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Biomass based energy intermediates boosting biofuel production

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Deliverable

D4.1 Logistics Concept

Version 3.0

Report on logistics processes for transport, handling and storage of biomass residues as well as energy carrier from feedstock sources to central conversion plants

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Table of Contents

List of Figures

List of Tables

Glossary

BD	bulk density
CP	catalytic pyrolysis
CCP	central conversion plant
DCP	decentral conversion plant
DFC	distance fixed costs
DM	dry matter
DVC	distance variable costs
Feedstock type	biogenic residue examined
FM	fresh mass
FP	fast pyrolysis
FTL	full truck loads
HHV	Higher heating value
HTC	hydrothermal carbonization
Intermediate	energy carrier produced in DCPs
ID	Intermediate depot
LR	logging residues
Nt	Net ton
ÖKL	*Österreichisches Kuratorium für Landtechnik und Landentwicklung*
SC	supply chain
SCM	supply chain management
SKU	stock keeping unit
TUL	*Transport, Umschlag und Lagerung*
WC	water content
WP	work package
wt%	weight percentage

Abstract

This report originated from the EU FP7 Project Bioboost and deals with logistics for biomass-based energy carrier production. The main purpose is about analysing the main logistics processes, i.e. transport, handling and storage for biomass residues as well as derived energy carrier through evaluating their costs and emissions. Although such logistics metrics for biomass logistics already exists in literature, these performance indicators seem to be inappropriate for this study due to the following reason: (i) intransparent underlying calculation scheme, (ii) missing practical insights, (iii) focus on biomass rather than on biomass residues, (iv) lack of product specification, (v) improper level of abstraction and (vi) missing experience with produced energy carrier. The overall goal of this report is to design and evaluate logistics processes for both product types biogenic residues as well as energy carriers. In doing so, existing literature and practical knowledge are analysed and synthesized. A sound calculation scheme is developed which provides a transparent and fitting basis for setting up the holistic logistics model in work package 4.

A comprehensive literature about biomass logistics processes marked the starting point of the analysis. In the course of the investigations, 18 interviews with Austrian practitioners in the fields of biomass operators and distributors, logistics service providers and research institutes have been conducted. The collected parameters have been synthesized in a database in order to calculate the required logistics metrics. In general, considering biomass residues transports farm tractors are inferior to trucks in terms of transport costs. The main reasons are lower average vehicle speeds, higher fuel consumption rates, higher equipment investment costs lower utilization of payloads. Yet, biomass is currently transported by farm tractors, especially in Austria, due to the unavailability of truck equipment. However, looking at some well advanced biomass logistics systems in Scandinavia, for instance, only trucks or even railway are used for transporting biomass. Furthermore, more and more logistics service providers specialized in biomass logistics are penetrating the market. Besides biomass transportation, also handling equipment is investigated based on practicability and operating efficiency. Here, the handling capability as well as waiting costs for idle transport equipment determines the performance of the handling assets. Finally, possible storage locations alongside the biomass supply chain are characterized based upon their storage capacities, annual throughput and total annual fixed operating costs.

Preface

The report in hand provides a summary of key findings in the field of biomass and energy carrier logistics deduced within the BioBoost project in the scope of work package 4 (WP4). This work package focuses on *Transport and Logistics*. As defined in the *BioBoost Description of Work (DOW)*, the overall objective in WP4 is given by the development of a holistic logistics model that optimizes biomass and energy carrier transportation regarding costs and CO_2 emissions as well as identifies optimal locations for decentral and central plants. In doing so, different tasks and interrelations with other work packages are defined. In particular, regular coordination with WP 1 (Feedstock potential, *IUNG*) and WP 6 (Techno-economic, social and environmental assessment of complete chains, *TNO*) are necessary.

The leader of work package 4, *FH OÖ Forschungs und Entwicklungs GmbH,* has put its focus on: (i) setting up a concept for the holistic logistics model and determining key parameters for the data model (Task 4.2), (ii) programming a first draft of a simulation-based optimization model (Task 4.3) and (iii) defining physical transport, handling and storage processes for biomass and energy carrier logistics in Task 4.1. The latter is elaborated in this report and represents the second version including adapted parameters and cost figures.

Based on an initial concept for a data model defined together with TNO and IUNG, FH OOE has made first considerations concerning a holistic logistics model and sketched a schematic representation for the planned decision-making support tool (Figure 1). It aims at configuring an optimal decentralized supply network topology for biomass-based energy carrier production in Europe according to a pre-defined set of key figures, e.g. feedstock costs, construction costs, logistics costs, etc. Reasons for organizing the network by setting up decentral and central conversion plants have already been elaborated in *Leible et al. (2006).* Uneconomical transportation of biomass residues featuring low energy contents favours a decentralized supply network which have short pre-haulage distances.

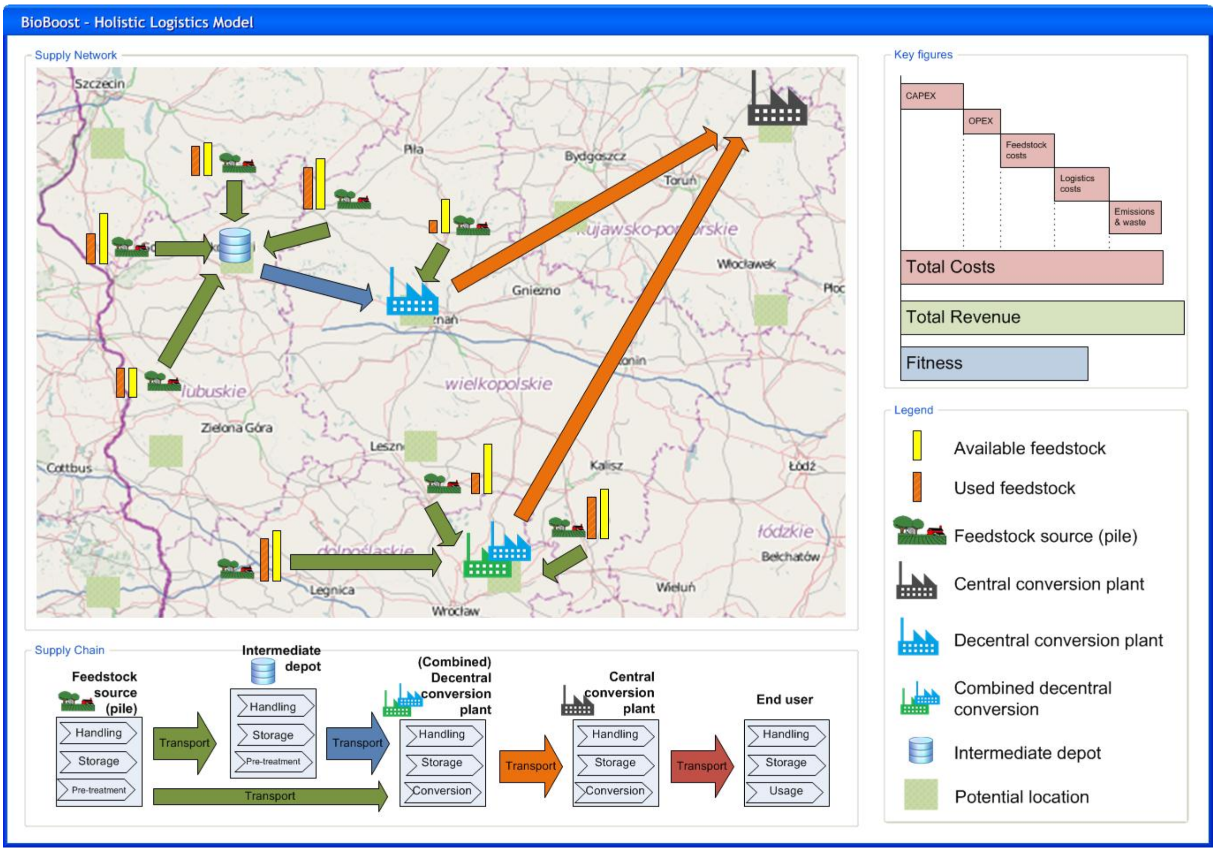


Figure 1: Schematic representation of holistic logistics model

1 Introduction

Based on an increasing relevance of physical distribution within the marketing context, a new discipline, called *TUL Logistik*[1] has evolved in the 1970s. Basically, TUL deals with three transfer functions as depicted in Table 1 *(Danzas Lotse, 2004, p. 9).* Correspondingly, plenty of authors have dedicated their focus to these main logistics processes *(Weber, 2012, p. 93ff)*. Recently, the attention has been directed towards Supply Chain Management (SCM) that represents the highest form of managing logistics processes. Yet, transporting, handling represents fundamental processes to all forms of logistics management and, therefore, those processes also define the study area for this report.

Table 1: Basic logistics processes

Transfer function	Transport	Handling	Storage
Based on	Spatial distribution	Material distribution	Temporal distribution
Demand for transfer function	Divergent locations of value creation (globalized production networks)	Divergent lot sizes in production, inventory, transportation, etc.	Divergent points in time of production and consumption

Within the BioBoost project, the main material types that are handled along the supply chain are classified into biomass residues *(a.k.a. feedstock types)* and energy carrier *(a.k.a. intermediates).* Because of divergent requirements of those materials for designing logistics processes, the supply chain is analysed separately: (i) *biomass logistics* and (ii) *energy carrier logistics*.

[1] The acronym *TUL* stands for the German terms for transport, handling and storage and has emerged from the German-speaking area.

Table 2: Overview about study area, material types and material

System boundaries for logistics	Material types	Material
Biomass logistics	Feedstock	o Straw as an agricultural residue (cereal, oilseeds and maize straw) o Wood chips as a forestry residue (logging residues, thinning wood, root biomass, wood balance) o Organic municipal waste (garden/park waste, food waste and kitchen waste)
Energy carrier logistics	Intermediate	o Biosyncrude (fast pyrolysis) o Catalytic pyrolysis oil (catalytic pyrolysis) o Biocoal (hydrothermal carbonization)

A major starting point for analysing logistics processes is given by reference pathways. The BioBoost project investigates three different conversion technologies: (i) fast pyrolysis, (ii) catalytic pyrolysis and (iii) hydrothermal carbonization. Each of these technologies deals with different feedstock types, production capacities, energy carrier applications of different scales, and side products. In order to reduce complexity at an early stage of the project, the project consortium agreed upon a fixed reference pathway for each conversion technology. Besides data related to energy carriers, these reference pathways also characterize the reference types of biomass (straw, wood chips and organic municipal waste).

The overall goal of this report is to evaluate costs and CO_2 emissions for biomass and energy carrier logistics processes. Logistics costs are dependent on certain process and product properties, i.e. weight and volume, throughput rates, stocks, capacities, machineries applied, storage periods, transport distance as well as market conditions *(Gudehus, 2012, p. 163)*. To start with, reference materials are specified according to logistics requirements. Then, logistics assets (i.e. transport, handling and storage equipment) are defined through applying practical insights. Based on these input data, performance parameters (e.g. storage capacity, throughput rates) are determined. Simultaneously, cost rates for logistics assets are evaluated. Finally, logistics costs are calculated using a pre-defined calculation scheme.

The report is structured as follows. A brief overview about the method of collecting data is described in Chapter 2. The third chapter is dedicated to a review on existing literature and practical knowledge related to biomass logistics. Biomass logistics is specified In chapter 4, whereas energy carrier logistics is delineated in chapter 5. Thereafter, different analyses are conducted in order to draw practical implications. Finally, chapter 7 provides conclusions and an outlook. Key implications for biomass logistics are summarized and links to other tasks in WP 4 and WP6 are stated.

2 Method of Collecting Data

2.1 General Approach

The realm of *Biomass logistics* represents not an untapped object of investigation. Several project reports, scientific papers as well as ample knowledge in practice are available today. This existing knowledge base has been analysed in a first step through conducting expert interviews and reviewing literature. All data were consolidated in a *Microsoft Excel* file in order to build up a foundation for subsequent calculations. Figure 2 provides an overview about the method of collecting data.

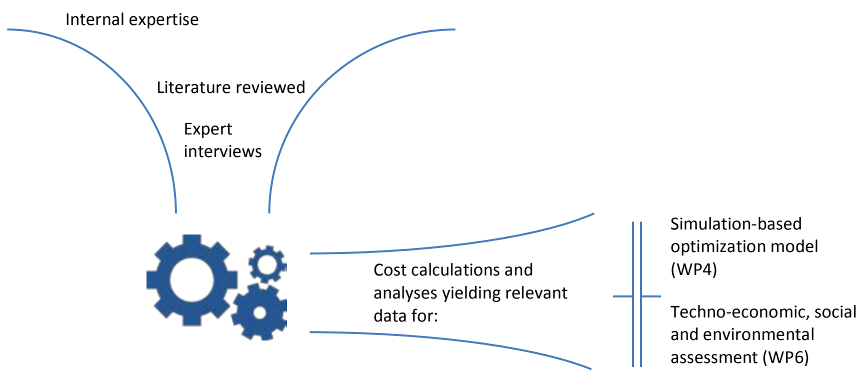


Figure 2: Method of collecting data

First of all, a desktop study is conducted by screening existing (project) reports related to biomass logistics. In addition, plenty of internet documents provided by companies engaged in biomass logistics are reviewed. Further, internally available expertise and experiences in the field of logistics and transportation are integrated. Based on this desktop study, some authors of reports reviewed as well as practitioners are contacted and expert interviews are conducted. These interviews not only provide valuable information for the analyses, but also enable validity checks of final results (logistics process costs). A list of experts interviewed can be retrieved from the annex. The BioBoost project consortium further provides valuable information upon feedstock potential, relevant feedstock types and conversion processes for this report.

2.2 System Boundary

Derived from the supply network representation, respective logistics processes are broken down to a linear supply chain representation which enables a business process view (Figure 1). The considered supply chain involves basically five echelons: feedstock sources (pile, roadside), intermediate depots, decentral conversion plants, central conversion plants as well as end users. In order to reduce complexity in terms of the optimization and simulation (Task 4.3) and because of already existing well-established energy supply networks, the final consumers are neglected.

The supply of biomass residues to feedstock source includes harvesting, pressing and field transport, or forwarding and consolidation. Within the BioBoost project these pre-treatment processes are investigated already in work package 1, and thus, are included in the feedstock costs.

An initial overview about the system boundary of the holistic logistics model is given in Figure 3.

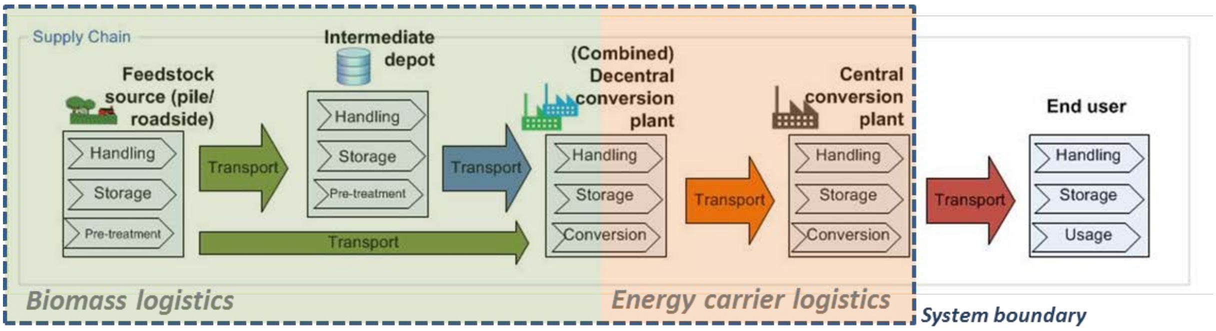


Figure 3: Overall system boundary

As already mentioned before, this report deals with the supply chain which includes all transport, handling and storage processes arising from pile/roadside towards feeding reactors at central conversion plants.

2.3 Logistics Asset Specification

As already mentioned above transport-, handling- and storage assets need to be specified in order to define parameters for logistics costs calculation. For this reason, a hierarchical classification of transport assets, originating from product characteristics and converging to transport modes, supports the specification of handling and storage assets (Figure 4). For instance, wheat straw is pressed into square bales, which constitute a loading unit. In contrast, bulky material, e.g. wood chips, can be manipulated more efficiently through applying, for instance, roll-off containers. A defined loading unit further determine the required handling asset. A telescopic handler needs different equipment in case of loading square bales than manipulating wood chips. With respect to the storage process, even transport means and modes influences storage assets. Transporting biomass via barges or rail cars require different infrastructure that would be needed in case of using road as a transport mode.

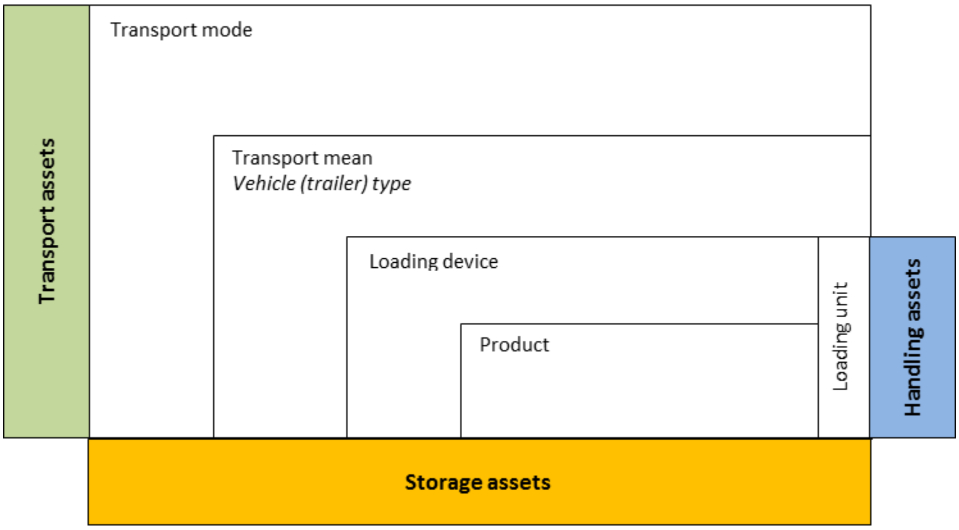


Figure 4: Overview about asset to be specified for logistics processes

In order to design biomass logistics, the authors defined reference assets that are used in practice. For instance, a 140 kW 4x4 farm tractor is defined as a reference vehicle type for transports by farm tractors. Correspondingly, cost and performance data are indicated.

