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Biomass based energy intermediates boosting biofuel production

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Deliverable

D 4.5 Risk analysis and safety concept for energy carrier handling

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Responsible:	FH OOE
Authors:	Stefan Rotter, Christian Rohrhofer, Gerald Schönwetter
Contact:	gerald.schoenwetter@fh-steyr.at
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Publishable Summary

Deliverable 4.5 is about a concept to cope with the risks from logistics processes. BioBoost examines three different conversion technologies (fast pyrolysis, catalytic pyrolysis and hydrothermal carbonization) with their respective raw materials that eventually lead to defined reference pathways.

This report demonstrates, how risks (in connection with the logistics processes of transporting, storing and handling of the materials) along these reference pathways have been identified and analysed before providing proposals to mitigate them. In order to do so, expert interviews and a sound literature review have been conducted. Risks have been seized by a combination of aforementioned literature research and interviews – not only with practioners from bio-business but also with many of the BioBoost project partners. This finally delivered a comprehensive understanding of risks. Following the identification of risks FH OOE built methodologies in order to rate and mitigate them. So, this report proposes how to cope with each of the identified risks, the result of which is then incorporated into the logistics model.

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1 Introduction

Within the scope of work package 4 (Transport & Logistics) in the BioBoost project, a particular emphasis lies on conducting a risk analysis and defining a safety concept. Comparable with data collected upon logistics process costs (D4.1), this task (T4.4) constitutes a complementary input for evaluating the complete value chain (WP6) through applying the developed simulation-based optimization model in WP4.

This risk analysis primarily deals with negative influencing factors emerging in respective logistics processes (transport, handling and storage) along the supply chain for individual products (i.e. biomass, energy carrier, side products) and technologies (fast pyrolysis, catalytic pyrolysis and hydrothermal carbonization). In detail, the most important hazards are identified based on existing literature, regulations as well as expert interviews. Afterwards they are then characterized in terms of causes and effects and finally evaluated based on expert assessments, which follows a risk matrix scheme. Finally, risk mitigation actions are determined for so-called *unacceptable risks*. This is all covered in a safety concept that also contains related costs.

The logistics reference pathways defined in D4.1 (Logistics Concept) serve as a feasible starting point within the risk analysis in order to identify initial hot spots (Figure 1).

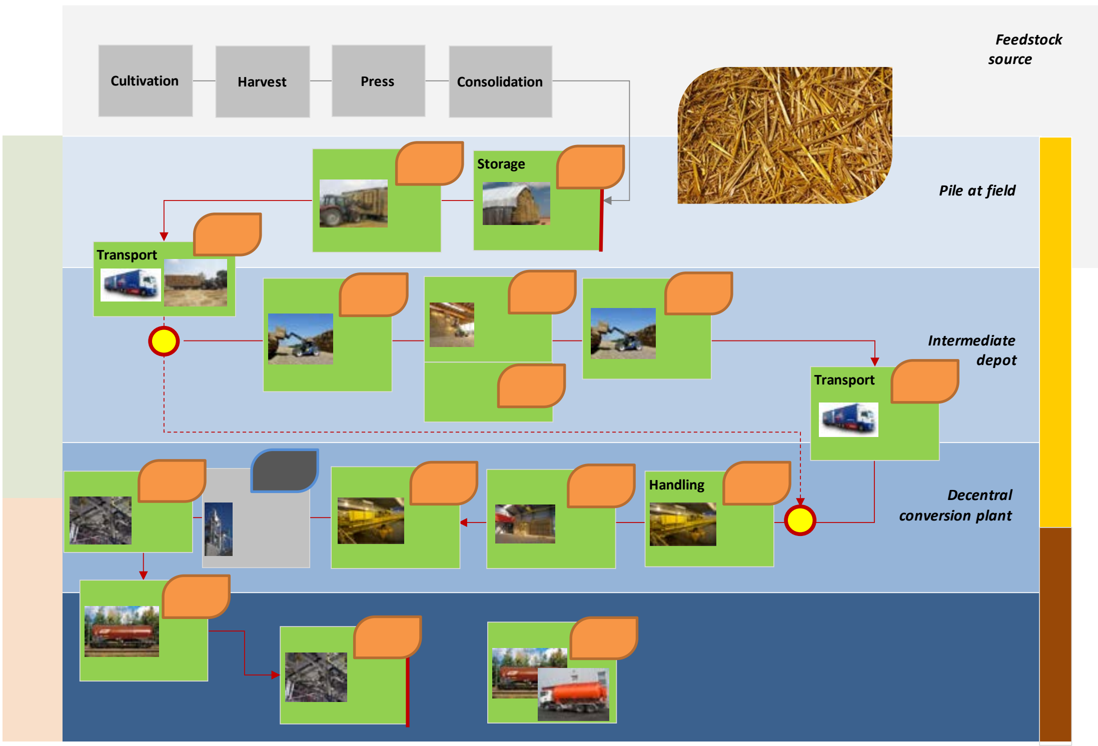

Figure 1: Logistics reference pathway scheme for risk identification

With respect to identifying risks, it is necessary to focus on (logistics) processes and products alike. In total, eight different products are investigated, which are:

(i) reference feedstocks: logging residue bundles, wood chips, straw square bales and municipal waste,
(ii) reference energy carrier: biosyncrude, biocoal, catalytic oil and
(iii) a side product: extracted phenolics.

The two latter product categories represent dangerous goods, which are subject to legislative regulations. Therefore those legal requirements for transporting dangerous goods are reviewed in this study.

The rest of the study is organized as follows: the information gained within the risk analysis is aligned with the structure defined in the risk assessment framework: risk identification & characterization, risk evaluation and risk mitigation. The latter comprises key components of a safety concept for the BioBoost supply chain. Finally, conclusions are drawn which also serve as input of the final assessment in work package 6.

2 Risk Analysis

The importance of performing risk analysis in both engineering and economics has recently experienced great importance. In general, markets have become vulnerable. In the context of supply chains, several trends, i.e. outsourcing, cost reduction, just-in-time and lean management as well as consolidation have boosted the risk potential along the supply chain *(Nargurney, 2012)*. When setting up a risk analysis, different key terms are essential to clarify in the forefront.

