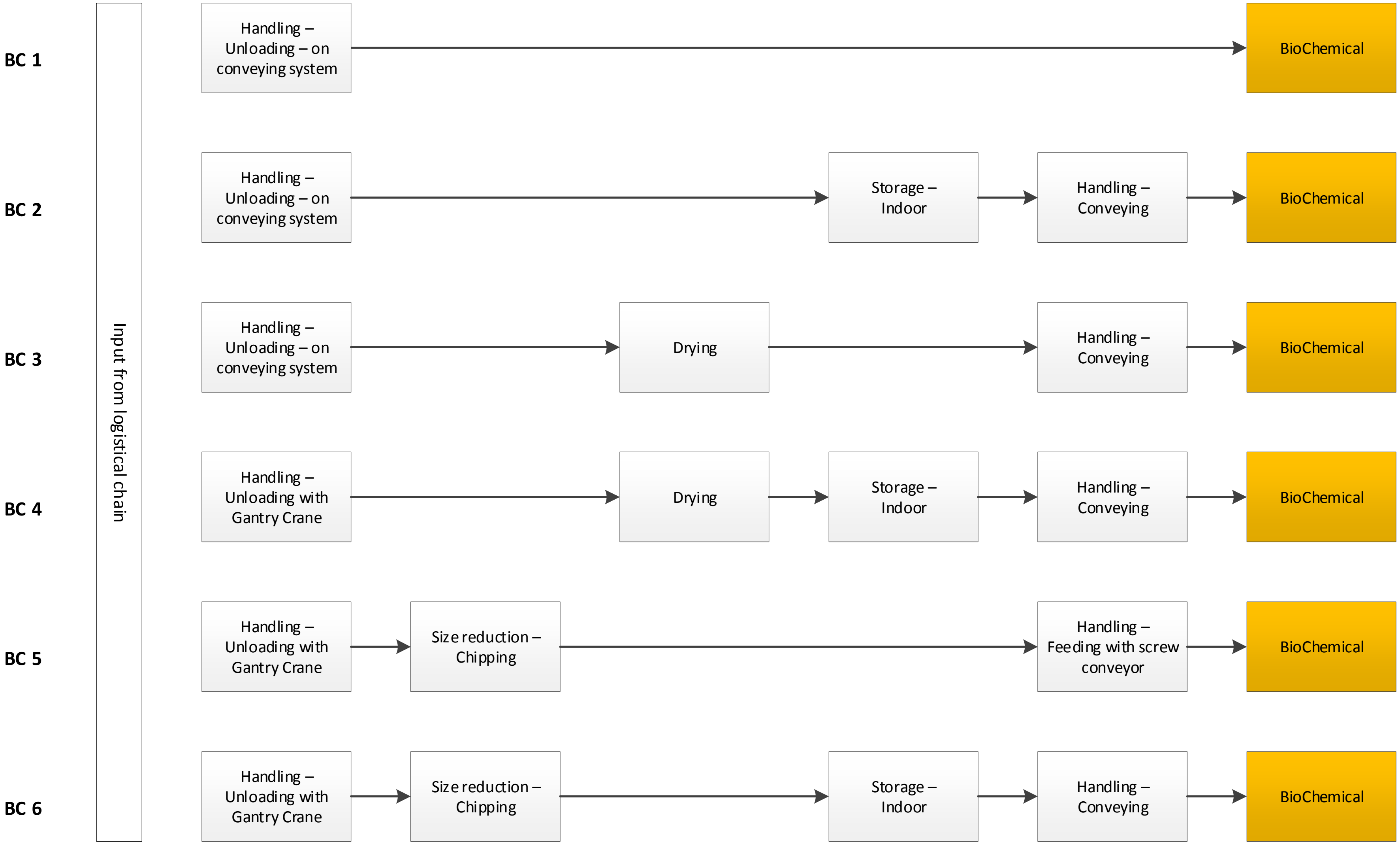

Figure 3.3a Possible set-up of on-site operations of biochemical conversion technology.

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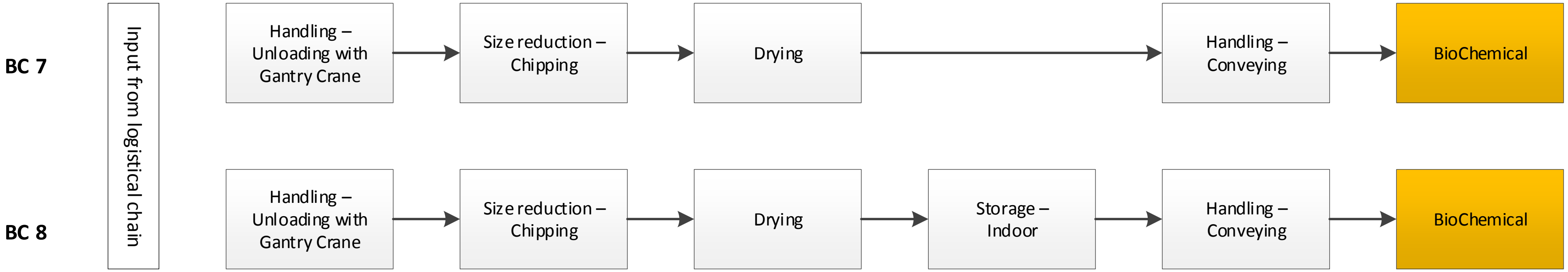