2.4 Logistics Cost Calculation Metrics

A crucial part in the BioBoost project represents the profitability analysis. Accordingly, a major aspect of this report is to analyse the structure of logistics costs. In virtue of assets specified, relevant fixed operating costs, e.g. costs for depreciation, maintenance, capital, fuel, labour, etc., are evaluated. More specifically, distance variable costs (DVC) and distance fixed costs (DFC) are determined.

Besides cost evaluation, also performance parameters (e.g. payload, average vehicle speed, fuel consumption, annual operating hours and milages, etc.) are determined in order to derive desired target metrics as given in Table 3. Dealing with biomass logistics, the dry matter (DM) content represents a crucial issue. Due to high and valueless proportion of water contained in biogenic residues (indicated as water content WC wt%), logistics processes need to be evaluated on the basis of dry matter content.

Table 3: Target metrics

Logistics process	Target metrics
Transport	*EUR / t $_{(DM)}$*km or EUR / t*
Handling	*EUR / t $_{(DM)}$*
Storage	*EUR / t $_{(DM)}$*

Initially, cost data are surveyed only for Austria. In order to transfer and allocate these data to the study area in BioBoost (EU 27 + Switzerland), major cost drivers are identified through the cost calculations. Then, indices for these major cost drivers (e.g. labour costs, fuel costs) are generated by applying statistics available for Europe. Finally, all logistics cost rates are validated by contacting experts interviewed.

All cost calculations prepared in this report represents a static and deterministic behaviour.

3 Review on Existing Literature and Practical Knowledge

In the course of the previous decades a rethinking in terms of alternative energy sources has taken place. Renewable energy sources, e.g. biomass, came to the fore and induced plenty of projects on a national as well as international level. Also the scientific community put emphasize on this topic. When it comes to energy generation based on biomass in an efficient way, logistics is supposed to play a decisive role. As a matter of fact, plenty of reports dedicated to biomass logistics have been published recently. The following represents not an exhaustive but selective abstract of existing literature.

3.1 Literature on Biomass Logistics

The *RENEW project (2008)*, which was run prior to BioBoost, has also dealt with biomass logistics. More specifically, a concept for biomass provision is evaluated (EUR/GJ) for agricultural and forestry residues as well as for energy crops. The respective costs are not only evaluated for a current state (base case), but also for two future scenarios assuming different levels of feedstock utilization. The overall supply chain is subdivided into two parts: (1) biomass provision up to the first gathering point and (2) biomass provision from the first gathering point. Basically, all costs are defined for six regions in Europe.

The *BioLog I project (2007)* aims at optimizing a supply chain for woody biomass by minimizing transports in Austria. Based on both an evaluation of disposal feedstock potential for woody biomass and an existing supply network of biomass conversion plants (BMK[2]) and the evaluated feedstock potential, transport costs are minimized through applying a linear programming (LP) model. In terms of allocating feedstock potential to BMKs, three types of heuristics are applied: (i) total cost minimum, (ii) market power and (iii) attraction of regions. By designing an optimal supply network, different types of terminals (agricultural, regional and industrial) are located through using the mathematical model and assumed logistics data.

[2] BMK = Biomassekraftwerk.

A further project called *Optimierung der regionalen Warenströme (Qualitäten, Transport, Aufkommen, etc.) über Biomasse-Logistikzentren (2008)* puts a strong focus on biomass logistics centres. More specifically, a location and allocation model that aims at minimizing transport and preparation costs in Styria (Austria) is set. With respect to the solution process, a mixed-integer programing (MIP) model and a geographic information system are used. Among further issues, processes for storage and handling in biomass logistics centres are designed and evaluated more in detail.

Another, quite recent project *Basisinformationen für eine nachhaltige Nutzung von landwirtschaftlichen Reststoffen zur Bioenergiebereitstellung (2012)* deals with straw as an agricultural residue associated with high potential in Germany for energy generating purposes. Among others, this project also dedicated its attention towards biomass logistics. In particular, supply chains are investigated in more detail by determining also logistics assets. Similar to this report, different options of configuring logistics costs (e.g. type of vehicle-trailer combination applied) are analysed and evaluated.

In 2005, the *Institute for Technology Assessment and Systems Analysis (ITAS)* published a study called *Entwicklungen von Szenarien über die Bereitstellung von land- und forstwirtschaftlicher Biomasse in zwei baden-württembergischen Regionen zur Herstellung von synthetischen Kraftstoffen (2005)*. Here, also the feedstock potential for biogenic residues is evaluated for Germany. Furthermore, supply costs (EUR/Mg DM) for straw, hay, maize and forest residues are calculated for different transport distance intervals.

The study *Leitfaden Bioenergie – Planung, Betrieb und Wirtschaftlichkeit von Bioenergieanlagen (2005)* indicates also valuable information on biomass logistics. Especially, technical specifications regarding biomass storage, e.g. quality losses of different feedstock types, storage techniques etc., are mentioned.

Practical insights into processes within biomass logistics provide the final report from the project *Optimierung der Beschaffungs- und Distributionslogistik bei großen Biogasanlagen (2007).* This project deals with both inbound as well as outbound logistics of biogas plants in Austria. Especially, technical specification of used assets and work time studies for different processes are presented in this report.

Further practical insights into converting straw into energy provide the study *Straw to Energy - Status, Technologies and Innovation in Denmark (2011).* Especially, types of bales and assets, e.g. telescopic handler, forklift trucks or gantry cranes, used for handling straw are specified. The *Wood Fuels Handbook (2008)* gives insights into main characteristics of log wood and wood chips. Additionally, this handbook indicated key figures (costs, productivity, etc.) for assets used along the supply chain.

Regarding the specification of storage assets, the report on *Biomass Logistics & Trade Centers (2010)* offers an implementation guide for such BLTCs. More precisely, three steps are described for a successful project implementation for future BLTC operators. Cost figures are also incorporated in this report.

With respect to biomass transports, several studies and scientific papers are reviewed. The *Biogas Forum Bayern (2010)* published several studies referring to biomass transports. The *BTL Wieselburg (2009)* also engages in biomass transportation. Several scientific papers are available *(Handler, 2009 and 2010).* Further papers related to biomass transports are published by Searcy et al. (2007), Singh et al. (2010) as well as Hamelinck et al. (2005).

Besides the projects mentioned above, further scientific work in the field of supply network planning for bioenergy generation is done. *Gold and Seuring (2011)* provide a recent literature review regarding supply chain and logistics issues for biomass-based energy production. Basically, literature with respect to both (i) operational issues regarding harvesting and collection, storage, transport and pre-treatment techniques as well as (ii) strategic issues referring supply system design are reviewed. *Moser (2012)* engages in location and capacity planning for *Biomass-to-Liquid (BtL)* plants in Austria. This thesis validates a production network for BtL characterized by a decentral pyrolysis and a central synthesis as an optimal supply network. *Freppaz et al. (2004)*, *Rentizelas et al. (2009)*, *Velazquez-Marti, Fernandez-Gonzalez (2010),* deals with mathematical models as decision support tools. *Perpiñá et al. (2009)* apply Geographic Information Systems (GIS) for optimizing biomass logistics.

Another interesting paper reviewed is given by *Lourdes Bravo (2011)*. Key barriers along a biofuel supply chain are investigated by applying a comprehensive literature review. This paper pinpoints variables that may hamper biomass-to-energy development. For instance, facility location and capacity are variables identified in the context of storage. Storage is a major cost driver in biomass logistics.

In addition to the reports reviewed, several books have been screened with respect to (biomass) logistics processes *(Gleissner, 2009; Kaltschmitt, 2009; Martin, 2009; Pfohl, 2010; Weber 2012).*

3.2 Practical Knowledge on Biomass Logistics

Besides the reports reviewed, practitioners have been contacted and interviewed in order to receive and verify data. This is because most of the before mentioned reports make assumptions in terms of cost data and do not verify the same in a transparent way. The interviews have mainly been conducted with Austrian organizations that are engaged in biomass logistics. Governmental agencies, educational and research institutions as well as transport, storage and biomass power plant operators and motor vehicle/trailer manufacturers are consulted (a comprehensive list of all experts interviewed can be retrieved from the annex). The gathered information has a major impact on the validity of logistics costs, because cost figures are based upon practical data sets.

4 Biomass Logistics – Designing and Evaluating Logistics Processes

This chapter aims at examining the design and evaluation of biomass logistics processes. For this purpose, a *Mircosoft Excel* file is generated which incorporates major computations.

4.1 Biomass Supply Chain in Detail

First of all, the overall supply chain depicted in Figure 5 need to be analyzed in more detail. Due to the fact that for producing biocoal (Hydrothermal Carbonization) a co-location concept[3] is aspired, and thus, biomass logistics are not investigated. For terms of wheat straw and wood chips, the biomass pre-treatment processes (cultivation, harvest, etc.) are neglected. Instead the holistic logistics model assumes that respective biomass residues are provided at piles at roadside. The biomass supply chain starts with the storage process at feedstock source and ends at the decentral conversion plant (DCP) when feeding the reactors (Figure 5). Correspondingly, the logistics costs are evaluated for this system.

The respective supply chain exhibits either two or three echelons, that is, biomass residues are transported directly from the feedstock source to the DCP or biomass residues are first transported to an intermediate depot (pre-carriage), stored intermediately and further transported to the DCP (on-carriage). Basically, each echelon features storage and handling processes (loading and unloading). The transport process occurs between echelons.

[3] HTC plants are located next to waste collection sites.

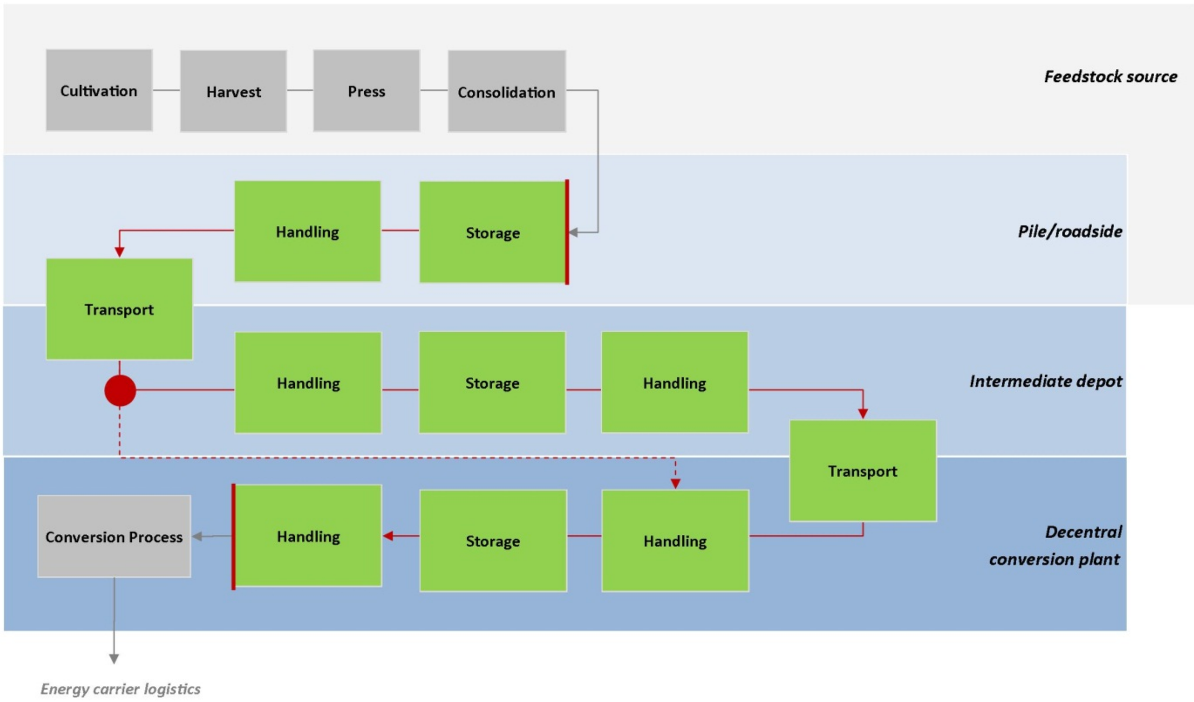


Figure 5: Biomass supply chain in detail

4.2 Specification of Reference Feedstock Types

In the BioBoost project three conversion technologies are examined: (i) fast pyrolysis (FP), (ii) catalytic pyrolysis (CP) and (iii) hydrothermal carbonization (HTC). For each technology a reference feedstock is defined.

Table 4: Conversion technology and defined reference feedstock types

Conversion technology	Reference feedstock type
Fast pyrolysis (FP)	Wheat straw
Catalytic pyrolysis (CP)	Wood chips from logging residues
Hydrothermal carbonization (HTC)	Organic municipal waste

Besides the typical product properties, i.e. weight and volume, that are relevant for evaluating logistics costs, *Kaltschmitt et al. (2009, p. 173ff)* provides an overview about additional product specifications that are key for modelling processes within biomass logistics (Table 5).

Table 5: Overview about product specification of biomass fuels

Product specification of biomass fuels	*Main effects on*
Water content (WC)	*Storability, caloric value, dry matter loss, self-heating, transportability*
Degradation	*Dry matter loss (technical and biological)*
Bulk density (BC)	*Transport- and storage costs, logistics concept*
Particle size	*Pourability, drying properties, dry matter loss*
Viscosity	*Handling, ability to blend*

A major influencing factor of manipulating biomass residues efficiently is given by the *water content (WC),* which is indicated as weight percentage (wt%). This parameter indicates the amount of water contained in biomass and may vary considerable. Biomass excluding the water content is denoted as *dry matter (DM).* Storing biomass leads to a decrease of water content (drying), but simultaneously to dry matter losses due to biological degradation and technical inefficiencies. Therefore, dry matter losses need to be defined for each feedstock type as well as storage location, too *(DBFZ, 2012, p. 67)*. The water content is also a crucial figure for the performance of conversion technologies. Therefore, required water content rates are indicated.

A further key figure with respect to product specifications represents the *bulk density (BD),* because this parameter influences the efficiency of transport and storage processes substantially *(BOKU, 2007, p. 9).* The bulk density represents a measurement that expresses the weight/volume ratio of materials. In case of increasing the BD, more feedstock can be transported which, in turn, increase the utilization of transport means *(KRONE, 2012, p. 37)*. Besides mass density, bulk density also considers voids which arise in terms of creating piles of materials and is determined as kg per m³ *(Francescato, V. et al., 2007, p. 8)*. That is, this ratio provides information concerning volume and weight of a material, which need to be transported, handled and stored. With respect to biomass logistics, transports of feedstock types associated with a low bulk density faces volume restrictions, whereas high density feedstock types reach payload restrictions *(Kaltschmitt et al., 2009, p. 278).* In general, the bulk density of biomass is influenced mainly by (i) water content, (ii) type of biomass and (iii) particle size *(Expert interview 4, 2012).*

Similar to the water content, particle size is also a crucial figure for the conversion processes in terms of working properly. It impacts the handling process due to pourability and drying activities. Furthermore, this parameter may cause an additional pre-treatment process, i.e. comminution. Finally, viscosity will play a major role in terms of manipulating energy carriers. Especially, *Biosyncrude*, that is, the mixture of pyrolysis oil and char, poses challenges for designing logistics processes due to its viscosity. For instance, the sedimentation of substances as well as quality degradation due to chemical reactions over time[4] demand particular attention *(Trippe et al., 2010, p. 421ff; KIT, 2012).*

4.2.1 Wheat Straw for Fast Pyrolysis

Within the BioBoost project, the *Karlsruhe Institute of Technology (KIT)* applies wheat straw as a reference feedstock type for fast pyrolysis. The conversion process requires the following feedstock properties: The water content should take on below 15 wt% and the particle size amounts to 10 mm. Further required technical specifications are depicted in Table 6.

Within the BioBoost project, the following supply scenario of wheat straw is defined. Square bales associated with a dimension of 2.4 x 1.2 x 0.9 m (length x width x height) and a weight of 500 kg FM are assumed *(Bernard KRONE GmbH (2012)*. Thereof, a bulk density of 193 kg/m³ (WC 14 wt%) is calculated. Due to the fact that all cost rates are calculated on the basis of dry matter (DM) which excludes the water content the bulk density is reduced to 166 kg/m³ DM. The square bales are stored in the form of covered (tarpaulin) piles directly on the field. On average, the bales are stored 6 months (assumption). The particle size of pressed wheat straw is assumed to account for 21 mm. Before feeding the straw to the fast pyrolysis reactor, the feedstock type needs to be comminuted. Correspondingly, assets at the decentral conversion plant need to be considered.