Hazard is an act or phenomenon that poses potential harm to persons or things and incorporates the source of harms and its potential consequences. *Probability* represents the occurrence rate of a hazardous event within a specified time period. Therefore, this figure provides information about the reliability of a system. A further key term deals with the consequence of an event and is stated as (*business) impact*. The adverse effects may evolve in different fields, i.e. product quality and quantity, environment, human health or technical equipment. The term risk is defined as the potential of losses resulting from an exposure to a hazard and is commonly evaluated as the product of the probability and (business) impact of a hazardous event *(Ayyub, 2003).*

$$\boldsymbol{Risk}\left(\frac{Consequence}{Time}\right) = \boldsymbol{Probability}\left(\frac{Event}{Time}\right) \times \boldsymbol{Impact}\left(\frac{Consequence}{Event}\right)$$

This equation is also used for operationalizing risk through calculating risk factors. Those risk factors can be allocated in a so-called risk matrix in order to support the decision-making process (e.g. risk acceptance boundary). Detailed insights are provided later in the section risk evaluation.

2.1 Risk Assessment Framework

As methodological foundation an assessment framework has been devised for managing the risks. An overview about the main structure of this framework is illustrated in the annex. Basically, potential hazards along the BioBoost supply chain are delineated according to the following scheme: (i) risk identification, (ii) risk characterization, (iii) risk evaluation and (iv) risk mitigation. Risks were identified from literature sources and from interviews with experts in the biomass business.

2.2 Risk Identification and Characterization

To start with, different sources of information have been reviewed in order to derive hazards with respect to transporting, handling and storing the respective products. The underlying risk assessment framework, which has been designed by the authors, features a structure that can be found in Figure 2. The framework is based on methods for risk analysis, which can be widely found in literature of economics and which was then modified to meet specific requirements from the BioBoost project:

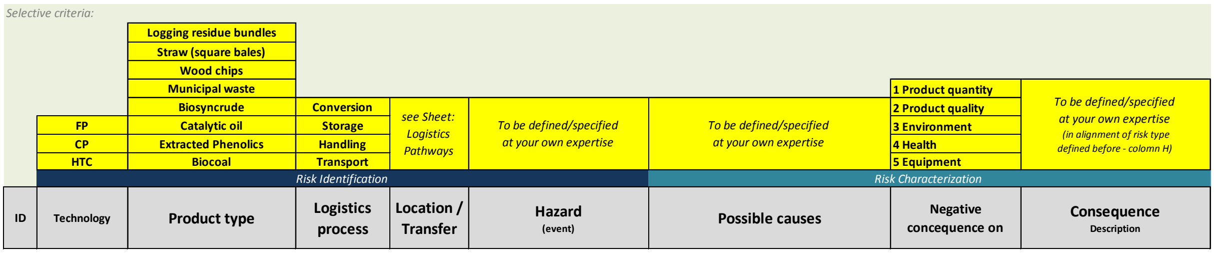

Figure 2: Structure of risk identification and characterization

Experts within the project team have been interviewed for their view on risks with their technologies. This was mainly done in a remote mode, which required exact descriptions and notes for each column in this table.

The following chapters specify the information sources, which have been used to generate the matrix.

2.2.1 Systematic Literature Review

In order to provide a sound base of information for the BioBoost risk analysis, a systematic literature search was conducted. In doing so, a 3-level literature search has been performed:

- **1st Level:** international and high-quality scientific papers, articles and other publications (EBSCO[1], Emerald[2] und Science Direct[3])
- **2nd Level:** other scientific resources and academic literature (Google Scholar)
- **3rd Level:** published project reports, articles, white papers, etc. (Google)

[1] http://web.b.ebscohost.com/

[2] http://www.emeraldinsight.com

[3] http://www.sciencedirect.com/

As guidance through this literature search a list of pre-defined keywords (and combinations) was prepared (see Annex).

The result of a search through scientific sources shows that the analysis of risks in the field of biomass primarily refers on economic and monetary factors (e.g. investment risks, internal rate of return). Operational risks in logistics (transport, storage and handling), however, remain almost unnoticed. At national and international project and publication level, there are far more useful research results for the biomass logistics than in scientific sources.

In the following summary key results from the systematic literature review are presented. Those are also incorporated in the BioBoost risk assessment framework.

A publication from the *IEA Bioenergy* (International Energy Agency) deals with safety aspects of solid biomass storage, transportation and feeding. The focus of this work are hazards from self-heating and fire, biomass off-gasing, dust and gas explosion and health risks in general (*IEA Bioenergy, 2013*).

The design and operation guide of the *CEA* (Combustion Engineering Association) deals with specific requirements in addition to the legislative risks in the areas of transportation, storage and processing of biomass (combustion). Furthermore, the issue of staff training is considered to minimize accidents at work *(Combustion Engineering Association, 2011)*.

Fire protection, storage times and storage geometries are core issues of the guide for fire prevention of the *Leitfaden zur Brandvermeidung bei der Lagerung von Biomasse*. The process of self-ignition is described by means of examples, and then provides recommendations for prevention in order to store biomass *(Bundesanstalt für Materialforschung und -prüfung, 2009)* safely.

The project deliverable *Risk Assessment - Health, Safety and Environment* of the *Gasification Guide* project is to perform a risk analysis on the basis of biomass power plants. These project results provide significant insights into the methodological implementation of a risk analysis in the biomass area *(Institute of Thermal Engineering, 2009)*.

The Conversion and Resource Evaluation Ltd. shows in their report *Transport, Storage Handling of Biomass Derived Fast Pyrolysis Liquids* standards and legislation in the transport of dangerous goods of different transport modalities. The classification, packaging, storage and transportation of liquids derived from the pyrolysis conversion deal with related risks *(Conversion and Resource Evaluation Ltd, 2006).*

2.2.2 Expert Interviews

In addition to scientific sources, expert interviews were conducted to survey potential risks along the BioBoost supply chain. The selected experts have contributed experiences from different areas of the biomass sector, which amended theoretical findings from above mentioned reports with practical relevance.

- **Expert I**
  Expert I has experience in the fields of straw and wood chip storage and handling. In addition to quality risks such as low bale density, high moisture content and low quality bailing he emphasized the risk inherent in storage locations. Furthermore, the risk associated with self-ignition of biomass by high humidity or external factors are quoted.