Figure 3.3b Possible set-up of on-site operations of biochemical conversion technology (continued).

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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 micro-organism 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.

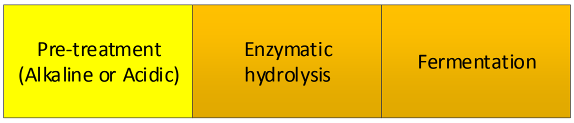

Figure 3.4 Scheme of subsequent steps in biochemical conversion technology.

In this biochemical process there is a preference for high carbohydrate biomass, specifically cellulose and hemicellulose as these can be converted into sugars relatively easily, 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 micro-organisms. Furthermore, as explained by Elbersen et al. (2016), lignin acts as a shield that prohibits the bio-conversion 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 however. It remains in the co-product, the lignin-rich residue. This implies however 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 projects 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 4.2 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 this and final chapter 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.

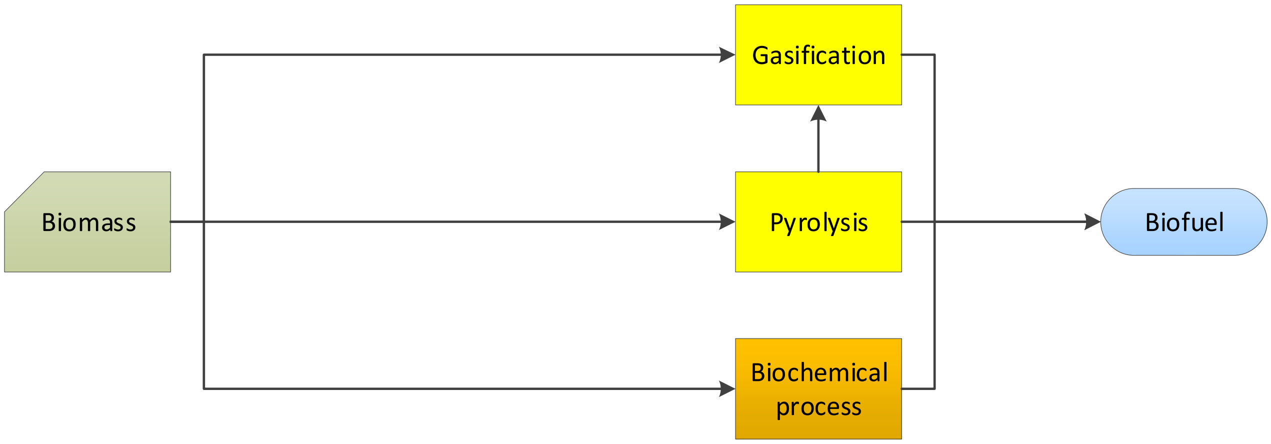

Figure 4.1 General biomass value chain options.

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.

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However, many other feedstock characteristics are much more challenging to be influenced by the logistic chain. Those characteristics need to be addressed by the final conversion technology itself like:

- chlorine content;
- ash deformation temperature;
- ash content;
- nitrogen content;
- feedstock composition.

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.

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.

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 intermeadiate 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. So storage is inevitable when biomass is needed year-round. The location where this is 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 near as possible to 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 biomass. This implies that biomass treatments near the biomass sources are crucial to bring down the cost of transport which 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/road side;
- 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 the figures underneath 8 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);
- multi-feedstock with local sourcing or local sourcing and point sourcing (harbour and or trainstation) (Figure 4.3)

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. And the biomass yard can supply one or more conversion installations in the wider local region or further away region with a mix of feedstocks.