[4] Chemical reactions arise in case of transporting, handling or storing *Biosyncrude* beyond a predefined temperature range *(KIT, 2012).*

Table 6: Reference feedstock type for fast pyrolysis: wheat straw

	Feedstock type	Wheat straw		
	Conversion technology	Fast Pyrolysis	Unit	References
Required specifications	Water content (WC)	15	wt%	*TNO, 2012*
	Particle size (length)	10	mm	*TNO, 2012*
	Impurity	-		*KIT, 2012*
	Ash content	6	wt%	*TNO, 2012*
	Net caloric value	13.44	MJ/kg	*TNO, 2012*
	Volume-based energy density	2.59	GJ/m³	*KIT, 2012*
	Feedstock costs	150	EUR/t FM	*Syncom, 2013*
Provided specifications	Provided product	**Square bales**		
	Bulk density (fresh mass)	193	kg/m³ FM	*KRONE, 2012*
	Bulk density (dry matter)	166	kg/m³ DM	*Calculation (based on FM and WC)*
	Water content (WC)	14	wt%	*Skott, 2011, p. 8, DBFZ, 2012, p. 7*
	Dry matter loss (closed stoage)	2	wt%	*DBFZ, 2012, p.67*
	Particle size (length)	21	mm	*Expert interviews, 2012*
Further specifications	Associated risks	None known		
	Required pre-treatment process	Comminution		*KIT, 2012*

4.2.2 Wood Chips for Catalytic Pyrolysis

The *Centre for Research and Technology Hellas (CERTH)* investigates catalytic pyrolysis within the BioBoost project. As a reference feedstock type for this conversion technology, wood chips based on logging residues (soft and hardwood) are defined. More precisely, the following required specifications are indicated. Wood chips to be converted need to exhibit a water content level of smaller than 8 %. Furthermore, the maximum particle size is given by 5 mm. Besides these parameters, further specifications are made as depicted in Table 7. Again, there is a divergence between required features for conversion and provided product characteristics at feedstock source.

Logging residues (LR) are defined "*as the unmerchantable above ground biomass left behind in a cutover area and consist of branches and unmerchantable tops (logging slash) and trees ignored because of their species, small size or inferior quality*" *(Pettersson, 2007, p. 782).* Due to high chipping costs at roadside and low bulk density of logging residues, an alternative recovering method has been developed. *Lindroos et al. (2010)* describe a roadside bundling method that generates so-called logging residue bundles (LRB) that (i) facilitates feedstock handling, (ii) increases bulk density and (iii) favour transports by broadly applied timber trucks. At the so-called "green state", bundled logging residues feature a WC of between 55 wt% (Scots pine) and 45 wt% (Norway spruce). During summer season logging residues stored at piles (windrows) at roadside landing; WC can decrease to approximately 25 wt% within one month of storage duration (uncovered storage). In case of storing loose LR uncovered for about 9 months, the WC increases again to wt40 % - due to contamination with snow and rain[5] *(Pettersson, 2007, p. 782f)*.

Further properties of logging residues bundles, e.g. ash content and caloric value, are also altered during storage process, but will not be elaborated here. Instead, the focus is put on the impact of water content on logistics processes. WC influences considerably *bulk density* and *dry matter loss* which represents two important parameters for transport, handling and storage. The former has already been described above.

“Dry matter losses can be caused either by microbial activity, most commonly fungal attacks (biological), or spillage of material during handling and storage (technical).” (Pettersson, 2007, p. 785). Consequently, this parameter reduces the available feedstock quantity at the feedstock source. All dry matter loss rates are defined latter.

The underlying supply scenario implicates storage of logging residue bundles at roadside landing. These compacted logging residues are picked up by a timber truck equipped with a crane. Furthermore, LRB are transferred into wood chips by chipping either at intermediate depots or at decentral conversion plants. The product properties of wood chips are displayed in Table 7.

Table 7: Reference feedstock type for catalytic pyrolysis: wood chips

	Feedstock type	**Wood chips**	*Logging residues from full tree logging operations (hard- an*	
	Conversion technology	Catalytic Pyrolysis	Unit	References
Required specifications	Water content (WC)	8	wt%	*TNO, 2012*
	Particle size (length)	5	mm	*TNO, 2012*
	Impurity	-		
	Ash content	0.54	wt%	*TNO, 2012*
	Net caloric value	16.0	MJ/kg	*Wood fuels handbook, 2008, p. 27*
	Volume-based energy density	4.41	GJ/m³	*TNO, 2012*
	Feedstock costs	80	EUR/t	*Syncom, 2013*
Provided specifications	Provided product 1	Logging residue bundles		*"Brown bundles"*
	Bulk density	254	kg/m³ FM	*Lindroos, O. et al (2010), p. 553*
	Bulk density (dry matter)	165	kg/m³ DM	*Calculation (based on FM and WC)*
	Water content (WC)	34.95	wt%	*Lindroos, O. et al (2010), p. 550*
	Provided product 2	Wood chips (logging residues)		
	Bulk density	276	kg/m³ FM	*Annex (Wood chips)*
	Bulk density (dry matter)	193	kg/m³ DM	*Calculation (based on FM and WC)*
	Water content (WC)	30	wt%	*Francescato, 2008, p. 11, 30*
	Dry matter loss (closed storage)	3	wt% (p.a.)	*Francescato, 2008, p.46*
	Particle size (length)	30	mm	*ÖNORM M 7133 (G30)*
Furhter specifications	Associated risks	Self-heating > 100°C		*Francescato, 2008, p.44*
	Required pre-treatment process	Comminution & drying		

[5] Logging residues can also be stored as compacted residues logs (bundles) produced at roadside landing. This concept implies lower WC rates in case of longer storage times. However, this system is still less well-developed and not broadly applied.

4.2.3 Organic municipal waste for Hydrothermal Carbonization

A third reference pathway has been defined for hydrothermal carbonization (HTC), which is examined by *AVA-CO2*. Here, organic municipal waste is defined as reference feedstock type. Principally, the water content does not play a role for this conversion technology. Instead, problems are encountered with respect to impurities, e.g. glass, metal, etc. detected in the waste. This challenge in processing also induces a pre-treatment process prior to the conversion process: Presorting

Within the BioBoost project it is assumed that organic municipal waste is available at a certain collection point (e.g. waste collection sites). Therefore, the waste collection process is not analysed here. In general, HTC plants are small-dimensioned as opposed to FP and CP plants (more details in Chapter 5). Correspondingly, these plants are designed to be located next to major organic waste collection places. This fact also implies that no logistics processes are examined for this conversion technology. It is assumed that reactors are fed fully automated through screw-conveyor. For the sake of completeness, specifications are made also for organic municipal waste as indicated in Table 8.

Table 8: Reference feedstock type for HTC: organic municipal waste

	Feedstock type	**Organic municipal waste**		
	Conversion technology	HTC	Unit	Reference
Required specifications	Water content (WC)	70	wt%	*TNO, 2013*
	Particle size (length)	50-500	mm	*TNO, 2013*
	Impurity	Problems encountered		
	Ash content	15	wt%	*TNO, 2013*
	Net caloric value (LHV)	16.9	MJ/kg	*TNO, 2013*
	Volume-based energy density	2.96	GJ/m³	*TNO, 2013*
	Feedstock costs	-60	EUR/t	*TNO, 2013*
Provided specifications	Provided product	Compacted organic waste		
	Bulk density (fresh mass)	175	kg/m³ DM	*TNO, 2013 (150-200 kg/m³ DM)*
	Water content (WC)	30	wt%	*TNO, 2013*
	Particle size (length)	50-500	mm	*TNO, 2013*
	Storage placement (assumed)	Organic waste collection point		
Further specifications	Associated risks	None known		
	Required pre-treatment process	Presorting		

Besides these reference feedstock types for the conversion technologies investigated in the BioBoost Project, other biogenic residues (as quoted in the minutes of the telephone conference from October 24th, 2012) might be further analysed in terms of logistics process design (Table 9).

Table 9: Potential feedstock types for further investigation

Conversion technology	Potential feedstock types for further investigation
Fast pyrolysis	Scrap wood A2, Miscanthus, Flour production residue middle fraction
Catalytic pyrolysis	Miscanthus
Hydrothermal carbonization	Spent grains from brewery

4.3 Specification of Assets and Infrastructure used for Biomass Logistics

Based on the feedstock properties, assets and infrastructure used for transport, handling and storage are defined in the following. Simultaneously, this set constitutes the basis for subsequent analyses. Referring back to Figure 4, a dependency of transport assets on storage and handling process exist. Especially, this interdependency determines the costs for handling considerably, as will be shown afterwards.

4.3.1 Loading Devices

Based on the product specifications, loading devices applied for manipulating biogenic residues in practice are identified. Principally, loading devices aims at increasing process efficiency for transport, handling and storage.

The combination of the product and loading device is defined as loading unit. For instance, a 40 m³ roll-off container loaded with wood chips represents a loading unit. A loading device is mainly characterized by its dimensions (metre), payload (ton) and volume, i.e. cargo space (cubic metre).

A square bale also embodies a type of loading device. The assumed reference square bale has the following dimensions: 2.4 x 1.2 x 0.9 m (length x width x height). According to *Krone*, a well-known producer of agricultural machinery, square bales associated with a total weight of 500 kg are feasible *(KRONE, 2012, p. 31)*. Retrieving the product data as introduced above, a bulk density of 193 kg_{FM}/m^3 and 166 kg_{DM}/m^3, respectively, can be calculated.

With respect to transporting wood chips, roll-off containers are broadly applied in practice. Especially for communition at road side landing using a mobile chipper, despite the dependency between chipper and transport mean, roll-off containers enables high utilization rates for both and, thus, reduce total costs. This is due to reduced waiting times for both assets. However, applying roll-off containers requires enough space to manoeuver these containers at roadside landing. Basically, roll-off devices are defined for both farm tractor transports (40 m³) and truck transports (30 m³). All specifications are displayed in Table 10.

Table 10: Loading devices as transport asset

Loading device					
Square bales			Unit		*Ref.: Krone BiG Pack 1290 HDP, Skott (2012)*
	Length	2.40	m		*Round bales features a lower bulk density than square bales (Kaltschmitt, 2009, p.280)*
	Width	1.20	m		
	Height	0.90	m		
	Volume	2.59	m³		
	Weight	500	kg (WC: 14 %)		
	Weight	430	kg DM		
	Bulk density	193	kg/m³ FM		
	Bulk density	166	kg/m³ DM		
Logging residue bundles			Unit		*Ref.: Lindroos et al. (2010), pp. 549-550*
	Length	4.8	m		
	Diameter	0.8	m		
	Volume	2.4	m³		
	Weight	610	kg FM (WC: 34.95%)		
	Weight	397	kg DM		
	Bulk Density	254	kg/m³ FM		
	Bulk Density	165	kg/m³ DM		
Roll-off container 40 m³			Unit		*Ref.: AVE Behältertyp (large size)*
	Length	7	m		Link
	Width	2.4	m		
	Height	2.4	m		
	cargo space	40	m³		
	Payload	13	t		
	Swing door				
Roll-off container 30 m³			Unit		*Ref.: AVE Behältertyp (medium size)*
	Length	5	m		Link
	Width	2.4	m		
	Height	2.6	m		
	cargo space	30	m³		
	Payload	13	t		
	Swing door				

4.3.2 Transport assets

These above specified loading devices are used in combination with transport means. Generally, transport means can be categorized according the transport modes road, rail, waterway, air and pipeline. Within the BioBoost project, only road and rail transportation are examined. Subordinately, transport means are compose of different vehicle and trailer types. For biomass logistics, only road transport and the following vehicle-trailer combinations are analysed for the selected feedstock types (Table 11).

Table 11: Vehicle-trailer combinations considered

Vehicle-trailer combination		Feedstock type	Max. cargo space / payload
Farm tractor and (two) tippers		Wheat straw and wood chips	70 m³ / 21.4 t
Farm tractor and platform trailer		Wheat straw	89 m³ / 18 t
Timber truck		Logging residue bundles	53 m³ / 22.9 t
Farm tractor and hook lift trailer for roll-off containers		Wood chips	40 m³ / 23 t
Truck and drawbar trailer		Wheat straw and wood chips	115 m³ / 25 t
Truck and drawbar/hook lift trailer for roll-off containers		Wood chips	60 m³ / 26 t

By virtue of expert interviews and existing literature, biomass residues are mainly transported on road networks. In general, transport distances in the biomass collection process (pile at roadside towards receiving point) need to be kept down, because of low energy as well as bulk density. Besides that, rail and waterway transportation rely on restricted handling locations (ports, stations and terminals) which require proper infrastructure and induce additional handling and storage costs (large quantities to be shipped). With respect to biomass logistics, these extra costs impose a considerable competitive disadvantage compared to road transportation *(Expert interview 6, 2012).* In terms of energy carriers also considers railway transportation due to high transport volumes that need to be shipped from two nodes within the supply network (form decentral conversion plant to central conversion plant.

As can be seen from Table 11, farm tractors and trucks are analysed for biomass transportation. In the following tables, tractor vehicles are specified:

Table 12: Vehicle properties: farm tractor

Vehicle properties: farm tractor	
Engine power	Four-wheel drive, 140 kW
Fuel consumption rate[6]	54.5 l/100 km
Operating life	8 years
Operating hours	1,500 h/p.a.[7]
Mileage	12,500 km[8]
Average vehicle speed	32.5 km/h
Investment costs	120,000 EUR
Residual value	15,000 EUR

Table 13: Vehicle properties: truck tractor

Vehicle properties: truck tractor	
Engine power	315 kW
Fuel consumption rate	32.5 l/100 km
Operating life	8 years
Operating hours	2,000 h/p.a.[9]
Mileage	75,000 km[10]
Average vehicle speed	55 km/h
Investment costs[11]	95,000 EUR
Residual value	30,000 EUR

Truck tractors are dedicated for transport operations, whereas farm tractors are primarily used for arable farming. This fact is reflected particularly in fuel consumption rates, annual

[6] Fuel consumption is indicated for transport purposes.
[7] Assumption: Days of operation per year: 250 d; hours of operation per day: 6 h.
[8] Assumption: Days of operation per year: 250 d; mileage per day: 50 km.
[9] Assumption: Days of operation per year: 250 d; hours of operation per day: 8 h.
[10] Assumption: Days of operation per year: 250 d; mileage per day: 300 km; 30 % thereof on tolled roads.
[11] Including truck type mounting (*Expert interview 12, 2012*).

mileages and average vehicle speeds (Table 12 and Table 13). Although farm tractors are inferior to truck tractors concerning transport performance, farm tractors are used in practice, especially in Austria. A major reason for that situation is a lack of professionalism in terms of biomass transports, because most farmers organize the transport by themselves and use their available equipment. In contrast, biomass transports in Scandinavia are mostly conducted by truck transportation or even railway transportations. In Finland, for instance, timber trucks are allowed to transport a payload of between 38 and 44 tons, whereas a payload of 17-22 tons for truck transportation is allowed in Central Europe *(Asikainen, Laitila, 2006, p.13)*.

Besides the tractor, also respective trailer types are specified. Principally, the dimensions (length, width, and height) are determined in order to derive the available cargo space and the maximum payload.

Transporting square bales and logging residue bundles implies considerations about stacking plans (Figure 6). The aim of stacking plans is to define the number of loading units that can be transported in order to maximize utilization of cargo space or payload. In doing so, the specifications for loading units and transport assets are applied.

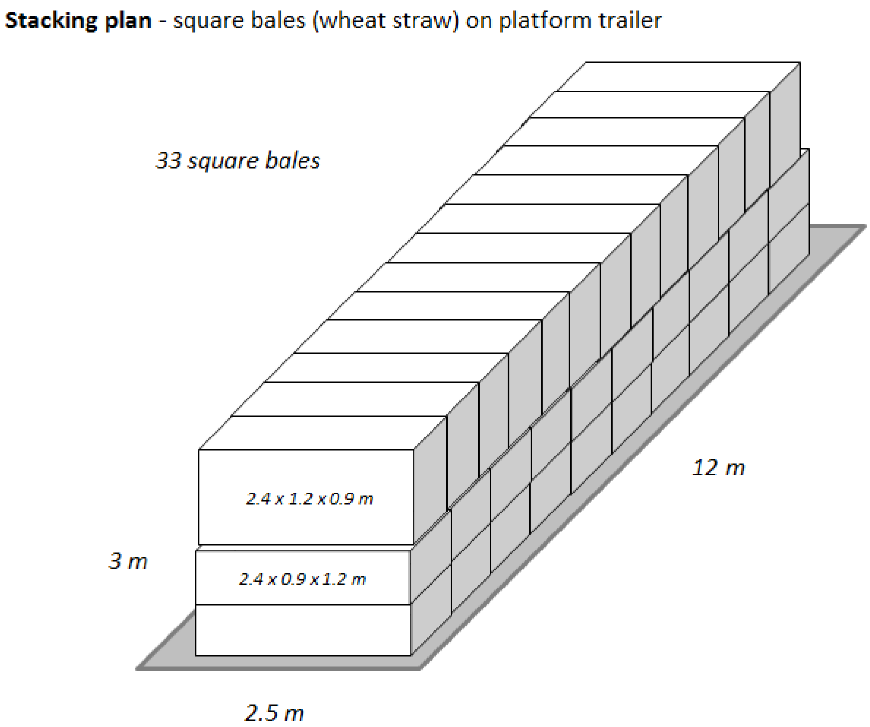


Figure 6: Stacking plan for square bales on a platform trailer

In determining the maximum amount of loading units, the comparison between tippers and platform trailers for square bales yields an increased loading capacity of +27 % (tippers: 26 square bales, platform trailer: 33). A platform trailer features an available cargo space of 88.5 m³ and a maximum payload of 18 tons.