- **Expert II:**
  Expert II offers harvesting services by leasing his machinery. The expert particularly warned of parasites near composting facilities. In addition, he also mentioned the biomass loss due to incorrect storage of straw bales on the field (e.g. without an underlying plastic foil). Rain or moisture from the ground leads to the damaging of the lowest layer of feedstock and reduces the straw quality significantly, or at worst, the biomass is totally lost and resulting disposal costs occur. Apart from quality issues in the raw material, this expert also discussed transportation issues with us. According to his opinion the risks associated with biomass handling such as poor cargo securing or overloaded trucks are negligible in practice.

- **Expert III:**
  Expert III is the operator of a biomass power plant for the production of district heating. The biggest challenge for the operation of the power plant is the continuous supply of the burner with high quality biomass. Extreme weather events lead to the loss of large amounts of biomass and subsequently to poor capacity utilization, if these raw materials cannot be replaced from other sources. Furthermore, the quality risk was stressed that occurs in the form of impurities or a high ash content of the biomass.
  Expert III also mentioned risks in manipulating biomass from arriving trucks by wheel loaders. Apparently, this process bears the risk of accidents with possible machine damage and personal injury.

- **Expert IV:**
  Expert IV is buyer in a biomass trading company and states, in essence, the risk of loss of calorific value. This is generally due to inadequate storage (leading to high moisture content) or poor quality (high amount of green grass in the straw) of the raw material.

- **Expert V:**
  Expert V is a research associate in the field of thermal conversion of biomass and is specialized in the process of fast pyrolysis. Potential risks span from production bottlenecks to high rainfall, unexpected increase in overall demand, insufficient storage capacity and unacceptable product quality to social impacts due to a high rate of in- and outbound shipments. Furthermore, attention was drawn to the risks posed by the emission of hazardous substances as part of leakages as well as risks in the handling process of biomass.

- **Expert VI:**
  Risks associated with the hydrothermal carbonization were pointed out by expert VI. The focus is mainly on impurities in the biomass, which on the one hand reduces the caloric value and on the other hand increases toxic emissions.

- **Expert VII:**
  Expert VII mentions risks in relation to the catalytic pyrolysis process, which are primarily due to biomass quality in terms of moisture content of the wood chips. A high share of green content is accompanied by a higher degree of biological degradation.

- **Expert VIII:**
  Expert VIII is a chemical engineer and highlights the risks associated with the handling of extracted phenolics (side product). Due to the toxicity risks, especially the risks in the transport and handling of the energy source are described.

The risks, which were identified during the expert interviews were then classified according to our risk framework.

2.2.3 Legal Framework

In case of transporting, handling and storing goods, corresponding national or international regulations are binding for every logistics service provider. Especially, the transportation of goods plays an outstanding role in this context. Above all there are road traffic regulations in Europe on national levels which define maximum payloads, speed limits as well as loading security. For instance, payloads for transporting timber are different within Europe, e.g. Austria (44 tons) and Finland (60 tons). Besides the national regulations with regard to load security, a further legal basis is given by pan-European guidelines and standards, e.g. EN 12195 or VDI 2700; both of them are regulative requirements coping with loading security of cargo on road transportation.

When it comes to manipulating dangerous goods, regulatory frameworks are set up for international enforcement and are, of course, binding. The international agreement on transporting dangerous goods is based on the so-called *United Nations Recommendations on the Transport of Dangerous Goods* (UNRTDG). This agreement represents recommendations and has no legal force. Therefore, based on these recommendations, international regulatory bodies for each transport mode evolved. In Europe, the following transport mode-specific regulations exist: ADR (*Accord Européen Relatif au Transport International des merchandises Dangereuses par Route*) for road transportation, RID (*Règlement Concernant le Transport International Ferroviaire des Marchandises Dangereuses*) for rail transportation as well as ADN (*Accord Européen Relative au Transport International des Merchandises Dangereuses par Voies de Navigation Intérieures*) for inland waterway transportation. Through EC Directive 94/55/EC as well as EC Directive 96/49/EC, the member states of the European Union were forced to align their domestic legislation concerning the transport of dangerous goods by road (ADR) and rail (RID) to these international regulations in January 1997. All of these European guidelines determine how producers/consignors and carriers should classify, package, label and transport dangerous goods *(Conversion and Resource Evaluation Ltd, 2006).*

In the following a legislative review for BioBoost's reference products (biomass, intermediate energy carrier and side products) is provided. The legal framework for manipulating biomass (in BioBoost there are three individual reference feedstock types investigated: logging residues, straw in form of square bales and municipal waste) is rather straightforward and regards general terms quoted in national road traffic regulations (e.g. payloads, loading dimensions, speed limits, etc.) as well as technical guidelines for load security. Guidelines like ADR, RID etc. relate to energy carriers whereas the transport of biomass products (e.g. straw) is a topic of national jurisdication. For instance, in case of transporting agricultural and forestry products in Germany, the legally allowed total vehicle height of 4 meters and total vehicle width of 2.55 meters may be exceeded (*Kaltschmitt et al., 2009, p. 279*) if required (to max. 3 m in width with particular vehicle identification).

When dealing with BioBoost's intermediate energy carriers and side products, the material safety data sheets (MSDS)[4] of each substance need to be reviewed. Based on the physical properties (flash point, corrosivity and toxicity), each product can be assigned to a specific UN number listed in the UN Dangerous Goods Catalogue. In the annex to this document an abstract of the catalogue for all relevant products investigated in this BioBoost work package can be found. Therein, regulations regarding packaging, portable tanks, tank property, vehicle type for transporting, handling and operations are defined. A detailed overview on the structure of the guideline on transporting dangerous goods can be extracted from the current ADR edition 2013 as well as RID edition 2013. Figure 3 provides insights into major regulations for each product type.

The acronym REACH constitutes a further, recent important body of regulations for chemical products within the European Union and stands for Registration, Evaluation, Authorization and Restriction of Chemicals. This regulatory framework came into force in 2007 and aims at improving the protection of human health and the environment from chemical risks. This regulation requires companies to identify and manage risks, which are related to their manufactured and traded products. Companies have to report risk management activities to the European Chemical Agency (ECHA). By the time of preparing this report, no REACH registration number has been available for any of the products covered in BioBoost. Substances from BioBoost are either excluded according to article 2 of the regulation (EC) No 1907/2006, annual quantities require no registration or registration has not yet taken place.