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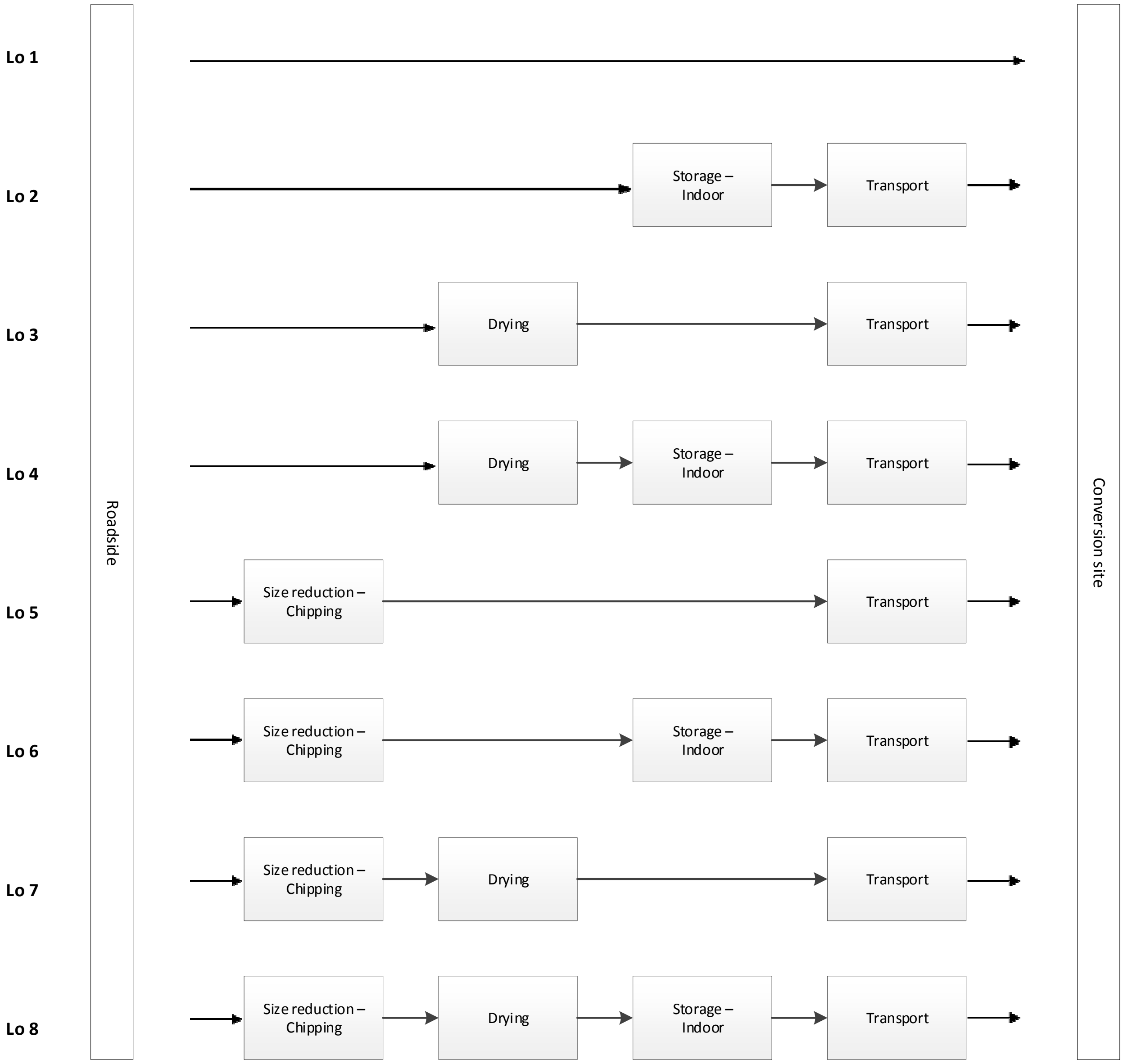

Figure 4.2. Possible set-ups of logistical chain from roadside to conversion plant gate.