In a next step, the capacity utilization of each vehicle-trailer combination is calculated. In general, full truck loads (FTL) are assumed for road transportation. This implies that either the cargo space or payload is fully utilized for haulage. For terms of biomass transports, it is assumed that there are no back hauls, that is, either vehicle-trailer combination is collecting a full truck load from one feedstock source and transporting to a decentral conversion plant. After unloading cargo, the transport vehicle drives back empty. This situation reduces the transport utilization rates substantially, but enables veritable cost calculation. In order to calculate the real utilization rate, the following formula is applied *(Blauwens et al., 2008, p. 46):*

$$Capacity\ utilization\ of\ transport\ assets\ (payload)$$

$$= \frac{Payload\ utilized_{(Source \to Sink)} + Payload\ utilized_{(Sink \to Source)}}{PayloadPayload\ available_{(Source \to Sink)} + Payload\ available_{(Sink \to Source)}}$$

The same holds true for computing cargo space utilized. Due to the fact that logistics cost rates are defined for tons dry matter, only the payload are considered here. Accordingly, the transport capacity figures are adapted. Table 14 provides an example about specifying capacity utilization of transport assets. A comprehensive list of all selected vehicle-trailer combinations can be retrieved from the annex.

Table 14: Selected vehicle-trailer combination as transport asset

Farm tractor and platform trailer (wheat straw)					
	Trailer	Length	12.0	m	
		Width	2.5	m	
		Height[1]	3.0	m	
		cargo space	88.5	m³	
		Max. payload	18.0	t	
		Square bales	33.0	units	
		Utilization of transport capacity	100%	46%	
		Total square bales	33	15	units
		Total payload available	18.0		t
		Total payload utilized	16.5		t FM
		Total payload utilized	14.2	6.5	t DM
		Total cargo space available	89		m³
		Total cargo space utilized	74		m³ FM

Ref.: Fliegl DPW 180 Dolly

Link

[1] Height of cargo space

4.3.3 Handling Assets

Similar to the transport asset specification, different handling equipment for manipulating biomass used in practice are analysed (Table 15).

Table 15: Handling equipment considered

Handling equipment	
Front-end loaders (farm tractor)	
Truck-mounted crane (timber truck)	
Telescopic handler	
Forklift truck	
Gantry crane	

In practice, different handling equipment is applied at different nodes defined within the BioBoost supply network (Figure 1) depending on the individual use case. Key properties of biomass handling assets are given by lifting height and lifting capacity. For instance, the height of the pile at the field in regard of storing square bales is restricted to the lifting height of front-end loaders, which are broadly used in practice. Moreover, the lifting capacity, that is the number of tons or cubic metre that can be manipulated by one single lift, limits handling performance essentially. In general, telescopic handlers are best suited for handling biomass, although this represents the second most expensive equipment. Front-end loaders imply the highest fuel consumption rates: 18.5 l/h are indicated for a 140 kW farm tractor at middle utilization *(OEKL, 2012)*. However, gantry cranes are assumed to be electrified. Table 16 provides an overview about the specifications made.

Table 16: Handling equipment properties

Handling equipment	Lifting height (m)	Lifting capacity (t and m³)		Annual operating time (h/p.a.)	Fuel consumption rate (l/h)	Investment costs (EUR)
Front-end loaders	3.7	2.0	2.3	1,500	18.5	6,900
Telescopic handler	8.6	5.5	4.0	2,000	7.0	90,000
Forklift truck	3.7	3.5	1.5	2,000	2.5	32,000
Gantry crane	8.0	4.0	4.0	5,000	--	330,000

Gantry cranes represent stationary handling equipment. Despite having a high performance rate (8-12 square bales per lifting *(DBFZ, 2012, p.68; Skøtt, 2011, p.13)*, gantry cranes require infrastructure (building, tracks, etc.). Therefore, the investment costs are significantly higher compared to other handling equipment. Table 17 shows major differences between mobile and stationary handling equipment.

Again, all selected handling assets are characterized in the annex.

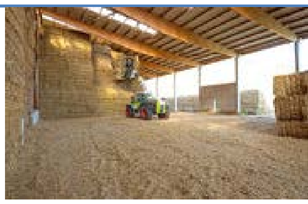
Table 17: Comparison between stationary and transportable handling equipment

Mobile handling equipment		Stationary handling equipment	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Flexible in application	Installation of required transport lanes (increased costs)	During unloading/loading process, water content and weight can be measured	High investment costs (crane and associated infra- and superstructure)
Comparatively low investment costs	Increased risk of accidents, e.g. risky handling in great lifting heights; further: need for safety installations, e.g. crash barriers)	Unloading/loading capacity up to 12 square bales at a time *(Skøtt, 2012)*	Bounded to tracks (limited options to manipulate material)
	Unloading/loading capacity: 1-2 square bales at a time *(Skøtt, 2012)*	Unloading/loading process can be fully automated, reduced hourly costs *(Voith Kransysteme, 2012)*,	
	Longer process lead times due to additional measurements (water content); up to 50 % additional time *(Skøtt, 2012)*	Better lifting height and capacity (t and m³)	

4.3.4 Storage Assets

Storage represents a major element in logistics. The process results from the time span between point in time of production and point in time of consumption. Within a supply network, each network node represents a potential storage location. Three storage locations are investigated in the BioBoost project, in which square bales, logging residue bundles and wood chips can be stored: (1) pile/roadside landing (feedstock source), (2) intermediate depot and (3) decentral conversion plant (Table 18).

Table 18: Storage locations considered

Storage locations (biomass logistics)		Square bales	Wood chips
1	Piles/roadside landing		
2	Intermediate depot		
3	Decentral conversion plant		

Square bales and logging residue bundles are produced and consolidated at the roadside landing in the form of piles. Principally, bales and bundles can be stored uncovered – contamination with rain and snow increases water content – or tarpaulins are used for covered storage. In BioBoost, it is assumed that tarpaulins are used in order to partly reduce the risk of remoistening and dry matter loss. Furthermore, it is assumed, that storage capacity at storage location 1 is unlimited.

In case of ensuring feedstock availability and reducing risk of remoistening, bales and bundles can also be forwarded to an intermediate depot directly after production. There, feedstock quality can be improved considerably (possibility of drying feedstock in closed storages) and dry matter loss can be further decreased. However, setting up an intermediate depot also implies additional costs for operating as well as handling costs. Concerning logging residue bundles additional added value can be executed. That is, LRB can be transformed into wood chips through chipping at the intermediate depot. This allows for lower chipping costs in comparison to mobile chippers at roadside landing.

In any case, feedstocks are further transported to the decentral conversion plant. There a safety stock of a five-day plant throughput is assumed. This figure can be reasoned by means of several publications, e.g. *Trippe et al, 2010, DBFZ, 2012 and FNR, 2005* and can be applied for both fast and catalytic pyrolysis. Correspondingly, this storage location is characterized by high levels of inventory turns.

A further aspect to be considered are risks that arise from storing, especially for storing wet biogenic residues, e.g. logging residues or wood chips. Associated risks are as follows *(FNR, 2005, p.79):*

- Dry matter loss through biological and technical processes (risk of loss)
- Self-heating through biological processes (hazard risk)
- Remoistening through uncovered storage (quality risk)
- Odour nuisance (environmental risk)
- Fungi and sporulation (health risk)

All of these risks will be intensively discussed in a subsequent risk assessment conducted also in the BioBoost project (Task 4.4).

For evaluating storage costs, required infrastructure at the individual storage locations need to be specified. This step includes dimensioning the storage yard and warehouse as well as specifying utilities, e.g. weigh-bridge, office container, etc. needed. First of all, dimensions of the storage yard and warehouses are specified for each storage location. In doing so, experiences from practitioners are applied. Bulky cargo in general are exposed to the angle of repose of piles (storage capacity reductions: 33 % (open storage) and 10 % (closed storage) *(Expert interview 15, 2012)*. Moreover, for reasons of stability, square bales require an interleaving layering in case of stacking. It is assumed that the storage capacity is not reduced, except for closed storage. Due to the roof construction (e.g. gabled roof) and a sufficient space for manipulating square bales in closed storages, an unusable storage capacity of 2 % is estimated. Figure 7 provides an overview about capacity reductions assumed for realistic storage capacities calculation for both open and closed storages. In terms of logging residue bundles, it is assumed that the loading units are stored only outside and are not subject to any storage capacity restrictions.

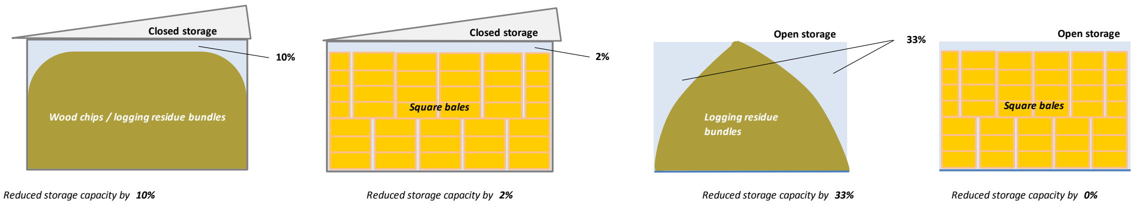


Figure 7: Reduced storage capacity

Based on input data from other BioBoost work packages and an existing study conducted by the *Waldverband Steiermark GmbH (2008)*, the following specifications are made for each storage location.

Table 19: Storage building specification

Storage building specifications	Piles / roadside landing		Intermediate depot (closed)		Intermediate depot (open)		Decentral conversion plant	
	Square bales	Logging residue bundles	Ware-house 1	Ware-house 2	Yard 1	Yard 2	Ware-house FP	Ware-house CP
Dimensions of storage yard / warehouse (length x width x height; m)	-[12]		40 x 25 x 7	40 x 25 x 7	50 x 30 x 8.6	50 x 30 x 8.6	80 x 33 x 8	65 x 33 x 8
Storage capacity (m³) (theoretical, feasible)[13]			7,000 theoretical	7,000 theoretical	12,900 theoretical	12,900 theoretical	18,346 feasible	13,284 feasible

Filling heights at open storage yards are restricted by lifting heights of the handling equipment. The dimensions for the intermediate depot are aligned with the study conducted by *Waldverband Steiermark GmbH (2008)*. This type of intermediate depot serves as a reference type for the logistics model. Specifically, an intermediate depot is able to store more than one feedstock type. The dimensions of the storage at the decentral conversion plant are selected in a way that both the capacity required for safety stock (correspond to a five-day plant throughput as defined above) as well as technical aspects (track length, lifting height.) of the gantry crane can be satisfied.

[12] Generally, it is assumed that the storage capacity at storage location 1 is not restricted to footprint.
[13] As the intermediate depot is not dedicated to a certain type of feedstock, only theoretical storage locations as per dimension can be indicated. In contrast, warehouses at decentral conversion plants are built for storing either square bales or wood chips. Therefore capacity reduction rates as indicated in Figure 7 are applied.

With respect to defining storage capacity, also sealed area for transport and handling activities are incorporated at intermediate depots as well as at the decentral conversion. For instance, Figure 8 shows a draft layout plan for storage at a fast pyrolysis plant. Approximately 300 m² are dedicated for a loading/unloading area, where square bales can be manipulated by a gantry crane within a closed warehouse.

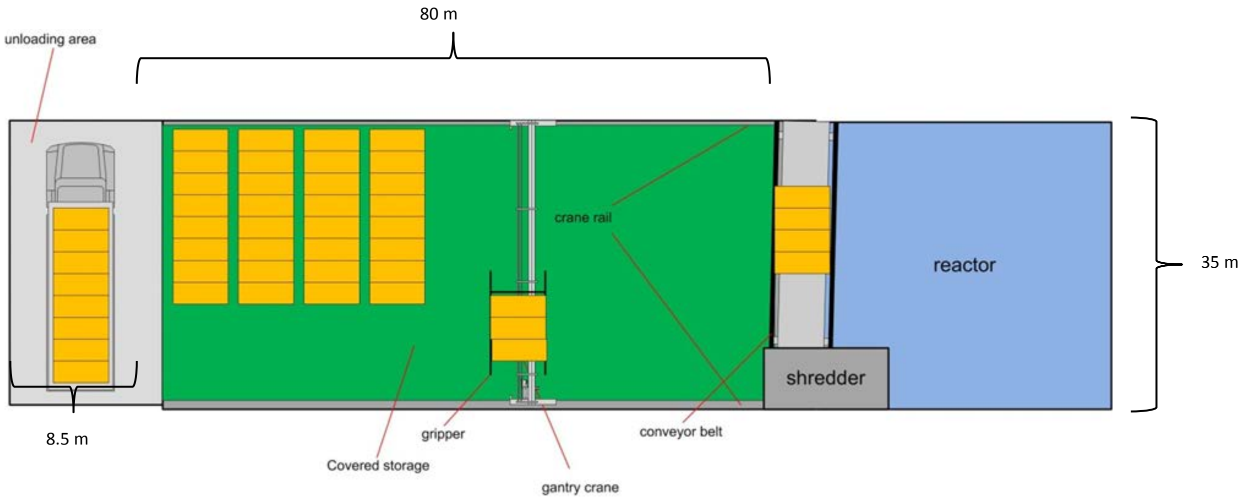


Figure 8: Draft layout plan for storage at DCP (FP)

Referring back to the question of whether to implement an intermediate depot or not depends on several factors. The following table provides a first overview about pros and cons of each individual supply path.

Table 20: Pros and cons of storage at pile/roadside landing and intermediate depot

Factor	Storage at	
	Pile / roadside landing *(square bales/ logging residues)*	**Intermediate depot** *(square bales/wood chips)*
Dry matter loss	High	Medium
Risk of remoistening	High	Low
Risk of self-heating	Low	High
Storage and handling costs	Low	High
Transport costs	High	Medium
Local weather conditions *Suitable for*	Dry climate zones *Southern Europe*	Humid climate zones *Central and Northern Europe*
Security of supply	Medium	High

As already mentioned above dry matter losses occur due to microbial activities on the one hand side and spillage during handling and storage processes on the other hand side. For instance, bottom parts of logging residues are left at roadside landing due to soil contamination. Biogenic residues associated with high water content, e.g. logging residues, generally imply a higher dry matter loss. This can mainly be ascribed to metabolic activities. However, dry matter loss increases by decreasing particle size, that is, wood chips are prone to dry matter loss, too. This is because of three major aspects *(Ashton et al, 2007):*

1) chipped biomass exhibit an increased area of exposed surfaces on which microbial activity can occur,
2) the smaller the particle size is, the less air flows through piles and, thus, prevents heat dissipation, and
3) chipping releases the soluble material of plant cells providing microbes with nutrients

The risk of remoistening is higher at piles and roadside landing due to insufficient shelter against weather, whereas closed storage enables higher drying rates. Further, microbial activities generate heat inside the piles. Again, the higher water content is, the higher the risk of self-heating. On a cost level, additional storage and handling costs in case of implementing an intermediate depot are confronted with higher transport costs that arise due to an increased number of trips towards a decentral conversion plant. This research question is examined in detail later within the cost analyses. Local weather conditions also influence the decision on whether to store at field or at an intermediate depot. Dry climate zones, e.g. Southern Europe, clearly favour storage at pile/roadside landing, whereas humid climate zones account for considering intermediate depots. Finally, the security supply constitutes a further aspect which favours the implementation of intermediate depots. Risk pooling is a concept of addressing variability in supply chains. This approach suggests that demand variability is reduced if demand is aggregated across locations. In general, this reduction in volatility accounts for a decrease in safety stock and therefore reduces average inventory levels *(Simchi-Levi, 2008, p.48).* This issue is crucial especially for supplying biomass. Due to high uncertainty arising through weather condition, harvest time and crop yield, an intermediate depot represents a mean of increasing supply security substantially.

4.4 Cost Calculations for Biomass Logistics Processes

Regarding cost calculations for biomass logistics processes, the following assumptions hold:

- *Fixed operating costs for each asset are investigated*
- *All costs are given on a net basis (excluding value added taxes)*
- *Annual interest rate is given by 4 % p.a.*
- *Fuel costs (diesel) amounts to 1.27 EUR/l*
- *Maintenance rate are as per VDI 2067*
- *Labour costs (gross wage) are given by 22.53 EUR/h or 35,820 EUR p.a. (details see Annex)*
- *No subsidies are considered*

As already indicated in Table 3 the target metrics are EUR/t (DM)*km or EUR/t (transport process) and EUR/t (DM) (handling and storage process). Cost rates for biomass are indicated on a dry matter basis. In practice, a prevalent billing option is given by invoicing biomass based on a dry matter basis *(Expert interview 15, 2012).*

4.4.1 Transport Costs

Based on the specifications made above concerning transport assets, all vehicle-trailer combinations are evaluated according to their operating costs. Specifically, distance variable costs (DVC), as well as distance fixed costs (DFC) are identified. Table 21 shows cost elements considered for transport costs evaluation. As already mentioned, dry matter basis represents a meaningful basis for biomass logistics cost calculation. Because of applying a real world routing network for Europe within the BioBoost project, transport costs need to be aligned with the holistic logistics model. Therefore, transport costs are calculated in the form of EUR/$t_{(DM)}$ *km.

Table 21: Cost elements considered for transport process

Cost elements	Distant fixed costs *DFC*	Distant variable costs *DVC*
Depreciation	x	
Maintenance	x	
Interest on investment	x	
Insurance	x	
Labour	x	
Tyres		x
Fuel		x
Lubricants		x
Road charges		x[14]

First of all, total annual direct costs are computed for each vehicle-trailer combination by means of the cost elements depicted above. Most of these costs are determined through consulting practitioners (see list of interviewed expert in Chapter 9.1) and standard values published by the Austrian Council for Agricultural Engineering and Rural Development (*Österreichisches Kuratorium für Landtechnik und Landentwicklung – ÖKL*). Costs for both vehicle (tractor unit) and trailer are surveyed. Besides indicating the annual operating cost, also performance-related data of each individual vehicle-trailer combination need to be specified. The following data are indicated (Table 22):

[14] Road charges arise only for truck transports. Here, it is assumed that 30 % of annual mileage concern tolled roads.