[4] Due to the fact that some substances are still being researched and tested by the time of preparing this report, partial information are not available.

Product type	Legal Framework & Specifications
Biomass *In general*	**Road traffic regulation** (national regulations and European-wide guidelines) Payload Speed limits Load dimensions Load security
Bio-oil *Energy carrier*	**ADR & RID** Shipping name: Wood, hydropyrolyzed Product condition: oil UN number: UN-2924 (Flammable liquid corrosive N.O.S.) Hazard class (transportation): 3 (Flammable Liquids) Hazard class (storage): Hazard identification number: 30 Packaging group: III Package restriction: ADR Tank code: L4BN REACH registration number: n.a. Storage restrictions (prohibition on storing goods with others):
Biocoal *Energy carrier*	**ADR & RID** Shipping name: AVA-cleancoal Product condition: pressed coal, moist UN-Number: UN-1361 (Carbon, animal or vegetable origin) Hazard class (transportation): 4.2 (Spontaneously Combustible Solids) Hazard class (storage): n.a. Hazard identification number: 40 Packaging group: II Package restriction: < 450 liter per package unit Tank code: SGAN REACH registration number: n.a. Storage restrictions (prohibition on storing goods with others): n.a.
Biosyncrude *Energy carrier*	**ADR & RID** Shipping name: Biosyncrude Product condition: Slurry UN number: 3265 (Corrosive liquid, acidic, organic, N.O.S.) Hazard class (transportation): 8 (Corrosive) Hazard class (storage): 8A Hazard identification number: 80 Packaging group: II Package restriction: Package unit Tank code: L4BN European waste catalogue number: 15 01 10 REACH registration number: n.a. Storage restrictions (prohibition on storing goods with others): TRGS 510
Extracted Phenolics *Side product*	**ADR & RID** Shipping name: Phenolic Product condition: Molten mass UN number: 2312 (Phenol, molten) Hazard class (transportation): 6.1 (Poison) Hazard class (storage): n.a. Hazard identification number: 60 Packaging group: II Package restriction: n.a. Tank code: L4BH REACH registration number: n.a. Storage restrictions (prohibition on storing goods with others): n.a.

Figure 3: Legal framework & specifications of all reference products investigated in BioBoost risk analysis. This figure refers to ADR and ADN regulations

2.2.4 List of Identified Risks

As a result of the conducted survey, a total of 40 risks was identified for all three reference conversion technologies. A detailed summary of risks for each conversion technology is provided in the annex.

A major risk for hydrothermal carbonization comes from impurities, e.g. glass, metals or synthetic material, contained in the reference feedstock type municipal waste. This threat may lead to reduced heating value and higher ash content leading to economic consequences. Furthermore, toxic emissions might be released when processing synthetic material. Impure feedstock represents a hazard for fast pyrolysis and catalytic pyrolysis, too.

A more general critical issue across all conversion technologies is given by traffic originated by conversion plants. Both traffic accidents and heavy transport traffic pose the main hazardous events identified in the survey. An effective action for risk mitigation represents the shift of transport volumes from road to railway.

Moisture content plays a crucial role for woody and strawy biomass especially, e.g. logging residues, wood chips and wheat straw. This feedstock property has major impact on intermediate energy carrier production. Therefore, this issue is also highlighted as a major potential hazard along the supply chain stated as *remoistening* and in general *high moisture/water content* of feedstock provided. These risks are affected by all logistics processes and require a proper protection of feedstock against water absorption.

Regarding threats originating by equipment used for logistics manipulation like poorly cleaned tanks, leakage of tanks, increasing pressure in tanks during transportation as well as not properly locked tank lids constitute the most important risks.

As can be seen in the risk portfolio presented later, fire hazard represents one of the *broadest* risks. This means that this hazard affects a great deal of so-called influencing areas[5]. Besides that, it represents a risk type that impacts all conversion technologies. However, most of these risks are already mitigated by technical installations which are already regulated by the general operating license for a conversion plant. These risks are not covered in this report, which concentrates on risks associated with logistics pathways only. Therefore, the average risk factor for all conversion technologies is rather low as shown in chapter 0. Nonetheless, focusing on each conversion technology individually, fire hazard plays a crucial role for wood chips applied for the catalytic pyrolysis pertaining to self (e.g. high microbiological activity) or external (e.g. torching or malfunction of electric devices) ignition.

2.2.5 Hazard Cause & Effect Chart

Based on the identified set of hazards along the supply chain, the next step is about characterizing those threats according their causes and effects. In doing so, the authors noticed that most hazards are interrelated with each other. Therefore, a so-called hazard cause and effect chart has been generated in order to receive deeper insights. As a major

[5] According to the risk assessment framework hazards can negatively influence the following areas: (1) product quantity, (2) product quality, (3) environment, (4) health and (5) equipment.

result, the most important risks are identified by pinpointing individual causes and effects of each hazard. Figure 4 provides a *big picture* of risk causality.