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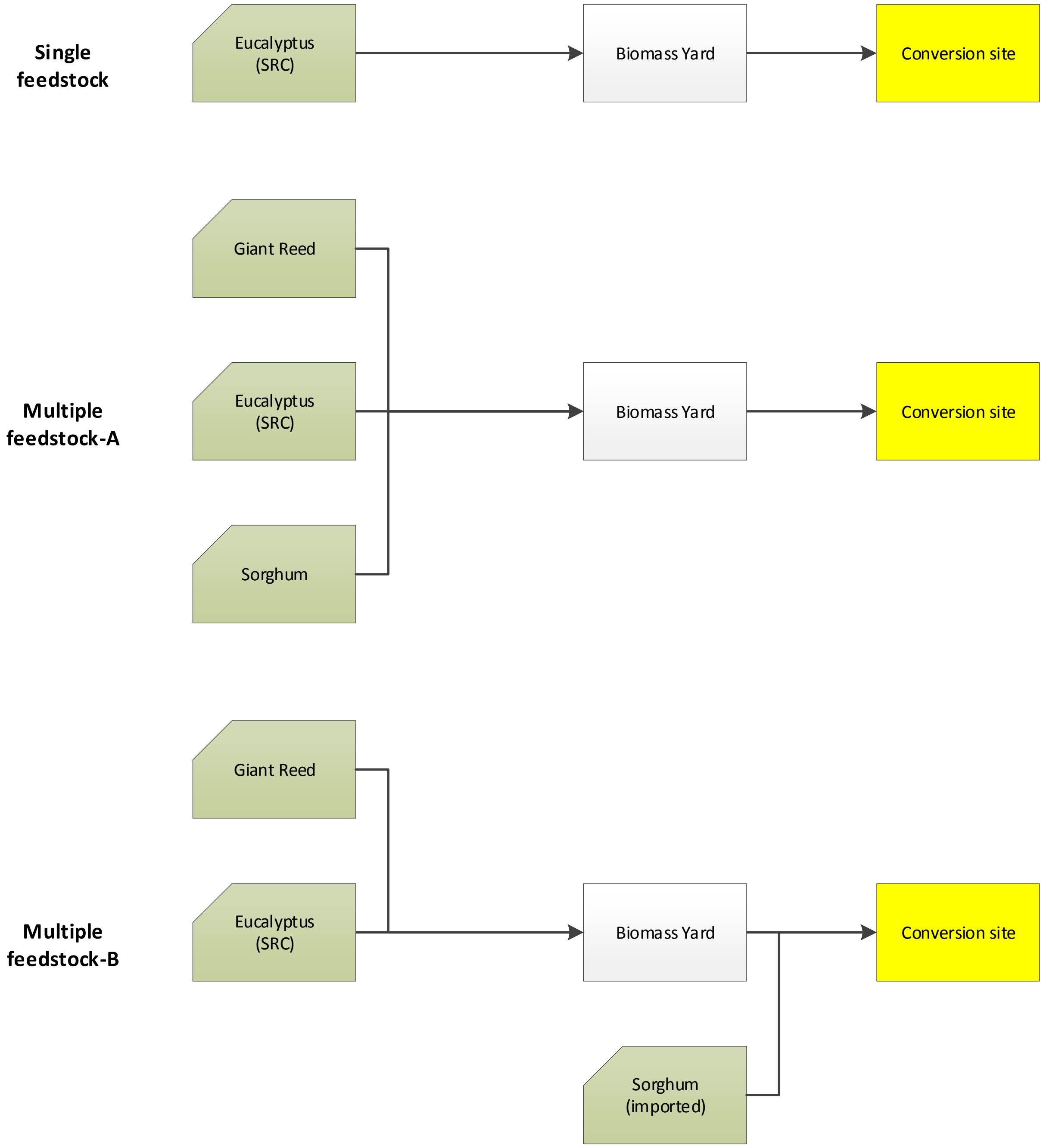

Figure 4.3 Schematic impression of a multi-feedstock system with local sourcing of different types of biomass produced in the region (A) and point sourcing of imported biomass e.g. at a harbour (B).

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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 multiple feedstock sourcing.
5) Variation of cases according to central and decentral biomass value chain organisation with intermediate collection points/biomass yards sourced locally by single and multiple feedstock types.
6) Variation of cases according to central and decentral chain organisation with intermediate collection point or yard sourced from local and long distance biomass.
7) Variations in logistical chain organisation 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 strat and can 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 combinatoins have been omitted in the table. An overview of these combinations is presented in Table 5.2.
- Storage of 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.

- 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 and indicated below:
    - GR/So 1 – Lo 2 – Ga/Py/BC 3
    - GR 2 – Lo 6 – Ga/Py 3
    - GR 2 – Lo 2 – Ga 7
- 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 and indicated below:
    - GR 2 – Lo 4 – Ga/Py/BC 5
    - GR 2 – Lo 3 – Ga/Py/BC 6
- When biomass feedstock will be washed, dried and stored at the convesion 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 and indicated below:
    - GR 3 – Lo 1 – Ga/Py 9
    - So 2/3 – Lo 5 – Ga/Py 9
- Transportation of wet feedstock to conversion plants increases costs and may therefore be less relevant (except maybe for the washing option at the conversion site). These combinations are marked with *[5] in Table 5.1 and indicated below:
    - GR/So/Eu 1 – Lo 2 – Ga/Py/BC 3
    - Eu 4/5/6 – Lo 1 – Ga/Py/BC 4
    - GR 2 – Lo 6 – Ga/Py/BC 3
    - GR 2 – Lo 5 – Ga/Py/BC 4
    - GR 2 – Lo 2 – Ga/Py/BC 7
    - GR 2 – Lo 1 – Ga/Py/BC 8
    - GR 2 – Lo 6 – Ga/Py/BC 3
    - Eu 3 – Lo 5 – Ga/Py/BC 3
    - Eu 3 – Lo 1 – Ga/Py/BC 7
- 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 up-loading , 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.