Table 22: Performance-related data for transport process

Performance-related data	Unit
Days of operating per year	d/yr
Operating hours per day	h/d
Operating hours per year	h/yr
Daily mileage	km/d
Mileage per year	km/yr
Mileage per year on tolled roads	%
Payload utilized	t (DM)
Fuel consumption rate	l/100 km[15]
Average vehicle speed	km/h

These data are required in order to break down the total annual operating costs towards (i) daily cost rates, (ii) hourly cost rates, (iii) kilometre cost rates and finally (iv) ton-kilometre cost rates.

The defined calculation scheme (Table 23) is introduced using the example of calculating transport costs for a farm tractor and a platform trailer. First, performance-related data as illustrated in Table 22 (orange-coloured cells) are defined according to both specifications made before (i.e. payload utilized) and experiences from practitioners. Farm tractors are primarily dedicated to agricultural applications. Therefore, daily operating hours are reduced to 6 hours (truck: 8 hours). Provided that farm tractors are operated 250 days each year, total operating hours per year amounts to 1,500 h. Moreover, practical experiences report that farm tractors exhibit a daily mileage of 50 km. In contrast, trucks are assumed to cover 300 km each day or 75,000 km each year (annual operating days: 250). This figure, of course, is indicated for transporting biomass with trucks and cannot be compared to mileage of logistics service provides which is considerable higher.

In total, a farm tractor and platform trailer induce annual costs of 72,776 EUR. Breaking total annual costs down to costs per ton-kilometre, it is assumed that a farm tractor is able to transport 6.5 tons (DM) of square bales for 32.5 km per hour. Finally, costs for using a farm tractor and platform trailer amounts to 0.23 EUR/t (DM) km

[15] Fuel consumption rates represents average values which also takes into account empty runs

Table 23: Calculation scheme for transport costs (example: farm tractor and platform trailer)

Farm tractor and platform trailer (wheat straw)				
Interest rate	%	4	Link	*Status: October 2012*
Days of operating per year	d/yr	250	250	*Expert interview*
Operating hours per day	h/d	6	Link	*Expert interview*
Operating hours per year	h/yr	1,500	Link	
Daily mileage	km/d	50	50	*Expert interview*
Mileage per year	km/yr	12,500	12,500	
Mileage per year on tolled roads	%	0	0	
Fuel cost	EUR/l	1	Link	*Status: October 2012, net price*
	Unit	Motor vehicle	Platform trailer	
Max. payload	t	0.0	18.0	
Capacity utilization	%		46%	
Payload utilized	t DM	0.0	6.5	
EU emission classification	class	IV	0	
Fuel consumption	l/100 km	54.50	0	*Handler, 2012*
Number of axles		2	2	
Number of tyres needed		4	12	
Service operating life	years	8	6	Link
Average vehicle speed	km/h	32.5	32.5	*Handler, 2009*
Investment costs with tyres	EUR	120,000	20,000	*net price, expert interview*
Residual value	EUR	15,000	10,000	*ÖKL, 2012*
Depreciation	EUR/yr	13,125	1,667	
Maintenance costs	EUR/yr	3,521	546	*ÖKL, 2012, excl. Tyres*
Interests on investment	EUR/yr	2,400	400	
Insurance costs	EUR/yr	200	20	*Expert interview*
Labour costs	EUR/yr	35,820	0	*see Annex*
Price per tire	EUR/ unit	7,000	400	*net price; expert interview*
Running distance of tyres	h	4,000	4,000	*Expert interview*
Cost for tyres	EUR/yr	2,625	1,800	
Fuel costs	EUR/yr	8,652	0	
Lubricant costs	EUR/yr	2,000	0	*Expert interview*
Road charges	EUR/yr	0	0	
Annual costs	EUR/yr	68,343	4,433	
Total annual fixed operating costs	**EUR/yr**	**72,776**		*net for transport combination*
Daily rate	EUR/d	291.10		
Hourly rate	EUR/h	48.52		
Kilometer rate	EUR/km	1.49		
Ton-kilometer rate	EUR/tkm	0.23		
Emission factor	kg CO2/l	2.62		Link
Fuel consumption	l/tkm	0.08		
CO2 Emissions	kg Co2/tkm	0.22		
Cost for idle times	EUR/h	38.47		

Transport costs for all other vehicle-trailer combinations are calculated likewise. Table 24 provides an overview of all other transport cost rates. As biocoal is also assumed to be transported by truck (silo truck) also the transport cost rates for this vehicle is evaluated at this stage.

Table 24: Transport cost rates

Transport Asset	Unit (tons dry matter)	Transport costs for: Wheat straw	Wood chips	Logging residue bundles	Biocoal
Farm tractor and tippers	EUR/t_{DM}km	0.45	0.25		
Farm tractor and hook lift trailer	EUR/t_{DM}km		0.48		
Farm tractor and platform trailer	EUR/t_{DM}km	0.23			
Truck and drawbar/hook lift trailer	EUR/t_{DM}km		0.29		
Truck and drawbar trailer	EUR/t_{DM}km	0.15	0.11		
Timber Truck	EUR/t_{DM}km			0.42	
Silo truck	EUR/t_{DM}km				0.17

In order to receive insights into the composition of total annual operating costs of all other vehicle-trailer combinations, an overview is provided in (Table 25).

Table 25: Overview about total annual direct costs of all vehicle-trailer combinations

Breakdown of total annual direct costs	Unit	Farm tractor and tippers (wheat straw, wood chips)	Farm tractor and platform trailer (wheat straw)	Farm tractor and hook lift trailer for roll-off container (wood chips)	Truck and drawbar trailer (wheat straw, wood chips)	Truck and drawbar/hook lift trailer for roll-off-container (wood chips)	Timber truck (logging residue bundle)	Silo truck	Mean values	Rel.Share	Main cost elements
Depreciation	EUR/yr	17,125	14,792	18,875	14,625	16,375	17,875	20,000	17,095	17%	17%
Maintenance costs	EUR/yr	4,541	4,067	4,694	10,000	14,000	14,000	8,000	8,472	9%	9%
Interests on investment	EUR/yr	3,080	2,800	2,620	3,240	3,420	3,660	3,800	3,231	3%	
Insurance costs	EUR/yr	240	220	240	2,600	2,600	2,600	2,500	1,571	2%	
Labour costs	EUR/yr	35,820	35,820	35,820	35,820	35,820	35,820	35,820	35,820	37%	37%
Cost for tyres	EUR/yr	3,825	4,425	3,525	3,600	3,600	3,600	3,600	3,739	4%	
Fuel costs	EUR/yr	8,652	8,652	8,652	30,956	30,956	30,956	30,956	21,397	22%	22%
Lubricant costs	EUR/yr	2,000	2,000	2,000	2,477	2,477	2,477	2,477	2,272	2%	
Road charges	EUR/yr	0	0	0	7,277	7,277	7,277	7,277	4,158	4%	
Total annual operating costs	EUR/yr	75,283	72,776	76,426	110,594	116,524	118,264	114,429	97,756		85%

Taking the mean values of each cost element introduced in Table 25, the following major cost drivers can be identified: (i) depreciation, (ii) maintenance costs, (iii) labour costs and (iv) fuel costs (Table 26) More specifically, these costs types represent 85 % of total annual operating costs (mean values). Accordingly, this set of cost elements are further used to allocate transport costs to the BioBoost study area by setting up proper indices. As can be seen in the annex, evaluated indices can be retrieved. These data are based on statistics published by the European Union as well as experiences from sales experts of a transport vehicle manufacturer. Construction costs have already been analysed in another work package. These data also serves as input parameter for the holistic logistics model.

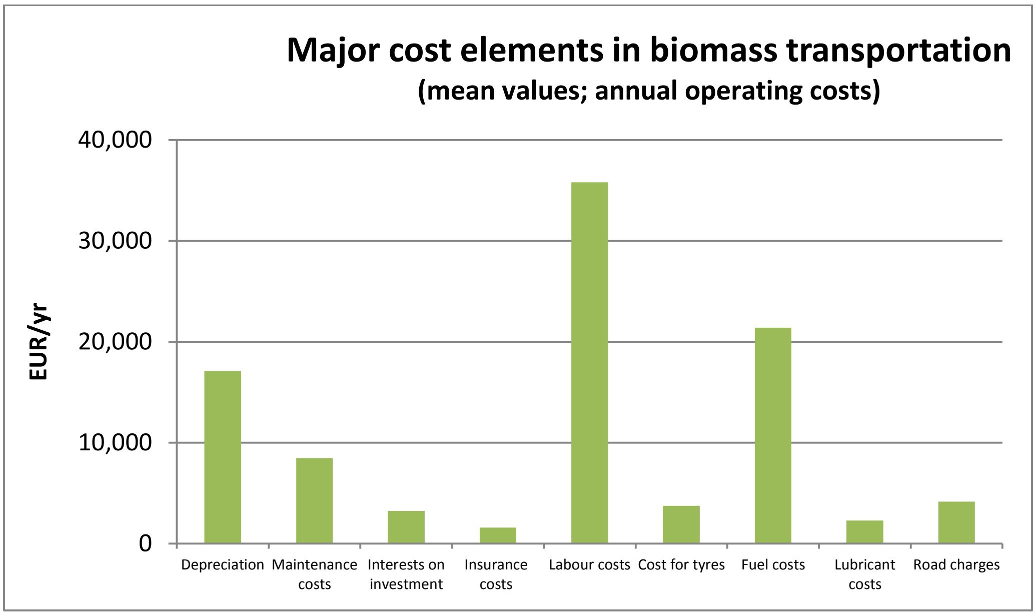


Table 26: Major cost elements in biomass transportation

4.4.2 Handling Costs

Four different handling assets are investigated in this report: (i) front-end loader (farm tractor), (ii) telescopic handler, (iii) forklift truck, and (iv) stationary gantry crane. In order to evaluate this equipment, hourly operating cost rates (EUR/h) are calculated. Table 27 provides an insight into the underlying calculation scheme.

Handling assets are evaluated based on fixed and variable costs. Figures are primarily taken from existing studies. For instance, a telescopic handler costs 34.85 EUR per hour. Besides that costs also idle times (waiting costs) of vehicle-trailer combination need to be considered. For this purpose, hourly distance fixed costs (DFC) are taken as waiting costs. Then, performance-related data (e.g. handling lead time per vehicle) are defined for wheat straw, logging residue bundles and wood chips.

Starting from a fully utilized payload of each investigated transport asset (Table 14, t DM (100%)), productivity (t DM/h) for each handling asset can be determined. Taking both hourly cost rates as already described and productivity rates, handling costs (EUR/t DM) can be defined for each handling equipment and vehicle-trailer combination. Furthermore, simple stock transfers, which do not consider a waiting vehicle-trailer combination, are evaluated.

In addition to the four handling assets, tipping process, handling roll-off containers, pumping activities at silo trucks and truck-mounted crane handling are evaluated in addition to the handling assets mentioned above.

Table 27: Calculation scheme for handling costs

Telescopic handler						
Investment costs	EUR	90,000	*Schnedl, 2008*			
Operating hours	h/yr	2,000	*DBFZ, 2012, p.67*			
Fixed costs	EUR/h	9.15	*DBFZ, 2012, p.67*			
Variable costs	EUR/h	25.70	*DBFZ, 2012, p.67*	*including labour costs*		
Hourly rate	EUR/h	34.85				
Handling equipment - total hourly rate	EUR/h	34.85	*including labour costs*			
Farm tractor and tippers	EUR/h	40.51	Cost for idle times (waiting)			
Farm tractor and platform trailer	EUR/h	38.47				
Truck and drawbar trailer	EUR/h	33.14				
Wheat straw						
Assumed lead time per handling process	1.5	min				
Handling capacity	1.29	t (DM)	*equals handling 3 square bales per lifting*			
Lead time II	1.2	min/t DM				
Performance data	Payload utilized (t DM)	Lead time I (min/vehicle)	Lead time II (min/t DM)	Productivity (t DM/h)		Handling cost (EUR/t DM)
Farm tractor and tippers	11.2	13	1.2	52		1.46
Farm tractor and platform trailer	14.2	17	1.2	52		1.42
Truck and drawbar trailer	17.2	20	1.2	52		1.32
Stock transfer			1.2	52		0.68
Wood chips						
Assumed lead time per handling process	1.5	min				
Handling capacity	0.8	t (DM)				
Lead time II	1.9	min/t				
Performance data	Payload utilized (t DM)	Lead time I (min/vehicle)	Lead time II (min/t DM)	Productivity (t DM/h)		Handling cost (EUR/t DM)
Farm tractor and tippers	11.2	22	1.9	31		2.44
Truck and drawbar trailer	17.2	33	1.9	31		2.20
Stock transfer			1.9	31		1.13

Table 28 provides an overview about all calculated handling cost rates.

Table 28: Handling cost rates

		Handling costs for				
Transport Asset	*Handling Asset*	*Unit (tons dry matter)*	Wheat straw	Wood chips	Logging residue bundles	Biocoal
Farm tractor and tippers	Front-end loaders (farm tractor)	*EUR/t$_{DM}$*	3.06	6.05		
Farm tractor and platform trailer		*EUR/t$_{DM}$*	3.01			
Truck and drawbar trailer		*EUR/t$_{DM}$*	2.85	5.62		
Stock transfer		*EUR/t$_{DM}$*	1.89	3.72		
Farm tractor and tippers	Telescopic handler	*EUR/t$_{DM}$*	1.46	2.44		
Farm tractor and platform trailer		*EUR/t$_{DM}$*	1.42			
Truck and drawbar trailer		*EUR/t$_{DM}$*	1.32	2.20		
Stock transfer		*EUR/t$_{DM}$*	0.68	1.13		
Farm tractor and tippers	Gantry crane	*EUR/t$_{DM}$*	0.95	4.22		
Farm tractor and platform trailer		*EUR/t$_{DM}$*	0.93			
Truck and drawbar trailer		*EUR/t$_{DM}$*	0.89	3.98		
Stock transfer		*EUR/t$_{DM}$*	0.65	2.91		
Farm tractor and tippers	Forklift truck	*EUR/t$_{DM}$*	2.11	6.27		
Farm tractor and platform trailer		*EUR/t$_{DM}$*	2.05			
Truck and drawbar trailer		*EUR/t$_{DM}$*	1.89	5.63		
Stock transfer		*EUR/t$_{DM}$*	0.93	2.77		
Farm tractor and tippers	Tipping (unloading)	*EUR/t$_{DM}$*		0.15		
Truck and drawbar trailer		*EUR/t$_{DM}$*		0.08		
Timber truck (logging residue bundle)	Crane	*EUR/t$_{DM}$*			1.06	
Silo truck	Pumping	*EUR/t$_{DM}$*				1.16
Farm tractor and hook lift trailer	Handling roll-off container	*EUR/t$_{DM}$*		0.22		
Truck and drawbar/hook lift trailer		*EUR/t$_{DM}$*		0.26		

In the search of the most appropriate handling asset for each reference feedstock type, the following inferences can be concluded. Gantry cranes indicate the lowest costs for handling wheat straw (square bales). This type of crane is able to simultaneously handle up to 12 bales per lifting (*Skøtt, 2011, p. 13).* However, in this analysis the handling capacity is restricted to 8 square bales according to the assumed lifting capacity of the gantry crane (4 ton). This figure corresponds to assumption made in *DBFZ, 2012, p. 68*. Furthermore, transferring square bales within the storage, gantry cranes seem to be the most efficient option. Facing different storage locations, gantry cranes are primarily applied at decentral conversion plants because of high investment costs. Front-end loaders (farm tractor), which represents the most expensive way of handling square bales, are mostly used at the feedstock source (pile at field), whereas telescopic handler are deployed at intermediate depots.

Handling cost rates for wood chips are generally higher than for square bales. This disparity can be reasoned by looking at provided feedstock specifications. Although wood chips have a clear advantage in terms of bulk density (193 kg/m³ DM) compared to wheat straw (166 kg/m³ DM), handling equipment which manipulate loose products are restricted by their volumic lifting capacity (in m³; loading shovel capacity). Therefore, handling is constrained rather by lifted volume than by lifted weight when it comes to handling loose products. In contrast, wheat straw is compacted to square bales, which results in increased efficiency in handling operations. The handling equipment is mostly restricted by lifted weight than by lifted volume. Consequently, the weight-related lifting capacity (tons DM) of handling assets is considerably lower for wood chips than for square bales (see Table 27).

Front-end loaders and fork lift trucks seem to be highly inappropriate for wood chips due to restricted lifting capacities. Although telescopic handler and gantry cranes exhibits the same lifting capacity (4 m³), gantry cranes seems to be unattractive, too. This is caused by high hourly costs of this handling asset (89.64 EUR/h) compared to the hourly cost for a telescopic handler (34.85 EUR/h). This same holds true for simple stock transfers.

However, the lowest handling costs for wood chips feature the manipulation by means of roll-off containers and the tipping process. This can be traced back to the ability to load and unload a vast amount of biogenic residues within a short period of time without required additional handling equipment.

4.4.3 Storage Costs

Inventory holding costs include variable costs (i.e. capital costs[16]) and fixed operating costs, e.g. warehousing, depreciation, insurance, etc. Here, storage costs are defined by fixed annual fixed operating costs and annual throughput quantities. Storage costs (EUR/t DM) are examined for wheat straw (square bales), logging residue bundles as well as for wood chips and for each storage location. Organic municipal waste is not regarded, because HTC plants are supposed to be located right next to waste collection yard.

On the basis of predefined supply scenarios for each reference feedstock, data on average storage periods and dry matter loss are provided. Expect for storage at decentral conversion location, these data are derived from expert interviews and existing literature on biomass logistics and are documented in the database. For dry matter losses at intermediate depots, the average value between open and closed storage is taken. As to data defined for storage at DCP, storage periods are computed by days of inventory (safety stock) as assumed above.