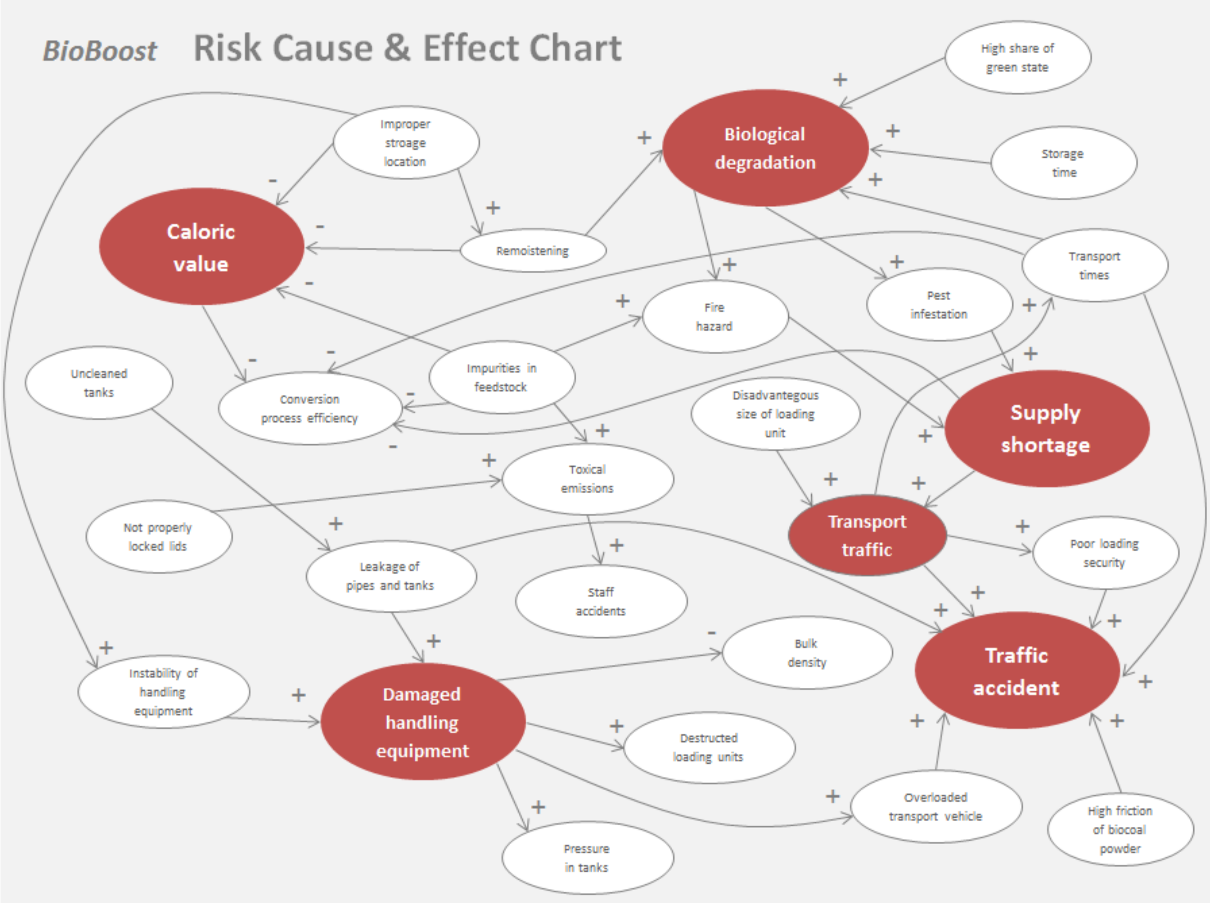

Figure 4: Risk cause & effect chart

This chart suggests that the most important risks according to their causes and/or effects are as follows: (i) reduced caloric value, (ii) biological degradation, (iii) supply shortage, (iv) transport traffic, (v) traffic accident and (vi) damaged handling equipment. As can be seen later on within the risk evaluation, the majority of those risks resemble the most important risks evaluated by the technology partners.

2.3 Risk Evaluation

In order to define (and finally rank) the most important risks, all threats identified in the forefront have been evaluated according to a predefined risk matrix by the technology partners within the BioBoost project. The following structure within the risk assessment framework has been provided:

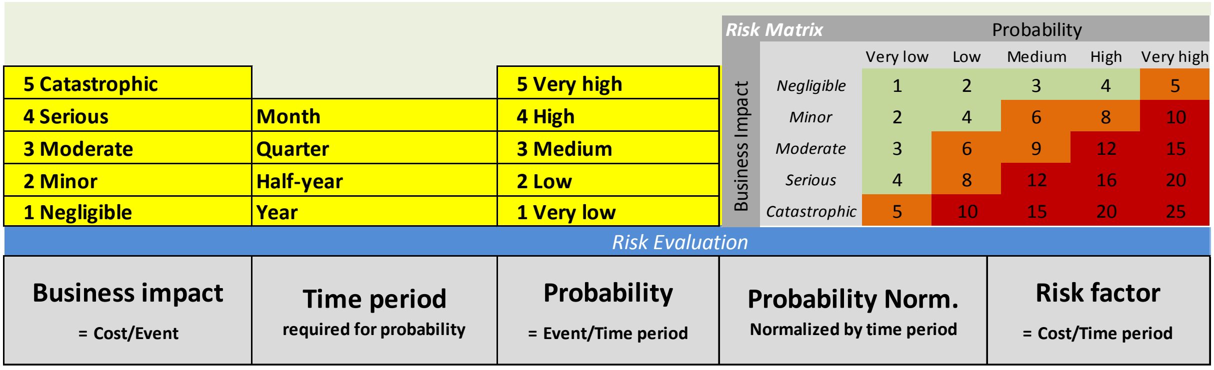

Figure 5: Structure of risk evaluation

Following the above depicted equation concerning risk, business impact as well as probability of occurrence of each hazard has been evaluated according to an operationalized scale (range between 1 and 5 indicating the severity of each risk). Furthermore, the reference time period has been added in order to further specifying the severity of each risk. Depending on the time period, the probability has been normalized by a certain factor.[6] Multiplying the defined business impact by the normalized probability yields the so-called risk factor. This key figure allows for a risk ranking and provides first implications about risk mitigation actions. The risk matrix as illustrated above is subdivided into three risk categories (Table 1). Only the category with the highest risk is further investigated with respect to risk mitigation actions. Risks with lower risk factors definitely exist but are lower in priority.

Table 1: Subgroups of risk categories out of the risk matrix

Risk factor		from		to	
	Low risk	1	≤	5	Acceptable
	Mid risk	5	≤	10	Undesirable
	High risk	10	≤	25	Unacceptable

2.3.1 Risk Portfolio

The main finding of the risk evaluation phase constitutes the so-called risk portfolio. This chart provides implications for risk mitigation strategies. All risks identified are arranged according their business impact (y-axis) and probability of occurrence (normalized by time period, x-axis). Moreover, the scope of each hazard, i.e. the number of influencing areas[7], is displayed in the form of the bubble size. As suggested by table 1, risks with a factor greater than 10 are further investigated.

The proposed risk portfolio is set up based on the mean values of business impact and probability for all conversion technologies. As already defined above, a detailed overview of risk factors for each technology can be found in the annex.