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Table 5.1. Overview of all combinations of feedstock at field/roadside and receiving conversion plant, connected by logistics. At each of these three stages 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, this is 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, So 1, 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 *[5]
		Lo 1	-	Ga 4	Drying, Storage *[5]
		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 *[5]
		Lo 1	-	Py 4	Drying, Storage *[5]
		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 *[5]
		Lo 1	-	BC 4	Drying, Storage *[1,5]
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 *[5]
		Lo 5	Chipping	Ga 4	Drying, Storage *[5]
		Lo 4	Drying, Storage *[3]	Ga 5	Chipping
		Lo 3	Drying *[3]	Ga 6	Chipping, Storage
		Lo 2	Storage *[2]	Ga 7	Chipping, Drying *[5]
		Lo 1	-	Ga 8	Chipping, Drying, Storage *[5]

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

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(Chapter 2)		(Chapter 4)		(Chapter 3)	
		Lo 2	Storage	BC 1	-
		Lo 1	-	BC 2	Storage
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]
		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	-
Feedstock at roadside		Logistics and biomass yard		Conversion plant	

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(Chapter 2)		(Chapter 4)		(Chapter 3)	
		Lo 5	Chipping	BC 2	Storage
		Lo 2	Storage	BC 5	Chipping
		Lo 1	-	BC 6	Chipping, Storage
Eu 3	Baling, Storage	Lo 7	Chipping, Drying	Ga 1	-
		Lo 5	Chipping	Ga 3	Drying *[5]
		Lo 3	Drying	Ga 5	Chipping
		Lo 1	-	Ga 7	Chipping, Drying *[5]
		Lo 5	Chipping	Ga 9	Washing, Drying, Storage
		Lo 7	Chipping, Drying	Py 1	-
		Lo 5	Chipping	Py 3	Drying *[5]
		Lo 3	Drying	Py 5	Chipping
		Lo 1	-	Py 7	Chipping, Drying *[5]
		Lo 5	Chipping	Py 9	Washing, Drying, Storage
		Lo 7	Chipping, Drying	BC 1	-
		Lo 5	Chipping	BC 3	Drying *[5]
		Lo 3	Drying	BC 5	Chipping
		Lo 1	-	BC 7	Chipping, Drying *[5]
Pyrolysis oil	-	L0 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

5.3 Selected chains

From the former it became clear that a biomass logistical chain can be very simple because most of the pre-treatments, drying and storage are done either at the field/road side or after the gate of the conversion plant. In this case only the transport is part of the logistical chain. A logistical chain can also be more complex when it involves all possible activities of pre-treatments, drying, storage, handling and transport. Such a complex logistical chain occurs when the on-field biomass treatment is minimized to harvesting and the conversion plant concentrates entirely on the direct conversion of the biomass when it enters the gate. In that case a logistical chain will need to include a 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 are included in a chain. Reasons to involve more feedstock types are because there is not enough biomass of one type in the near distance to reach the minimal demand of the conversion plant, to create more security of supply of biomass at an acceptable price. Whether a conversion process can handle multiple feedstock, needs to be evaluated in the conversion process experiments, but it also needs to be evaluated whether it is efficient 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 sources.

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 case studies. These case studies need to be areas where at least one of the 4 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:

1) Variation of cases according to varying quantities and spatial dispersion situations for biomass: low density dispersed versus high spatial concentration.
2) Mono feedstock sources versus multiple feedstock sourcing.
3) Variation of cases according to central and decentral biomass value chain organisation with intermediate collection points/biomass yards sourced locally by single and multiple feedstock types.
4) Variation of cases according to central and decentral chain organisation with intermediate collection point or yard sourced from local and long distance biomass.
5) Variations in logistical chain organisation 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.

In Table 5.2 an overview is presented of the possible variations in combinations of feedstock –conversion technology-spatial biomass dispersion patterns- logistical chain options that can be tested in case studies. Suggestions are also made for type of possible case study areas.In the last column it is mentioned which logistical chain combinations from Table 5.1 can be tested in these specific situations.