[16] Capital costs represent opportunity costs for the capital that is tied up in inventory.

Dry matter losses are given by loss rates defined for closed storage at intermediate depots. Table 29 provides an overview about key storage parameters. It is further assumed that wood chips are not stored at roadside landing and logging residues bundles are not stored at decentral conversion plants because of direct processing (e.g. logging residues are directly chipped into roll-of containers).

Table 29: Storage periods and dry matter losses assumed for storage locations

			Feedstock types		
Storage periods	*Storage location*	*Unit*	Wheat straw	Logging residue bundles	Wood chips
Pile/roadside landing	1	months	6.00	12.00	-
Intermediate depot	2	months	3.00	3.00	3.00
Decentral conversion plant	3	months	0.17	-	0.17
			Feedstock types		
Dry matter loss (within storage period)	*Storage location*	*Unit*	Wheat straw	Logging residue bundles	Wood chips
Pile/roadside landing	1	wt%/month	1.33%	0.25%	-
Intermediate depot	2	wt%/month	0.83%	0.29%	0.50%
Decentral conversion plant	3	wt%/month	0.33%	-	0.33%

The calculation scheme is introduced using the example of an intermediate depot (Table 30). Based on the specifications made for an intermediate depot, investment costs are defined in an initial step. Each storage location is assessed according to its total annual fixed operating costs including (i) depreciation, (ii) interests on investments, (iii) maintenance and (iv) labour costs. Cost figures are taken from the report conducted by *Waldverband Steiermark GmbH, in 2012 (p. 209f)*. Costs for real estate are disregarded due to major regional differences within the study area. Regarding labour costs, practitioners stated that one full-time and one part-time worker are required for operating an intermediate depot in that order *(Expert interview 15, 2012)*. In total, the calculation yields annual operating fixed costs of 108,930 EUR for an intermediate depot. By means of storage capacities and storage periods (defined above) for each feedstock the annual throughput quantity is calculated. Finally, storage costs per ton dry matter are computed as the quotient of annual fixed operating costs and annual throughput quantities of each individual feedstock type[17]. The same procedure applies for storage costs at DCP. With respect to storage costs for piles at roadside landing, storage costs are not subject to plot areas. Thus, only costs for tarpaulins of 1.99 EUR/t DM are

[17] For the sake of simplicity in terms of calculating storage costs at ID for each feedstock type, it is assumed that only one type of feedstock is stored at that storage location.

quoted for both wheat straw and logging residue bundles *(DBFZ, 2012, p. 67)*. Table 31 illustrates all storage cost rates evaluated.

Table 30: Calculation scheme for storage costs

Storage location2:	*Intermediate depot*			
Interest rate	%	4		
		Investment	Depreciation	Maintenance
Plot area paved	EUR	300,000	12,000	3,000
Sealed area for transport	EUR	75,000	3,000	750
Sealed area for closed storage	EUR	30,000	1,200	300
Sealed area for open storage	EUR	45,000	1,800	450
Warehouse	EUR	300,000	12,000	3,000
Weigh-bridge	EUR	30,000	1,500	600
Office container and equipment	EUR	10,000	2,000	100
Total costs	EUR	780,000	31,500	8,100
Annual fixed operating costs				
Depreciation	EUR/yr	31,500		
Interests on investment	EUR/yr	15,600		
Maintenance	EUR/yr	8,100		
Labour	EUR/yr	53,730		
Total annual fixed operating costs	EUR/yr	108,930		
		Wheat straw	Logging residue bundles	Wood chips
Storage capacity	t (DM)/yr	6,556	2,856	5,764
Annual throughput	t (DM)/yr	26,225	11,424	23,054
Storage costs per ton	EUR/t (DM)	4.15	9.53	4.72

Table 31: Storage cost rates

			Storage costs for		
Storage costs	*Storage location*	*Unit (tons dry matter)*	Wheat straw	Logging residue bundles	Wood chips
Pile/roadside landing	1	EUR/t_{DM}	1.99	1.99	-
Intermediate depot	2	EUR/t_{DM}	4.15	9.53	4.72
Decentral conversion plant	3	EUR/t_{DM}	0.61	-	0.56

The considerable difference of storage costs between intermediate depots and decentral conversion plants can be explained by looking at inventory turnover rates. Inventory positioned at ID is turned four times per year, whereas stock at DCP features an inventory turnover rate of about 58 (warehouse FP) and 71 (warehouse CP).

After designing and evaluating logistics processes for biogenic residues, the focus is put on energy carriers which are produced at decentral conversion plants. Three reference energy carriers are investigated: biosyncrude, catalytic oil and biocoal. As worked out in this chapter, the following analyses also aim at defining essential input data for the holistic logistics model as depicted in Figure 1.

5 Energy Carrier Logistics – Designing and Evaluating Logistics Processes

Referring back to Figure 3, the second part of the supply chain, i.e. energy carrier logistics[18], is examined. Similar to the chapter before, product characteristics are described first. Then, the associated logistics equipment used in practice is defined. Finally, the logistics processes transport and handling are evaluated in order to obtain a cost rate. By setting system boundaries, the second part of the supply chain considered in the BioBoost project is introduced briefly.

5.1 Energy Carrier Supply Chain in Detail

After supplying decentral conversion plants with biogenic residues, feedstocks are converted into energy carries. With respect to logistics operations, the fully-automated conversion processes play a minor role. Instead, the focus in WP 4 is further put on transport and handling produced energy carrier. It is assumed that products are stored in silos which represent an integrated component of the conversion plants considered. Thus, storage costs for energy carrier are not considered in both plant types, decentral conversion plant (DCP) as well as central conversion plant (CCP). Figure 9 delineates a scheme of evaluated logistics processes for each conversion technology.

In alignment with WP 1, a transfer location is set for each reference feedstock type. All pre-treatment processes, e.g. harvesting, pressing, forwarding, etc., are analysed in WP 1. In other words, logistics operations start '*ex feedstock placed into field storage*'. Along the supply chain, some alternatives of logistically manipulating products are possible. These are denoted by yellow cycles. This scheme serves as a framework for final managerial implications introduced in Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**.

[18] Energy carrier corresponds to the term *intermediate*.

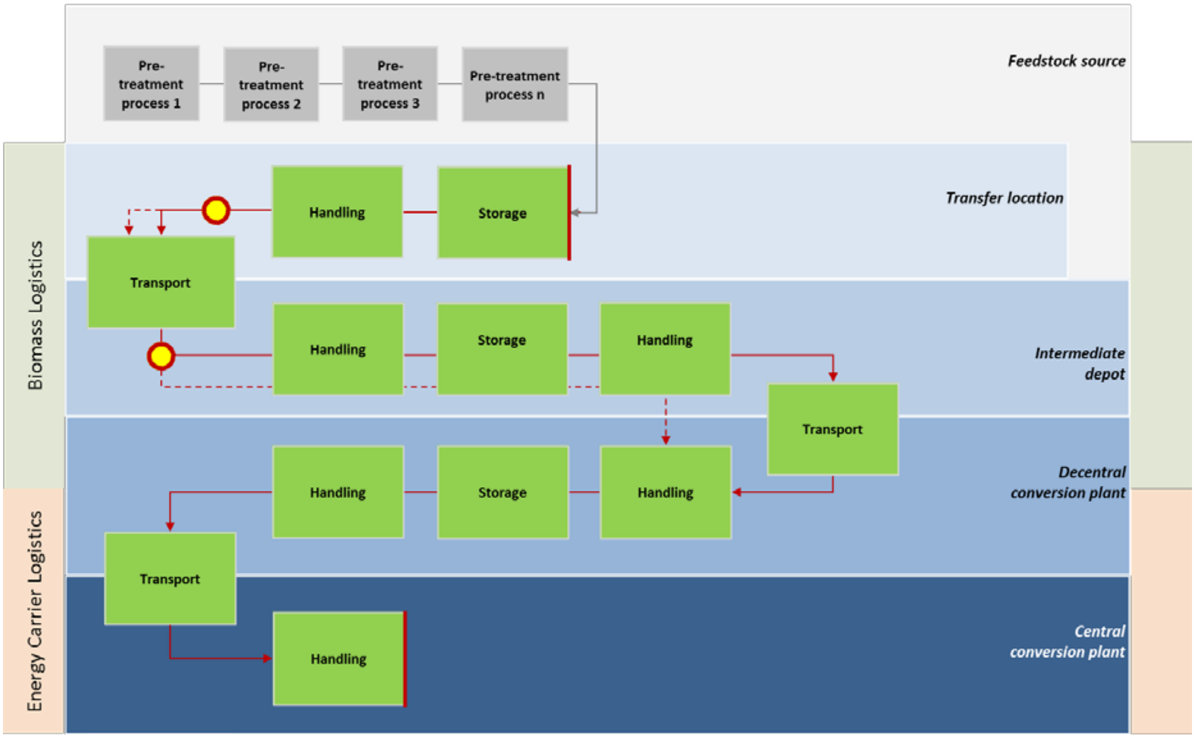


Figure 9: Biomass and energy carrier supply chain in detail

5.2 Specification of Decentral Conversion Process

Three conversion technologies are investigated in BioBoost: (i) fast pyrolysis (FP), (ii) catalytic pyrolysis (CP) and (iii) hydrothermal carbonization (HTC). The reason for conducting information on the conversion process is about determining throughput rates for the logistics processes which impacts the design of logistics operations considerably. For instance, rail transportation should be considered in case of facing high production quantities which are forwarded applying direct transports[19]. Table 32 provides an overview of input (biomass) and output (energy carrier) quantities of each conversion process in the form of daily throughput rates. In addition, the energy production capacities as well as a mass conversion factors are defined.

[19] Direct transports imply shipments of products from location A to B without changing transport mean.

Table 32: Specification of decentral conversion processes

Decentral conversion process	*Unit*	Fast Pyrolysis	Catalytic Pyrolysis	Hydrothermal Carbonization
Energy production capacity	MW/yr	88.2	50.0	5.1
Input (biomass)	t DM/d	600	505	66
Output (energy carrier)	t/d	406	132	46
Mass conversion factor		0.68	0.25	0.69

The planned FP conversion plants (88.2 MW/yr) require an annual input quantity (wheat straw) of 175,000 tons per year. The conversion process yields 118,500 tons of the energy carrier *Biosyncrude* each year. This ratio corresponds to a mass conversion factor of 0.68. Furthermore, plants are characterized by technical operating times. A FP plant is supposed to produce 24 hours and thus an annual operating time of 7,000 hours, which already considers idle times (approximately 20 %) due to maintenance, etc., is assumed.

A CP plant (50 MW) requires 180,000 tons (DM) of wood chips and produces 45,000 tons of catalytic oil each year. Assuming that the plant is 8,000 hours each year in operation, 505 tons (DM) of biogenic residues need to be transported towards conversion plant. Correspondingly, the plant yields 132 tons of catalytic oil each day.

Compared to fast and catalytic pyrolysis, HTC plants represent rather small plants (MW 5.1). Here, 66 t (DM) of organic municipal waste are converted into 46 t biocoal each day. This corresponds to a mass conversion factor of 0.69.

By means of these mass throughputs, railway transportation may be considered as an further transport mean within energy carrier logistics. Especially for fast pyrolysis and catalytic pyrolysis, rail transports may constitute a cost-efficient transport alternative.

5.3 Specification of Energy Carriers

Energy carriers demand higher technical and safety requirements on logistics processes. As a matter of fact, safety standards constitute a crucial issue in designing transport, handling and storage operations. Subsequent to this report, a deeper analysis is conducted on risk assessment and safety requirements along the BioBoost supply chain (Task 4.4). The following tables show some initial properties of energy carrier analysed (Table 33 - Table 35).

Table 33: Specification of biosyncrude

Energy carrier	**Biosyncrude**	
State of matter	Slurry	
Hazard identification		*Shortcut of European hazard symbols*
UN number	3265	
Transport hazard class	8	
Packaging class	II	
Tank code	L4BN	
Mass density	1,200	kg/m³
Caloric value (HHV)	17.04	MJ/kg
Volume-based energy density	20	GJ/m³
Water content (WC)	28.5	wt%

Table 34: Specification of catalytic pyrolysis oil

Energy carrier	**Catalytic pyrolysis oil**		
State of matter	Liquids		
Hazard identification	Xn, Xi and N	*Shortcut of European hazard symbols*	
UN number	3265		
Transport hazard class	8		
Packaging class	II		
Tank code	L4BN		
Mass density	1,100	kg/m³ (DM)	
Water content (WC)	8.6	wt%	
Ash content	0.2	wt%	
Caloric value (HHV)	32	MJ/kg	
Volume-based energy density	35	GJ/m³	
Pour point	-39	°C	
Flash point	29	°C	
Viscosity (pour point)	13.69	cSt (mm²/s)	
Viscosity (flash point)	13.69	cSt (mm²/s)	
Degradation	*Accelerated ageing tests showed an increase in the bio-oil's viscosity but no deposition of material was observed. However it is suspected to form phases after storage for more than a year*		
Cleaning	*Container should be rinsed with aceton or similar polar solvent and afterwards cleaned with soap and water*		
Tank material	*Since it is not suspected for corrosion at normal temperatures regular stainless steel should be sufficient*		

Table 35: Specification of biocoal

Energy carrier	**Biocoal**		
State of matter	Pellets		
Disposal code	190199		
UN number	1361		
Denomination of disposal type	*Abfälle aus Abfallbehandlungsanlagen, öffentlichen*		
Bulk density	1,300	kg/m³	
Bulk density (dry matter)	910	kg/m³	
Caloric value (LHV)	21	MJ/kg	
Volume-based energy density	24.5	GJ/m³	
Water content (WC)	30	wt%	
Ash content	21	wt%	
Flash point	80	°C	

With respect to evaluating logistics operations, bulk density as well as dangerous goods regulations represents two key parameters for the selection of loading devices

5.4 Specification of Assets for Energy Carrier Logistics

Based on the mass throughputs of conversion plants depicted in Table 32, rail transportation are perceived as a highly attractive transport mean for fast and catalytic pyrolysis. Therefore, a logistics service provider has been contacted in order to specify required assets for railway transportation.

Both energy carriers biosyncrude as well as catalytic pyrolysis oil feature the same UN number 3265 *(Corrosive liquid, acidic, organic, n.o.s.).* This property restricts the set of potential loading devices. Table 36 gives insights into the specification of the selected type of tank wagon which comply with the UN number.

Table 36: Specification of tank wagon

Railway transportation					
Tank wagon					
	Length	17.0	m		
	Width	3.1	m		
	Height	4.3	m		
	Cargo space	95	m³		
	Max. payload	65	t		
	Utilization of transport capacity	**Biosyncrude**	**CP oil**		
	Total payload available	65	65	t	*Ref.: VTG 1695.80*
	Total payload utilized	65	65	t	Link
	Total cargo space available	95	95	m³	
	Total cargo space utilized	54	58	m³	
	Total cargo space utilized	57%	61%		

HTC plants incorporate low mass throughputs, biocoal are appropriate for road transportation. More specifically, silo trucks fit the product characteristics best *(Expert interview 18, 2013).* The following specifications are made (Table 37).

Table 37: Specification of silo trucks

Silo truck (biocoal)						
	Truck (container)	Length	8.0	m		
		Container diameter	2.4	m		
		Height	2.9	m		
		cargo space	32.0	m³		
		Max. payload	18.0	t		
		Utilization of transport capacity	100%	50%		
		Total payload available	18.0		t	
		Total payload utilized	18.0		t	
		Total payload utilized	12.6	6.3	t DM	*Ref.: Tropper TN 32/4 AL*
		Total cargo space available	32		m³	Link
		Total cargo space utilized	14		m³	

For handling activities, no special equipment is necessary. All energy carriers are considered to be pumpable, and thus, products are directly feed in the ductwork of the respective conversion plant. Instead workers are required to trigger the pumping process.

5.5 Cost Calculations for Energy Carrier Logistics Processes

By means of the calculation scheme as introduced in Table 23, transport costs for silo trucks are calculated. According to practitioners, investment costs for truck-mounted silos amount to 95,000 EUR. Besides higher investment costs, costs for tires also increase. Overall, the transport costs increase to 0.17 EUR/tkm (DM) (Table 38). The handling costs for a silo truck amount to 1.20 EUR/t (DM), provided that a silo truck is associated with a handling capacity of 13 t (DM) and a handling lead time of 25 min/vehicle *(Expert interview 18, 2013)*.