[6] Factors assumed for probability normalization: year = 1, half-year = 1.5, quarter = 1.75 and month = 2.

[7] The number of influencing areas equals how often each hazard was named in combination with the identified risks. It relates to the entries in column „hazards“ of the risk matrix, which is shown in figure 2.

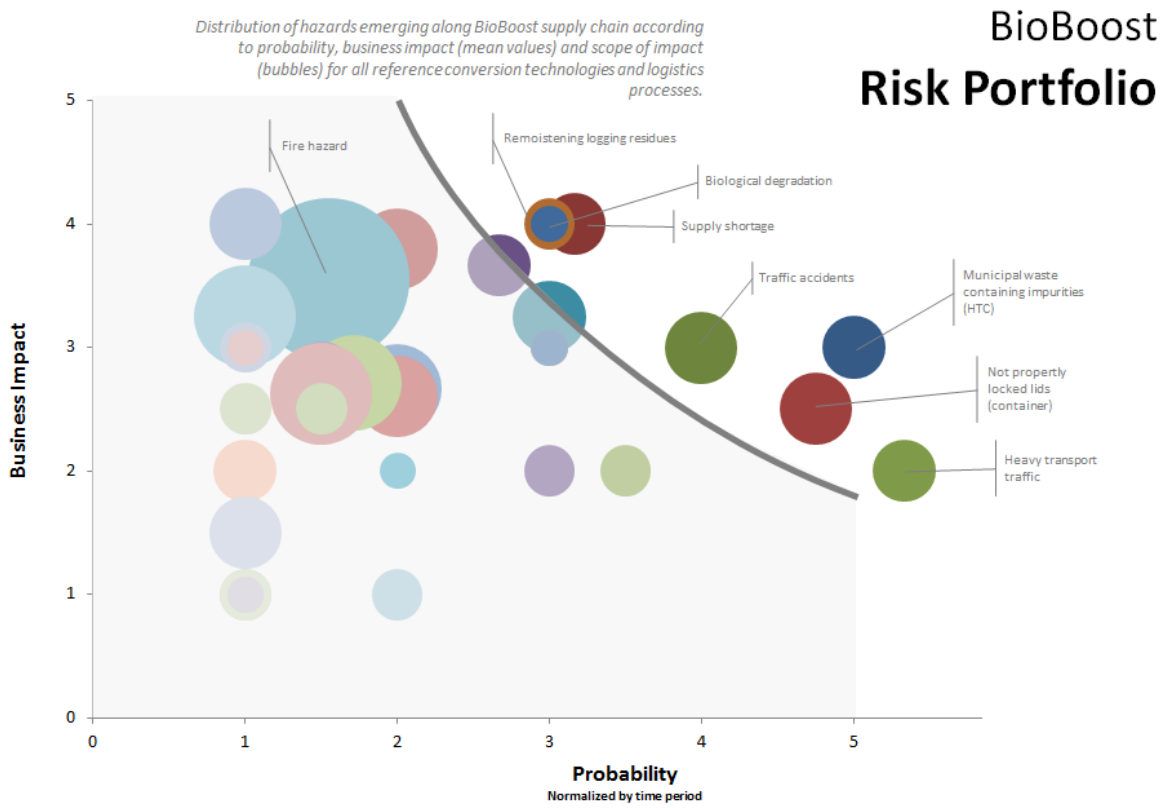

Figure 6: Risk portfolio

The following table indicates the top 9 risks with an associated risk factor greater than 10. Simultaneously, this selection represents the fundament for risk mitigation strategies, which are discussed in chapter 2.4.

Table 2: Risk portfolio - table view

BioBoost Risk Portfolio	Business impact - Scale (mean value)	Probability Norm. (mean value)	Business impact - Scope (number of consequences)	Risk factor
Municipal waste containing impurities	3.0	5.0	3.0	15.0
Supply shortage	4.0	3.2	3.0	12.7
Traffic accident	3.0	4.0	4.0	12.0
Biological degradation	4.0	3.0	1.0	12.0
High moisture content	4.0	3.0	1.0	12.0
High share green state (needles, leaves)	4.0	3.0	2.0	12.0
Wrong particle size	4.0	3.0	1.0	12.0
Not properly locked lids	2.5	4.8	4.0	11.9
Heavy transport traffic	2.0	5.3	3.0	10.7

2.3.2 Risk Maps

A further analysis on the collected data refers to the logistics reference pathways of figure 1. Due to the fact that each hazard corresponds to a logistics process within a certain location along the supply chain, risks can be located in so-called risk maps in order to easily identify critical processes. In order to detect high-risk logistics processes, the sum of risk factors for each logistics process have been computed.