Table 5.3 Logistical chain options and case selection options

Biomass type	Spatial dispersion & quantity (within 100 km radius)	Type conversion process & end product and minimal biomass need (ton DM/year)	Direct transport field to conversion or with intermediate collection point/biomass yard	Mono feedstock or multi feedstock/feedstock from point source	Suggested case study region/country	Suggested logistical options to be tested from Table 5.1
Giant reed (Arundo donax)	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 field – conversion installation	• Multiple feedstock: security of feedstock supply cannot be expected from new crop on abandoned lands • Second feedstock agricultural lignocellulosic residues (straw, stubbles from arable crops • Biomass sorghum as a second crop on existing arable land	Southern Italian/Spanish/Greek region with high share of abandoned marginal lands and other residue production and intercropping options	GR 1/ Lo 1/ BC 4 GR 2/Lo 1/BC 8 GR3/Lo1/BC 6
	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)	• Multiple feedstock: security of feedstock supply cannot be expected from new crop on abandoned lands • Additional point source feedstock (from EU and overseas)	Italian/Greek/Spanish region with high share of abandoned marginal lands and other residue production and intercropping options and harbour (or imports)	GR 1-3/Lo 2-8/ BC 1-8
	High spatial dispersion (on marginal-unused/abandoned lands) with low per ha yield	gasification (minimal 200,000 ton dm/y)	Direct transport field – conversion installation	• Multiple feedstock: security of feedstock supply cannot be expected from new crop on abandoned lands • Second feedstock agricultural lignocellulosic residues (straw, stubbles from arable crops • Biomass sorghum as a second crop on existing arable land	Southern Italian region with high share of abandoned marginal lands and other residue production and intercropping options/ Spanish region with high share of abandoned marginal lands and other residue use options	GR 1/ Lo 1/ GA 4 & 9 GR 2/ Lo1/ GA 8 GR 3/Lo 1/GA 2&9

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Biomass type	Spatial dispersion & quantity (within 100 km radius)	Type conversion process & end product and minimal biomass need (ton DM/year)	Direct transport field to conversion or with intermediate collection point/biomass yard	Mono feedstock or multi feedstock/feedstock from point source	Suggested case study region/country	Suggested logistical options to be tested from Table 5.1
	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)	• Multiple feedstock: security of feedstock supply cannot be expected from new crop on abandoned lands • Additional point source feedstock (from EU and overseas)	Italian/Greek/Spanish region with high share of abandoned marginal lands and other residue production and intercropping options and harbour (or imports)	GR 1-3/ Lo 2-8/ GA 1-9
	High spatial dispersion (on marginal-unused/abandoned lands) with low per ha yield	Pyrolysis 35,000 ton dm/y	Direct transport field – conversion installation	• One feedstock	Spanish/Italian or Greek region with high share of abandoned marginal lands	GR 1/ Lo 1/ Py 4&9 GR 2/Lo 1/ Py 8 GR 3/Lo 1/Py 2&9
	High-intermediate 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)	• Multiple feedstock: security of feedstock supply cannot be expected from new crop on abandoned lands • Additional point source feedstock (from EU and overseas)	Spanish/Italian or Greek region with high share of abandoned marginal lands	GR 1/ Lo 2-4/ Py 1-3 GR 2/Lo 2-8/ Py 1-7 GR 3/Lo 2/ Py 1
	High-intermediate spatial dispersion (on marginal-unused/abandoned lands) with low per ha yield	Gasification of Pyrolysis oil	Direct transport– conversion installation		Spanish/Italian or Greek region	All of the above with Ga 10 added
Eucalyptus SRC or	Intermediate spatial dispersion on marginal	Pyrolysis (minimal	Direct transport field – conversion	• Mono-feedstock, only	Italian region with high share of	Eu 1 & 4-6/ Lo 1/ Py 4&9

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Biomass type	Spatial dispersion & quantity (within 100 km radius)	Type conversion process & end product and minimal biomass need (ton DM/year)	Direct transport field to conversion or with intermediate collection point/biomass yard	Mono feedstock or multi feedstock/feedstock from point source	Suggested case study region/country	Suggested logistical options to be tested from Table 5.1
MRC	lands (agricultural-abandoned/forest-abandoned)	35,000 ton dm/y)	installation	eucalyptus (SRC or MRC)	abandoned marginal land	Eu 2/ Lo1/ Py 2&9 Eu 3/ Lo 1/ Py 7
	High-intermediate spatial dispersion (on marginal-unused/abandoned lands) with low per ha yield	Gasification of Pyrolysis oil	Direct transport– conversion installation	• -	Spanish/Italian or Greek region	The above with Ga 10 added
	High concentration on marginal/forest land	Gasification (minimal 200,000 ton dm/y)	Direct transport field – conversion installation	• Mono-feedstock, only eucalyptus (SRC or MRC)	Italian or Greek region	Eu 1 & 4-6/ Lo 1/ Ga 4&9 Eu 2/ Lo1/ Ga 2&9 Eu 3/ Lo 1/ Ga 7
	High concentration on marginal/forest land	Gasification (minimal 200,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multiple feedstock: other woody residues in region • Imported wood residue chips	Italian or Greek region	Eu 1 & 4-6/ Lo 2-4/ Ga 1-3 Eu 2/ Lo 2/ Ga 1 Eu 3/ Lo 3,5,7,9/ Ga 1,3,5,7
	Intermediate spatial dispersion on marginal lands (agricultural-abandoned/forest-abandoned)	Biochemical conversion into biofuel (minimal 100,000 ton dm/y)	Direct transport field – conversion installation	• Mono-feedstock, only eucalyptus (SRC or MRC)	Italian or Greek region	Eu 1 & 4-6/ Lo 1/ Bc 4 Eu 2/ Lo1/ BC 2 Eu 3/ Lo 1/ Bc 7