Table 38: Calculation scheme for silo trucks

Silo truck (biocoal)				
Interest rate	%	4	Link	*Status: October 2012*
Days of operating	d/yr	250		*Assumption*
Operating hours per day	h/d	8	Link	
Operating hours per year	h/yr	2,000		
Daily mileage	km/d	300		
Mileage per year	km/yr	75,000		
Mileage per year on tolled roads	%	30		*Assumption*
Fuel cost	EUR/l	1.27	Link	*Status: October 2012, net price*
	Unit	Motor vehicle	*Additional remarks*	
Max. payload	t	18.0		
Payload utilized	t DM	6.3		
EU emission classification	class	IV		
Fuel consumption	l/ 100 km	32.5	*Handler, 2012*	
Number of axles	units	4		
Number of tires needed	units	12		
Service operating life	years	8	Link	
Average. Vehicle speed	km/h	55.0	*Handler, 2009*	
Investment costs with tires	EUR	190,000	*net price*	*Tropper, 2013*
Residual value	EUR	30,000		
Depreciation	EUR/yr	20,000		
Maintenance costs	EUR/yr	8,000	*Expert interview*	
Interests on investment	EUR/yr	3,800		
Insurance costs	EUR/yr	2,500		
Labor costs	EUR/yr	35,820	*see Annex*	
Price per tire	EUR/unit	400	*net price*	
Running distance of tires	km	100,000		
Cost for tires	EUR/yr	3,600		
Fuel costs	EUR/yr	30,956		
Lubricant costs	EUR/yr	2,477	*8 % of fuel costs*	
Road charges	EUR/yr	7,277	*cost rate per km: 0.3234*	
Annual costs	EUR/yr	114,429	*net*	
Total annual costs	**EUR/yr**	**114,429**	*net for transport combination*	
Daily rate	EUR/d	457.72		
Hourly rate	EUR/h	57.21		
Kilometer rate	EUR/km	1.04		
Ton-kilometer rate	EUR/tkm	0.17		
Emission factor	kg CO2/l	2.62		Link
Fuel consumption	l/tkm	0.05		
CO2 Emissions	kg CO2/tkm	0.14		
Cost for idle times	EUR/h	35.06		

Costs for railway transports are evaluated differently. Rail transports defined within BioBoost are subject to the following scenario: Generally, dedicated block trains circulate between decentral and central conversion plants. That is, each type of conversion plant has an access to the railway network (e.g. through railway siding). Furthermore, departures and arrivals follow a regular railway schedules. On the basis of mass throughputs of conversion plants and practical experiences the following train capacities are assumed: 1,200 Nt West transport relation and 1,000 Nt East transport relation. In compliance with this segmentation, costs for rail transports are evaluated according different transport distance classes. That is, regardless of the real covered distance, the same cost rate is charged for a certain distance class. Practitioners regard 200 km as a realistic transport distance, from which railway operations are competitive to road transportation *(Expert interview 17, 2013).*

As Table 39 suggests, the transport cost rates are considerably lower than calculated for road transportation – especially with increasing distances.

Table 39: Transport costs for rail transport

	Transport costs Transport distance classes (km)	1200 Ntons Relation West	1000 Ntons Relation East	Unit	1200 Ntons Relation West	1000 Ntons Relation East	Unit
≤	200	11	12	EUR/Nt	0.055	0.060	EUR/Ntkm
≤	400	18	19	EUR/Nt	0.045	0.048	EUR/Ntkm
≤	600	25	26	EUR/Nt	0.042	0.043	EUR/Ntkm
≤	800	30	32	EUR/Nt	0.038	0.040	EUR/Ntkm
≤	1000	34	38	EUR/Nt	0.034	0.038	EUR/Ntkm
≤	1200	38	44	EUR/Nt	0.032	0.037	EUR/Ntkm
≤	1400	42	49	EUR/Nt	0.030	0.035	EUR/Ntkm
≤	1600	45	53	EUR/Nt	0.028	0.033	EUR/Ntkm
≤	1800	48	57	EUR/Nt	0.027	0.032	EUR/Ntkm
≤	2000	50	60	EUR/Nt	0.025	0.030	EUR/Ntkm

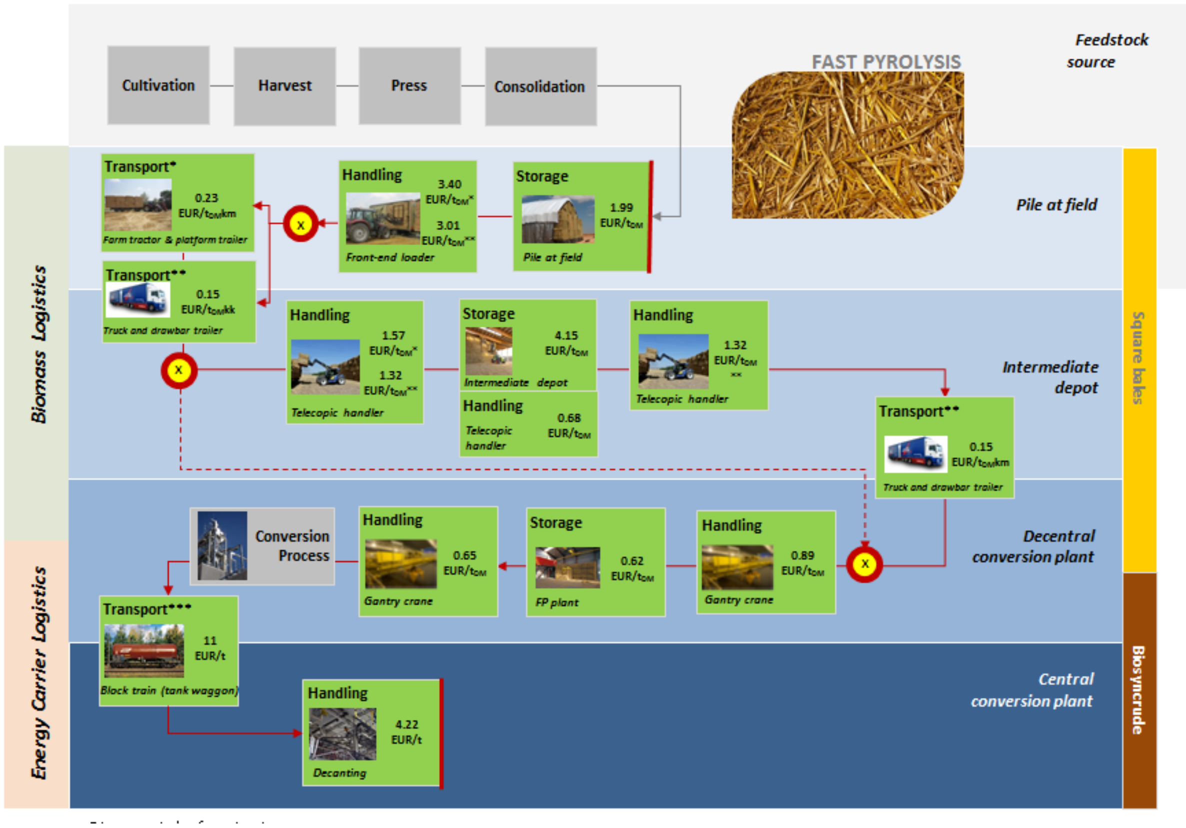
Handling costs for railway operations include the following cost items (Table 40). As already mentioned above, mainly workers are required for loading and unloading activities. Thus, labour costs constitute the largest cost fraction. In terms of processing trains, a service fee is charged. Costs for shunting, electricity and miscellaneous costs are further defined. In total, handling costs for each tank wagon aggregate to 274.50 EUR. Provided that a tank wagon features a maximum payload of 65 tons (Table 36), a handling cost rate of 4.22 EUR/t is computed *(Expert interview 17, 2013).*

Table 40: Handling costs for rail operations

Handling block train	Quantity	Cost rates (EUR)	Sum (EUR)	Total (EUR)	Cost rate (EUR/t)
Loading/unloading (labour costs)	2.50	50.00	125.00		
Flat charge (for processing trains)	55.00	0.90	49.50		
Shunting	0.50	50.00	25.00		
Electricity and miscellaneous	1.50	50.00	75.00	274.50	4.22

6 Logistics Reference Pathways

Both parts of the BioBoost supply chain, i.e. biomass logistics and energy carrier logistics, are analysed for each conversion technology. Assets are defined and logistics cost rates are evaluated. Through gained information, logistics reference pathways for each technology are set in the following. These logistics reference pathways aim at visualizing the evaluated logistics process costs through using the example of selected logistics assets. With respect to the holistic logistic model, all cost rates are provided in order to determine the optimal asset mix.



* transports by farm tractor
** transports by truck
*** transports by rail

Figure 10: Logistics reference pathways for fast pyrolysis

Pre-treatment processes at the feedstock source are analysed in work package 1. In order to define the interface between WP1 and WP4 a supply scenario is delineated: Square bales associated with specified product properties (e.g. weight, dimension) are piled up at the field and are covered through tarpaulins during on-field storage. Costs only incur for tarpaulins. Pressed bales are handled on demand using farm tractors with front-end loaders. Thereafter, two potential transport vehicles can be used for transporting feedstock towards either intermediate depots or directly to the decentral conversion plants. Depending on the availability of transport equipment and practical applications, the split between farm tractors and trucks differentiates within the study area. For instance, farm tractors (farm tractor and platform trailer) are commonly used in Austria, whereas mostly trucks (truck and drawbar trailer) are used for biomass transports in Western Europe. Based on the trade-off between transport costs and additional costs for implementing an intermediate depot (i.e. additional handling and storage costs), the decision is made upon transporting feedstock directly to the decentral conversion plant or using an intermediate storage depot. At decentral conversion plants, gantry cranes are used for loading, unloading and stock transfers. The produced energy carrier is further transported by railway. A type of railway vehicle is selected which fulfils requirements of the given dangerous goods class. Finally, the tank waggons are depleted at the central conversion plant.

By modelling the logistics reference pathway for catalytic pyrolysis, three different products are considered: (i) logging residue bundles, (ii) wood chips and (iii) catalytic oil (Figure 11). The feedstock source is defined as slash piles at roadside landing. There, feedstock is stored and handled through truck-mounted cranes. Generally, timber trucks are applied for transporting those bundles. Depending on whether to transport biomass via intermediate depot or directly to the decentral conversion plant, additional handling costs at the depot and storage costs arise or not. Moreover, logging residue bundles are transformed either at ID or at DCP into wood chips. Therefore, costs for chipping need to be considered, too. Cost figures for this process are derived from *Asikainen, Laitila (2006).* At the decentral conversion plant, screw conveyors and telescopic handler are in use for transferring stock and feeding the conversion process. The energy carrier logistics is equal to the process as depicted for fast pyrolysis.

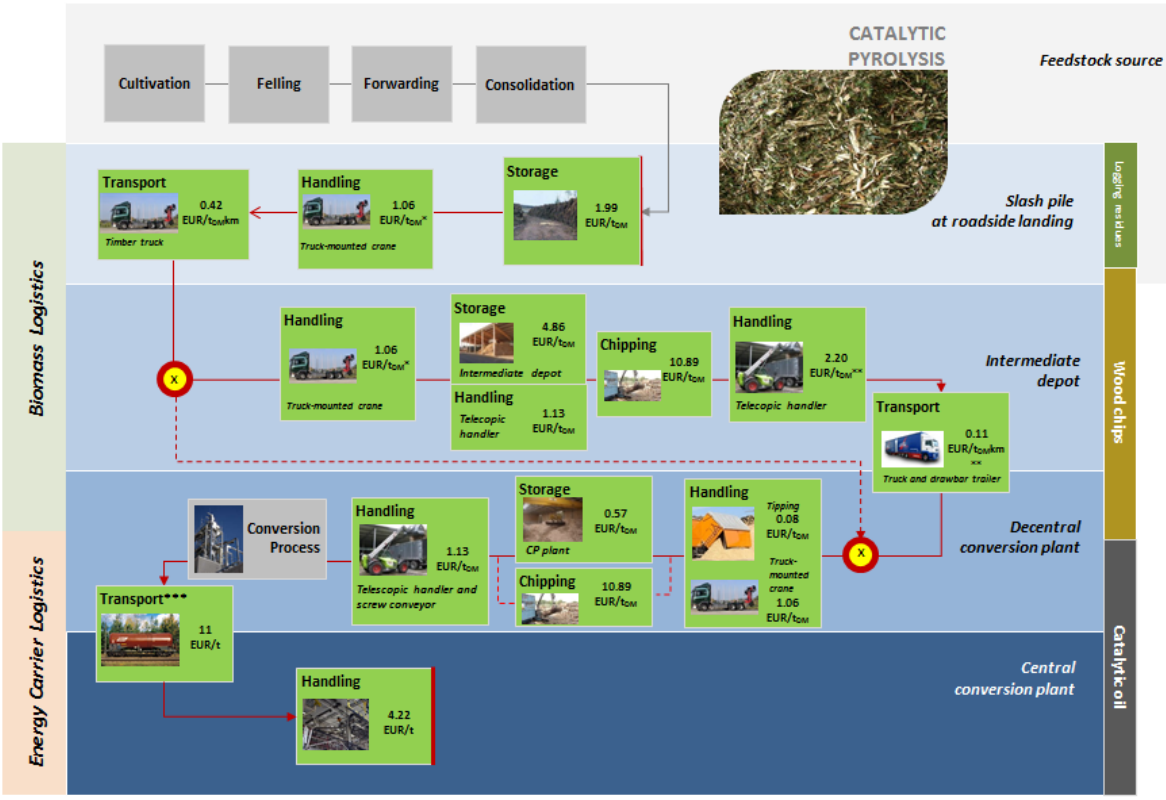
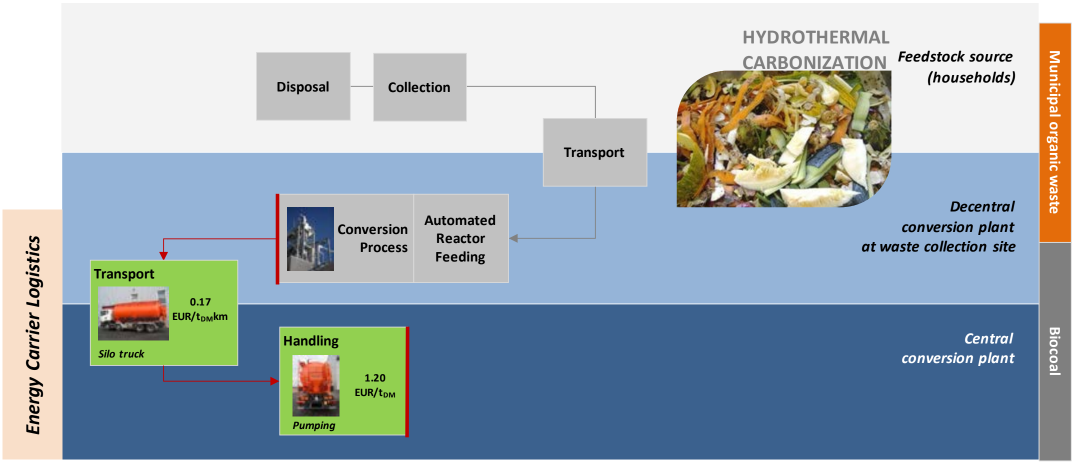


Figure 11: Logistics reference pathways for catalytic pyrolysis

Hydrothermal carbonization does not consider biomass logistics processes. It is assumed that conversion plants are located at waste collection sites, where organic municipal waste is collected and directly fed into the reactors. Therefore, only the reference pathway for energy carrier logistics is defined. Pelletized biocoal is transported using silo trucks and handled through pumping (Figure 12).



* transports by farm tractor
** transports by truck
*** transports by rail

Figure 12: Logistics reference pathways for hydrothermal carbonization

7 Conclusions and Outlook

This report is dedicated to design and evaluate processes in the field of biomass logistics as well as energy carrier logistics. Information based on existing literature as well as implicit, not published, practical knowledge are consolidated and investigated. Finally, key implications about logistics costs are drawn.

First, relevant transport, handling and storage assets are determined. Thereby, plenty of expert interviews are conducted. By virtue of these specifications, cost calculations are run in a second step in order to derive target metrics. In general terms, farm tractors features higher costs compared to trucks with respect to transports. This can be reasoned by performance data and the fact that this type of transport means is not exclusively dedicated for transports. However, as interviews with practitioners showed, the usage of farm tractors is prevalent in practice (partially due to a lack of investments in trucks).

Referring to the handling process, different assets are investigated: (1) farm tractor with front loader, (2) forklift truck, (3) telescopic handler and (4) gantry crane. Additionally, loading and unloading of roll-off containers, tipping, pumping and handling with truck-mounted cranes are documented. In doing so, some preferential handling assets are identified for each reference feedstock type. The storage process is analysed by specifying proper infrastructure and calculating costs.

The illustrated results serve as a major input for both a techno-economic, social and environmental assessment of complete chains conducted in WP6 as well as ongoing activities in WP4. More specifically, the simulation-based optimization model is fed with key figures generated in this report.

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9 Annex

9.1 List of expert interviewed

Table 41: List of expert interviewed

	Interviews conducted with:
1	Agrarservice Hubmann OB
2	AVE Österreich GmbH
3	Biomassekraftwerk Güssing GmbH & Co KG
4	BLT Wieselburg, Lehr- und Forschungszentrum Franisco Josephinum
5	Energie AG Oberösterreich, Kraftwerke GmbH (Biomassekraftwerk Timelkam)
6	FH OÖ, Forschungs & Entwicklungs GmbH
7	Hanl Hackschnitzelerzeugung und Holzhandel
8	Landwirtschaftskammer Steiermark
9	Maschinenring
10	Müllverbrennungsanlage (MVA) Pfaffenau
11	Österreichische Bundesforste AG
12	Riedler Anhänger GmbH
13	Schachinger Logistik Holding GmbH
14	Spedition Billitz
15	Waldverband Steiermark (Biomassehof Leoben)
16	Wien Energie GmbH
17	ChemFreight Transport, Logistik & Waggonvermietung GmbH
18	Tropper Maschinen und Anlagen GmbH

9.2 Interview Guide

Table 42: Interview guide

Interview conducted with:	
Company	
Name	
Function	
Condact details	
	1) How is the process of <u>biomass transport</u> designed? a. Which biomass types and annual quantities (throughput) are manipulated? b. Who (farmer, own staff, LSP) is responsible for transportation (coordination, costs, risks)? c. Which loading units and vehicle (trailer) types are used (for which distances) for transportation? d. Are there any value added steps (pre-treatment activities) before or after transportation (e.g. comminution)? e. What is the average, cost-efficient transport distance (from source to sink)? f. What are major performance data (average vehicle speed, payload, fuel consumption, etc.)? g. What are the main cost drivers for biomass transports?
	2) How is the process of <u>biomass handling</u> designed? a. Who (farmer, own staff, LSP) is responsible for handling (coordination, costs, risks)? b. Which types of handling equipment are used for which type of biomass? c. What are major performance data (tons handled per hour, fuel consumption)? d. What are the main cost drivers for biomass handling?
	3) How is the process of <u>biomass storage</u> designed? a. What is the local storage capacity (roofed and open top) as well as average days of inventory? b. What are the main cost drivers for biomass storage? c. Which types of handling equipment are used for which type of biomass? d. Are there any pre-treatment activities as part of storing biomass?
	4) Where do major problems related to the before-mentioned logistics processes arise along a biomass supply chain?