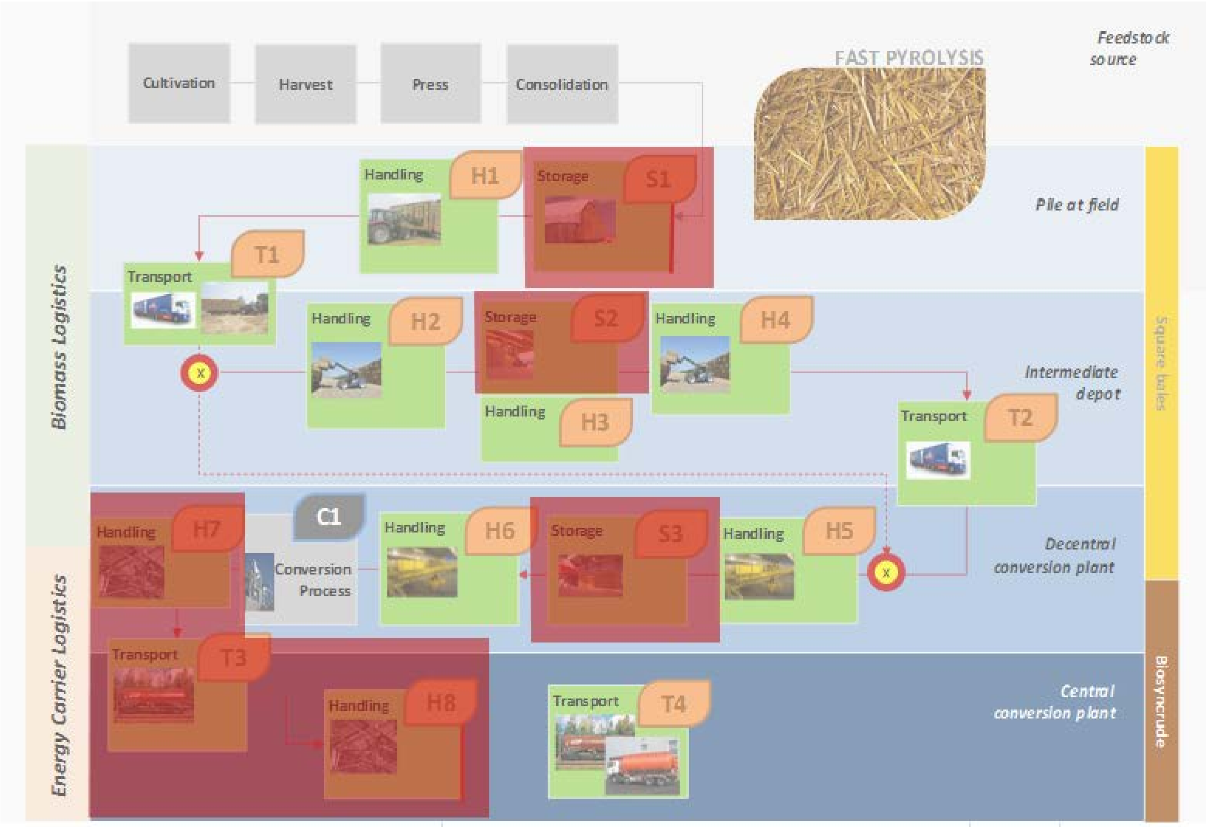

Figure 7: Risk map - Fast pyrolysis. Dark, red shaded rectangles indicate areas with highest risks

Storage processes at each echelon pose risks pertaining to remoistening of straw, fire hazard as well as pest infestation (insects) that lead to supply shortages. With respect to handling of intermediate energy carrier, fire hazard, leakage of pipes and containers as well as quality degradation of the product (so-called *aging*) due to long transport and handling lead times depict potential threats. Moreover, uncleaned tanks represent another major risk in terms of handling intermediate energy carriers.

Figure 8: Risk map -Catalytic pyrolysis. Dark, red shaded rectangles indicate areas with highest risks

Again, storage processes along the supply chain imply risks primarily based on high moisture content or remoistening. Possible causes in this context may be a high share of green state (needles, leaves) in feedstock or a lack of protection against water absorption. Biological degradation, fire hazard due to self-ignition and, finally, a reduced caloric value of feedstock are potential effects. Risks associated with handling of intermediate energy carriers are given by cracking pipes, incorrect installation of pump tubing, increasing pressure in tanks, leakage of pipes as well as uncleaned tanks.

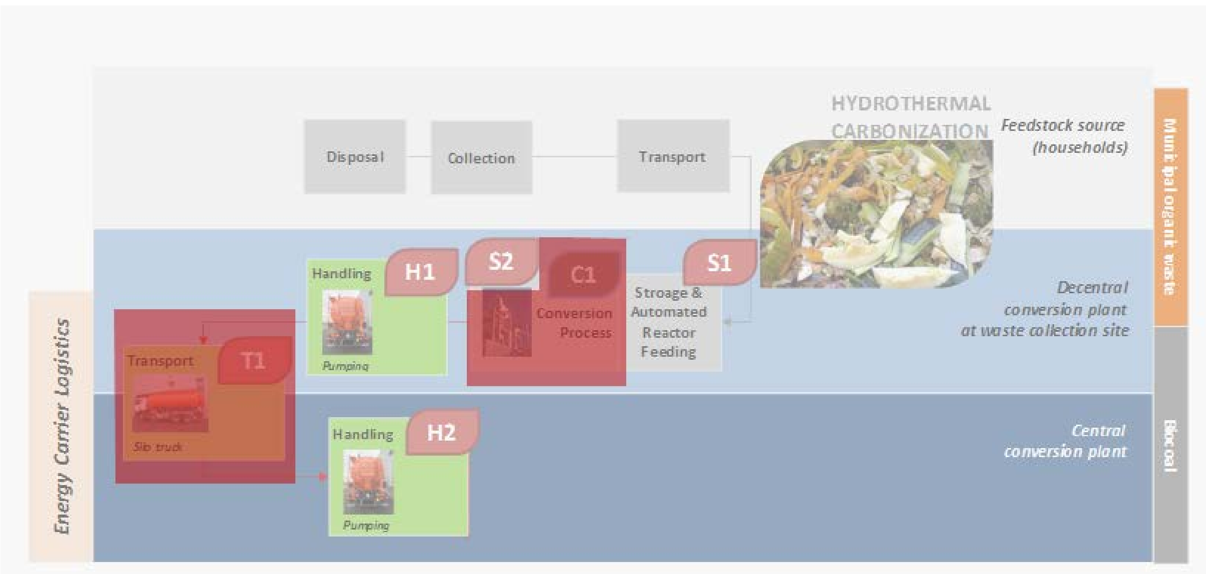

Figure 9: Risk map - Hydrothermal Carbonization. Dark, red shaded rectangles indicate areas with highest risks

According to the risk assessment conducted for hydrothermal carbonization, the conversion process at the HTC plant exhibits the highest risk. More specifically, the impurities contained in the input feedstock represent a considerable hazard for the energy carrier production. Moreover, a failure of filter systems of the plant leads to smell nuisance for the environment. Both of these threats are already considered in the plant approval procedure and, therefore, taken into account in the investment costs of plants. Concerning the transportation of the HTC energy carrier[8] a major risk emerges. In case of transporting powdered biocoal, *hot spot* creation inside the transport load might lead to fire hazards, which is caused by particle friction.

2.4 Risk Mitigation – Safety Concept

In the BioBoost risk portfolio, the top 9 risks were calculated on the basis of risk factors and consequential costs of such risks. The aim is to minimize or eliminate unacceptable risks associated with the operations.