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Biomass type	Spatial dispersion & quantity (within 100 km radius)	Type conversion process & end product and minimal biomass need (ton DM/year)	Direct transport field to conversion or with intermediate collection point/biomass yard	Mono feedstock or multi feedstock/feedstock from point source	Suggested case study region/country	Suggested logistical options to be tested from Table 5.1
	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)	• Multiple feedstock: other woody residues in region • Imported wood residue chips	Italian or Greek region	Eu 1 & 4-6/ Lo 2-4/ Bc 1-3 Eu 2/ Lo 2/ Bc 1 Eu 3/ Lo 3,5,7/ Bc 1,3,5
Biomass sorghum	Intermediate spatial dispersion on marginal lands (agricultural-abandoned/forest-abandoned)	Pyrolysis (minimal 35,000 ton dm/y)	Direct transport field – conversion installation	• Mono-feedstock, only eucalyptus (SRC or MRC)	Italian region with high share of abandoned marginal land	So 1/ Lo 1/ Py 4&9 So 2/ Lo 1/ Py 6 So 3/ Lo 1/ Py 6
	High-intermediate spatial dispersion (on marginal-unused/abandoned lands) with low per ha yield	Gasification of Pyrolysis oil	Direct transport– conversion installation	• -	Spanish/Italian or Greek region	The above with Ga10 added
	High concentration on marginal/forest land	Gasification (minimal 200,000 ton dm/y)	Direct transport field – conversion installation	• Mono-feedstock, only eucalyptus (SRC or MRC)	Italian or Greek region	So 1/ Lo 1/ Ga 4&9 So 2/ Lo1/ Ga 6 So 3/ Lo 1/ Ga 6
	• High concentration on marginal/forest land	Gasification (minimal 200,000 ton dm/y)	With intermediate collection points and pre-treatment (biomass yards)	• Multiple feedstock: other woody residues in region • Imported wood residue chips	Italian or Greek region	So 1/ Lo 2-4/ Ga 1-3 So 2/ Lo 2,5,6/ Ga 1,2,5 So 3/ Lo 2,5,6/ Ga 1,2,5

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Biomass type	**Spatial dispersion & quantity (within 100 km radius)**	**Type conversion process & end product and minimal biomass need (ton DM/year)**	**Direct transport field to conversion or with intermediate collection point/biomass yard**	**Mono feedstock or multi feedstock/feedstock from point source**	**Suggested case study region/country**	**Suggested logistical options to be tested from Table 5.1**
	• Intermediate spatial dispersion on marginal lands (agricultural-abandoned/forest-abandoned)	Biochemical conversion into biofuel (minimal 100,000 ton dm/y)	Direct transport field – conversion installation	• Mono-feedstock, only eucalyptus (SRC or MRC)	Italian or Greek region	So 1/ Lo 1/ Bc 4&9 So 2/ Lo1/ Bc 6 So 3/ Lo 1/ Bc 6
	• 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)	• Multiple feedstock: other woody residues in region • Imported wood residue chips	Italian or Greek region	So 1/ Lo 2-4/ Bc 1-3 So 2/ Lo 2,5,6/ Bc 1,2,5 So 3/ Lo 2,5,6/ Bc 1,2,5
Lignin rich residue	• High concentration	Gasification (minimal 200,000 ton dm/y)	Direct transport	• Mono-feedstock	Italian/ Greek/spanish region	LG 1/ Lo 1/BC 1
	• High concentration	Pyrolysis	Direct transport	• Mono-feedstock	Italian/ Greek/spanish region	LG 1/ Lo 1/Ga 1

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5.3 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, LacaGIStics 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 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 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.

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

References

Assirelli, A.; Santangelo, E.; Acampora, A.; Del Guidice, A., Civitarese, V. & Pari, L. (2018). THE INCREASE OF THE PARTICLE SIZE OF CHOPPED ARUNDO BY MEANS OF A CHIPPER PROTOTYPE. EUBCE 2018. Conference papers.

Anttila, P., T. Mustonen, A. Asikainen & M. Tuukkanen, 2014. Novel business and service models of the forest biomass supply. Infres, Deliverable D3.5, 10 pp.

Biocore, 2014. Building tomorrow's biorefineries; Findings from case studies. Synthesis report from Biocore project (www.biocore-europe.org), 15 pp.

Bioboost, 2013. Status Month 14. Presentation, 32 pp.

Bjørkvoll, T., 2015. Sustainability assessment of biomass supply chains from energy crops in Europe. Presentation at Conference on Mobilization of woody biomass for energy and industrial use – Smart logistics for forest residues, prunings and dedicated plantations, Rome, 19 pp.