9.3 Listing of Selected Vehicle-trailer Combinations

Part 1

Vehicle (trailer) type

Road transportation

Farm tractor and tippers (wheat straw)

1st Trailer	Length	5.0		m
	Width	2.5		m
	Height[1]	2.8		m
	cargo space	35.0		m³
	Max. payload	10.7		t
	Square bales	13.0		units
2nd trailer	Length	5.0		m
	Width	2.5		m
	Height[1]	2.8		m
	cargo space	35.0		m³
	Max. payload	10.7		t
	Square bales	13.0		units
	Utilization of transport capacity	100%	30%	
	Total square bales	26	7	units
	Total payload available	21.4		t
	Total payload utilized	13.0		t FM
	Total payload utilized	11.2	3.4	t DM
	Total cargo space available	70		m³
	Total cargo space utilized	67		m³

Ref.: 140 kW 4x4 farm tractor
Link
Ref.: HB Brantner PW 13000
Link
[1] Height of cargo space

Farm tractor and tippers (wood chips)

1st Trailer	Length	5.0		m
	Width	2.5		m
	Height[1]	2.8		m
	cargo space	35.0		m³
	Max. payload	10.7		t
2nd trailer	Length	5.0		m
	Width	2.5		m
	Height[1]	2.8		m
	cargo space	35.0		m³
	Max. payload	10.7		t
	Utilization of transport capacity	100%	45%	
	Total payload available	21.4		t
	Total payload utilized	19.3		t FM
	Total payload utilized	13.5	6.1	t DM
	Total cargo space available	70		m³
	Total cargo space utilized	70		m³

Link
Ref.: HB Brantner PW 13000
Link
[1] Height of cargo space

Farm tractor and platform trailer (wheat straw)

Trailer	Length	12.0		m
	Width	2.5		m
	Height[1]	3.0		m
	cargo space	88.5		m³
	Max. payload	18.0		t
	Square bales	33.0		units
	Utilization of transport capacity	100%	46%	
	Total square bales	33	15	units
	Total payload available	18.0		t
	Total payload utilized	16.5		t FM
	Total payload utilized	14.2	6.5	t DM
	Total cargo space available	89		m³
	Total cargo space utilized	74		m³

Ref.: Fliegl DPW 180 Dolly
Link
[1] Height of cargo space

Farm tractor and hook lift trailer for roll-off container (wood chips)

Trailer	Length	7.0		m
	Width	2.4		m
	Height	2.4		m
	Cargo space	40.0		m³
	Max. payload	13.0		t
	Utilization of transport capacity	100%	42%	
	Payload available	13.0		t
	Payload utilized	11.0		t FM
	Payload utilized	7.7	3.3	t DM
	Cargo space available	40		m³
	Cargo space utilized	40		m³

Ref.: Krampe THL 23 L (Hook lift trailer)
Link

Truck and drawbar trailer (wheat straw)

Truck	Length	7.7		m
	Width	2.5		m
	Height	3.0		m
	cargo space	56		m³
	Max. payload	12.5		t
	Square bales	20.0		units
Trailer	Length	7.7		m
	Width	2.5		m
	Height	3.1		m
	cargo space	59		m³
	Max. payload	12.5		t
	Square bales	20.0		units
	Utilization of transport capacity	100%	40%	
	Total square bales	40	16	units
	Total payload available	25.0		t
	Total payload utilized	20.0		t FM
	Total payload utilized	17.2	6.9	t DM
	Total cargo space available	115		m³
	Total cargo space utilized	104		m³

Ref.: Mercedes Axor 2543 *Link*
Ref.: Loth Spedition *Link*

Ref.: Riedler Anhänger Wood chips tipper
Link

Truck and drawbar trailer (wood chips)

Truck	Length	7.7		m
	Width	2.5		m
	Height	3.0		m
	cargo space	56.0		m³
	Max. payload	12.5		t
Trailer	Length	7.7		m
	Width	2.5		m
	Height	3.1		m
	cargo space	59.0		m³
	Max. payload	12.5		t
	Utilization of transport capacity	100%	50%	
	Total payload available	25.0		t
	Total payload utilized	25.0		t FM
	Total payload utilized	17.5	8.8	t DM
	Total cargo space available	115		m³
	Total cargo space utilized	91		m³

Ref.: Mercedes Axor 2543
Link

Ref.: Riedler Anhänger Wood chips tipper
Link

Part 2

Timber truck (logging residue bundle)

Truck	Length	6.0	m	
	Width	2.6	m	
	Height	3.0	m	
	cargo space	46.1	m³	
	Max. payload	8.2	t	
	Bundles	11.0		
Trailer	Length	5.8	m	
	Width	2.5	m	
	Height	3.0	m	
	cargo space	42.3	m³	
	Max. payload	14.7	t	
	Bundles	11.0		
	Utilization of transport capacity	100%	29%	
	Total payload available	22.9		t
	Total payload utilized	13.4		t FM
	Total payload utilized	8.7	2.6	t DM
	Total cargo space available	88		m³
	Total cargo space utilized	53		m³

Riedler 3-axle timber truck + crane
Riedler 2-axle timber trailer

Truck and drawbar/hook lift trailer for roll-off-container (wood chips)

Truck (container)	Length	5.0	m	
	Width	2.4	m	
	Height	2.6	m	
	cargo space	30.0	m³	
	Max. payload	13.0	t	
Trailer (container)	Length	5.0	m	
	Width	2.4	m	
	Height	2.6	m	
	cargo space	30.0	m³	
	Max. payload	13.0	t	
	Utilization of transport capacity	100%	32%	
	Total payload available	26.0		t
	Total payload utilized	16.5		t FM
	Total payload utilized	11.6	3.7	t DM
	Total cargo space available	60		m³
	Total cargo space utilized	42		m³

Ref.: AVE RT 17.65
Link

Truck - waste collection vehicle (biodegradable municipal waste)

Truck				
	Max. payload	11.5	t	*AVE, 2012*
	Container capacity	0.06	t	*AVE, 2012*
	Utilization of transport capacity	100%	100%	
	Total payload available	11.5	11.5	t

Silo truck (biocoal)

Truck (container)	Length	8.0	m	
	Container diameter	2.4	m	
	Height	2.9	m	
	cargo space	32.0	m³	
	Max. payload	18.0	t	
	Utilization of transport capacity	100%	50%	
	Total payload available	18.0		t
	Total payload utilized	18.0		t
	Total payload utilized	12.6	6.3	t DM
	Total cargo space available	32		m³
	Total cargo space utilized	14		m³

Ref.: Tropper TN 32/4 AL
Link

Railway transportation

Tank wagon

Length	17.0	m	
Width	3.1	m	
Height	4.3	m	
Cargo space	95	m³	
Max. payload	65	t	
Utilization of transport capacity	**Biosyncrude**	**CP oil**	
Total payload available	65	65	t
Total payload utilized	65	65	t
Total cargo space available	95	95	m³
Total cargo space utilized	54	59	m³
Total cargo space utilized	57%	62%	

Ref.: VTG 1695.80
Link

9.4 Listing of Selected Handling Equipment

Handling assets

Front-end loaders (farm tractor)					
Front-loader framework	Lifting height	3.7	m	*CNH, 2012*	Link
	Lifting capacity	2	t		Link
	Lifting capacity	2.3	m³		Link
	Annual operating time	1500.0	h/yr		

Telescopic handler				*Ref.: Merlo P 55.9CS*
Lifting height	8.6	m		Link
Lifting capacity	5.5	t		
Lifting capacity	4	m³		Link
Fuel consumption	7	l/h		
Annual operating time	2,000	h/yr	*DBFZ, 2012*	

Forklift truck			*Ref.: Still RX 70-35 T*
Lifting height	3.7	m	Link
Lifting capacity	3.5	t	
Lifting capacity	1.5	m³	Link
Fuel consumption	2.5	l/h	
Annual operating time	2,000	h/yr	

Gantry crane

		Option 1	Option 2	Option 3
Lifting height	m	10	8	8
Lifting capacity	t	3	4	6.3
Lifting capacity (gripper)	m³	2	4	4
Width	m	25	33	33
Length	m	40	60	90
Lifting speed (empty run)	m/min	12	16	18
Lifting speed (full load)	m/min	10	13	13
Running speed (lifting device)	m/min	40	40	40
Running speed (crane)	m/min	63	63	63
Investment costs (excl. tracks)	EUR	210,000	330,000	340,000
Operating hours	h/yr	5,000	5,000	5,000

Unloading biodegradable municipal waste, wood chips (tipping) and logging residue bundles

Truck and drawbar trailer			
	Tipping process lead time	2.5	min/vehicle
	Push-off process lead time	10	min/vehicle
Truck - biodegradable municipal waste collection vehicle			
	Tipping process lead time	60	min/vehicle
Timber truck (logging residue bundle)			
	Unloading lead time with crane	15	min/vehicle
Silo truck (biocoal)			
	Unloading lead time (pumping)	25	min/vehicle


Walking floor

Loading biodegradable municipal waste

Truck - waste collection vehicle			
	Loading time	2	min/container

9.5 Listing of Selected Storage Equipment

Storage location 1:	*Pile/roadside landing*		
Open Storage	Unit	Pile - wheat straw - covered (tarpaulin)	Pile - logging residue bundles - uncovered
Dry matter loss	wt%	8%	3%
Storage periode	months	6	12
Dry matter loss / month	wt% / month	1.33%	0.25%
Storage capacity	t (DM)	*Unlimited*	*Unlimited*



There are no investments for storage infrastructure --> use available terrain

Storage location 2:	Intermediate depot			
Closed storage	Unit	Warehouse 1	Warehouse 2	Total warehouse capacity
Length	m	40	40	
Width	m	25	25	
Roof edge	m	7	7	
Footprint (gross)	m²	1,000	1,000	2,000
Storage capacity (theoretical)	m³	7,000	7,000	14,000


Open storage	Unit	Yard 1	Yard 2	Total yard capacity
Length	m	50	50	
Width	m	30	30	
Filling height	m	8.6	8.6	
Footprint	m²	1,500	1,500	
Storage capacity (theoretical)	m³	12,900	12,900	25,800

Storage capacity	Unit	Wheat straw	Logging residues bundle	Wood chips
Bulk density (dry matter)	kg/m³ DM	166	165	193
Closed storage	t (DM)	2,276	-	2,430
Open storage	t (DM)	4,280	2,856	3,334
Storage capacity (available)	t (DM)	6,556	2,856	5,764

		Wheat straw	Logging residues bundle	Wood chips	
Storage period (assumed)	months	3	3	3	*Expert interview 15, 2012*

Dry matter losses	Unit	Wheat straw	Logging residues bundle	Wood chips
Closed storage, covered (tarpaulin)	wt%	4.00%	0.75%	2.00%
Open storage, covered warehouse	wt%	1.00%	1.00%	1.00%

Dry matter losses	Unit	Wheat straw	Logging residues bundle	Wood chips
Closed storage, covered (tarpaulin)	wt%/month	1.33%	0.25%	0.67%
Open storage, covered warehouse	wt%/month	0.33%	0.33%	0.33%

Total area	Unit	
Plot area paved	m²	10,000
Sealed area for transport	m²	5,000
Sealed area for covered storage	m²	2,000
Sealed area for open storage	m²	3,000

Additional assets
Weigh-bridge
Office container and equipment

Figures for cost analysis	Plot area	Depreciation period	Maintenance rate
	m²	yr	%
Plot area paved	10,000	25	1%
Sealed area for transport	5,000	25	1%
Sealed area for closed storage	2,000	25	1%
Sealed area for open storage	3,000	25	1%
Warehouse		25	1%
Weigh-bridge		20	2%
Office container and equipment		5	1%

Storage location 3:	Decentral conversion plant		
Required Capacity	Unit	Fast Pyrolysis	Catalytic Pyrolysis
Safety storage	d	5.00	5.00
Square bales	units	6,977	-
Closed Storage	Unit	Warehouse FP	Warehouse CP
Length	m	80	65
Width	m	33	33
Roof edge	m	10	10
Footprint	m²	2,640	2,145
Unloading area	m²	300	300
Area available for storage	m²	2,340	1,845
Storage capacity	m³	18,346	13,284
Storage capacity		Wheat straw	Wood chips
Bulk density (dry matter)	kg/m³ DM	166	193
Storage capacity (required)	t (DM)	3,000	2,527
Storage capacity (available)	t (DM)	3,043	2,562
		Wheat straw	Wood chips
Storage period (assumed)	months	0.17	0.17
Dry matter losses	Unit	Wheat straw	Wood chips
Open storage, covered warehouse	wt%/month	0.33%	0.33%

Potential layout plan (fast pyrolysis)

Total area		Warehouse FP	Warehouse CP
Plot area paved	m²	2,640	2,145
Sealed area for transport	m²	300	300
Sealed area for closed storage	m²	2,340	1,845

Figures for cost analysis	Plot area	Depreciation period	Maintenance rate
	m²	yr	%
Plot area paved		25	1%
Sealed area for transport	300	25	1%
Sealed area for closed storage	2,640	25	1%
Sealed area for open storage			
Warehouse		25	1%
Weigh-bridge			
Office container and equipment			

9.6 Labour Cost Calculation

Table 43 Labour cost calculation

Labour costs				
Social security contribution ratio	31%	paid by employer		
Weeks to be paid by the employer				
	weeks	%		
Annual gross wage	52.2	100%		
Christmas allowance	4.33	8%		
Holiday allowance	4.33	8%		
Social security contribution (wage)	16.18	31%		
Social security contribution (wage)	2.68	5.1%		
Total	79.73			
Theoretical time of performance				
	weeks	days	hours	
Annual gross working time	52.20	261	2010	
Vacation	5.00	25	193	
Illness	3.20	16	123	
National holidays	2.20	11	85	
Other absence	0.50	3	19	
Annual net working time	41.30	207	1590	
Non-wage working time	38.43	weeks		
Non-wage labor costs	93%			
Productivity factor	70%			
Feasible time of performance				
	weeks	days	hours	
Annual net working time	28.9	145	1113	
Non-wage labor costs (incl. non-productivity)		176%		
Labor cost calculation				
Assumed gross wage per month	1,498.18	EUR	paid to employee	Link
Allowance per month	200.00	EUR	paid to employee	
Assumed gross wage per month	2,984.98	EUR	paid by employer	
Assumed gross wage per year	35,819.74	EUR	paid by employer	
Assumed gross wage per hour	22.53	EUR	paid by employer	

9.7 Index for Major Cost Drivers

Table 44: Index for major cost drivers

Index for		Labour costs				Fuel costs		Vehicle investment costs	
Country Code		Gross hourly wage (EUR/h)	Social security contribution ratio (% of gross hourly wage)	Total hourly wage (EUR/h)	**Labor costs index**	Diesel fuel gross price (EUR/l)	**Fuel cost index**	Index by sales expert (100 = Mean in Europe)	**Investment cost index**
BE	Belgium	39.3	47%	57.8	1.44	1.42	1.00	103	1.00
SE	Sweden	39.1	52%	59.4	1.49	1.67	1.19	108	1.05
DK	Denmark	38.9	15%	44.7	1.12	1.48	1.05	106	1.03
FR	France	34.2	50%	51.3	1.28	1.37	0.97	97	0.94
LU	Luxembourg	33.7	15%	38.8	0.97	1.26	0.89	103	1.00
NL	Netherlands	31.1	30%	40.4	1.01	1.47	1.04	106	1.03
DE	Germany	30.1	28%	38.5	0.96	1.50	1.07	99	0.96
FI	Finland	29.7	28%	38.0	0.95	1.55	1.10	108	1.05
AT	Austria	29.2	37%	40.0	1.00	1.41	1.00	103	1.00
IE	Irland	27.4	18%	32.3	0.81	1.58	1.12	105	1.02
IT	Italy	26.7	41%	37.6	0.94	1.71	1.21	107	1.04
ES	Spain	20.6	37%	28.2	0.71	1.36	0.96	89	0.86
UK	Great Britain	20.1	16%	23.3	0.58	1.73	1.23	100	0.97
CY	Cyprus	16.5	21%	20.0	0.50	1.34	0.95	86	0.83
GR	Greece	16.4	29%	21.2	0.53	1.44	1.02	89	0.86
SI	Slovenia	14.4	17%	16.8	0.42	1.40	0.99	105	1.02
PT	Portugal	12.1	26%	15.2	0.38	1.45	1.03	105	1.02
MT	Malta	11.9	10%	13.1	0.33	1.40	0.99	89	0.86
CZ	Czech Rep.	10.5	37%	14.4	0.36	1.43	1.01	109	1.06
SK	Slovakia	8.4	36%	11.4	0.29	1.44	1.02	109	1.06
EE	Estonia	8.1	37%	11.1	0.28	1.40	0.99	91	0.88
HU	Hungary	7.6	34%	10.2	0.25	1.52	1.08	109	1.06
PL	Poland	7.1	20%	8.5	0.21	1.36	0.96	91	0.88
LV	Latvia	5.9	27%	7.5	0.19	1.38	0.98	91	0.88
LT	Lithuania	5.5	40%	7.7	0.19	1.32	0.94	91	0.88
RO	Romania	4.5	31%	5.9	0.15	1.33	0.94	109	1.06
BG	Bulgaria	3.5	19%	4.2	0.10	1.31	0.93	109	1.06
CH	Switzerland	41.9	20%	50.3	1.26	1.62	1.15	109	1.06