Boer, J. den, A. Dyjakon & P. Bukowski, 2015. Environmental, economic and social issues for new logistics chains for biomass from prunings. Presentation at Conference on Mobilization of woody biomass for energy and industrial use – Smart logistics for forest residues, prunings and dedicated plantations, Rome, 23 pp.

Elbersen, W., Bakker, R. , Harmsen, P., Vis, M., Alakangas, E (2015). S2BIOM Deliverable D2.2. A selection method to match biomass types with the best conversion technologies. S2Biom Project Grant Agreement n°608622

EuroPruning, 2015. Deliverable 2.2 Results with conclusions of each demonstration (by zone and step). Unpublished document (at date of September 2015)

EuroPruning, 2013. Annex II Demonstration Site Tech Sheets. Working document, 11 pp.

Gabrielle, B., T. Flatberg, A. Perrin, J. Wohlfahrt, T. Bjørkwoll, I. Echevarria Goni, R. van der Linden, C. Loyce, E. Pelzer, G. Ragaglini, I. Shield & N. Yates, 2015a. Improving logistics for biomass supply from energy crops in Europe: main results from the Logist'EC project. In: Proceedings of the 23rd European Biomass Conference and Exhibition, 1-4 June 2015, Vienna, Austria, 1-5. Combined with Powerpoint Presentation.

Gebresenbet, G. & T. Bosona, 2015. Logistics cost of biomass from pruning – EuroPruning assessment. Presentation at Conference on Mobilization of woody biomass for energy and industrial use – Smart logistics for forest residues, prunings and dedicated plantations, Rome, 21 pp.

Infres, 2015. Project website. www.infres.eu

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

Khuspe, S. S., Gupta, P. K., Kulkarni, D. K., Mehta, U., & Mascarenhas, A. F. (1987). Increased biomass production by tissue culture of Eucalyptus. *Canadian Journal of Forest Research*, *17*(11), 1361-1363.

Kronberger, G. & E. Pitzer, 2015. BioBoost Logistic Model. Deliverable D4.3 of the BioBoost project (www.bioboost.eu), 24 pp.

Lammens, T., Vis, M, te Raa, R., Van den Berg, D., Kärki, J., Uslu, A., Mozaffarian, H., Harmsen, P. , de Groot, H. (2016). D2.3 Database of biomass conversion technologies. S2Biom Project Grant Agreement n°608622

LogistEC, 2015. Project website. www.logistecproject.eu

LogistEC, 2013. Logistics for Energy Crops Biomass. Project flyer, 2 pp.

Nobili, 2015. The WS 320 Bio. Presentation at Conference on Mobilization of woody biomass for energy and industrial use – Smart logistics for forest residues, prunings and dedicated plantations, Rome, 12 pp.

Pari, L., 2015. Developing of two pruning harvesting prototypes. First results. Presentation at Conference on Mobilization of woody biomass for energy and industrial use – Smart logistics for forest residues, prunings and dedicated plantations, Rome, 23 pp.

Patel, M., S. Giarola & N. Shah, 2013. Description of alternative supply chains and their performance measures for the biorefinery and for a time-phased, scaled-up biorefining industry validated through regionally specific models. Deliverable 1.4 & 1.5 of the Biocore (BIOCOmmodity refinery) project, 110 pp.

Pitzer, E. & S. Rotter, 2012. BIOBOOST WP4: Transport & Logistics. Presentation, 16 pp.

Rotter, S. & C. Rohrhofer, 2012. Biomass Logistics. Deliverable 1.4 of the BioBoost project (www.bioboost.eu), 47 pp.

Rotter, S. & C. Rohrhofer, 2014. Logistics concept. Deliverable 4.1 of the BioBoost project (www.bioboost.eu), 74 pp.

Saikia, R., Chutia, R. S., Kataki, R., & Pant, K. K. (2015). Perennial grass (Arundo donax L.) as a feedstock for thermo-chemical conversion to energy and materials. *Bioresource technology*, *188*, 265-272.

Sanchez, D. G. Barberena, G. Ragaglini, C. Tozzini, R. Villani, I. Shield, N. Yates & I. de Campo, 2015. Progress in annual an perennial herbaceous energy crops harvesting and handling: Preliminary results on fibre Sorghum and Miscanthus experiences within the EU LogistEC project. In: Proceedings of the 23rd European Biomass Conference and Exhibition, 1-4 June 2015, Vienna, Austria, 187-192.

Santangelo, E., Scarfone, A., Del Giudice, A., Acampora, A., Alfano, V., Suardi, A., & Pari, L. (2015). Harvesting systems for poplar short rotation coppice. *Industrial Crops and Products*, *75*, 85-92

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

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

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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