As part of the third phase of the BioBoost Risk Assessment “risk mitigation" possible actions for risk mitigation are collected during the systematic literature review and the expert interviews (see table 3) and described in detail. This makes it possible to minimize or eliminate risks occurring.

Table 3: Actions for risk mitigation

BioBoost Risk Portfolio	Actions for Risk mitigation
Municipal waste containing impurities	Pretreatment
Supply shortage	Invest in intermediate depots
Traffic accident	- (Exogenic force)
Biological degradation	Storage location & time, Storage replenishment policy (FIFO)
High moisture content	Selection of feedstock (quality management), storage time
High share green state (needles, leaves)	Selection of feedstock (quality management)
Wrong particle size	Chipping process at SC echelon, quality management
Not properly locked lids	Staff training
Heavy transport traffic	Transportation Impact Analysis (TIA)

- **Pretreatment:** To avoid any dirt in the biomass which can lead to considerable damage of the system and consequently to loss of production, an appropriate pretreatment of the raw biomass is required. This can happen either upstream at the supplier and will be done by appropriate quality management and / or performed by machines in the conversion plant. In the BioBoost model, the pretreatment costs are already included in CAPEX (see D6.1).

- **Investment in intermediate depots:** To minimize or avoid supply shortages, the use of intermediate depots should be considered. These warehouses are covered in the logistics model of BioBoost. The cost of intermediate depots have already been collected and calculated in D4.1 and are part of the simulation model.

[8] Two product types are investigated here: pellets and powder.

- **Biological degradation**: Biological degradation is substantially caused by improper storage like not maintaining FIFO rules. In combination with other factors (e.g. high humidity in raw biomass) biological degradation is accelerated.
  A proper risk mitigation action is therefore prompt processing while considering required moisture contents. This definitely leads to higher storage costs.

- **High moisture content & high share of green state**: This risk can be minimized by appropriate quality management in the goods delivery, when only biomass is accepted that meets minimum requirements. Quality characteristics of biomass (e.g. moisture content) need to be defined in contracts with suppliers. Needless to say the increase of quality requirements leads to higher feedstock costs.

- **Wrong particle size:** The risk of a wrong particle size, as described in the previous point, is also reduced by an adequate quality management or eliminated with a subsequent chipping process. The chipping costs are already included in the BioBoost logistics process calculations.

- **Not properly locked lids:** Not properly locked lids for tank containers and tank wagons can lead to spills and subsequently cause damage to humans and the environment (e.g. groundwater contamination). To minimize this risk sufficient employee training is necessary.

- **Heavy transport traffic:** High production throughput at conversion plants induces correspondingly high frequency of supplies. In D1.4 a traffic impact analysis (TIA) for inbound transport flows was conducted with the result that no detailed traffic impact study is required by the current system configurations. In order to obtain inferences regarding inbound as well as outbound transport flows, the following analysis provides insights about daily trips generated at the decentral conversion plant as well as interarrival and interdeparture times. As can be seen in table 4, the daily trips generated are below the recommended threshold of 750 trips per day *(ITE, 2013).* The fast pyrolysis plant features the most daily trips generated at a conversion plant. There is also a differentiation made between truck and rail transportation within the outbound logistics (trip production) pertaining to different transport vehicle used. Looking at interarrival times, transport vehicles arrive at decentral conversion plants (fast and catalytic pyrolysis) theoretically every 10 and 12 minutes respectively.

Table 4: TIA for DCP inbound & outbound

Traffic impact assessment (TIA) for DCP inbound & outbound

Decentral conversion process	Unit	Fast Pyrolysis	Catalytic Pyrolysis	Hydrothermal Carbonization
Input (biomass)	t DM/d	600	505	66
Output (energy carrier)	t/d	406	132	46
Payloads of transport vehicles (according to logistics pathways)	**Unit**	**Payloads**		
Truck and drawbar trailer (wheat straw)	t DM	17,2		
Truck and drawbar trailer (wood chips)	t DM	17,5		
Silo truck (biocoal)	t DM	12,6		
Tank wagon (railway)	t	65		
Tank wagon (truck)	t	25		
Trip generation[1]		**FP Plant**	**CP Plant**	**HTC Plant**
Trip attraction	# trips/d	70	58	-
Trip production (truck)*	# trips/d	33	11	8
Trip production (railway)**	# trips/d	13	5	-
Total trips*	# trips/d	103	69	8
Total trips**	# trips/d	83	63	-
Estimated time factors for pickup & deliveries				
Weeks per year	w	48		
Days per week	d	5,5		
Delivery windows (7AM-7PM)	h	12		
Delivery windows (7AM-7PM)	min	720		
Interarrival times (inbound biomass)				
Interarrival time (deliver)*	min	10	12	-
Interdeparture times (outbound energy carrier)				
Interdeparture time (pickup)*	min	22	66	90
Interdeparture time (pickup)**	min	56	144	-

[1] Trip generation comprises trip attraction (inbound logistics: biomass) and trip production (outbound logistics: energy carrier). For each transport flow, both full as well as empty trucks are considered.

(*) these numbers relate to **road** transport for both DCP inbound and outbound traffic

(**) these numbers relate to DCP inbound **road** traffic and DCP outbound **rail** traffic

In order to extend the risk analysis mid level risks (risk factor 5 ≤ 10) were also examined (see table 5).

Table 5: Mid level risks (risk factor 5≤10)

BioBoost Risk Portfolio	Business impact - Scale (mean value)	Probability Norm. (mean value)	Business impact - Scope (number of consequences)	Risk factor
Equipment damage	3,7	2,7	3,0	9,8
(Re-)Moistening of wood chips (> 30 % WC)	3,3	3,0	4,0	9,8
Impure wood chips	3,0	3,0	1,0	9,0
Reduced caloric value	3,0	3,0	1,0	9,0
Cracking pipes	3,8	2,0	5,0	7,6
Failure of filter systems	2,0	3,5	2,0	7,0
Uncleaned tanks	2,0	3,0	2,0	6,0
Fire hazard	3,6	1,6	20,0	5,5
Impure straw bales	2,7	2,0	3,0	5,3
Leakage of tanks	2,7	2,0	6,0	5,3
Quality degradation	2,6	2,0	5,0	5,2

In general, mid level risks can be subdivided in quality and technical and / or equipment risks.

Table 6: Mid level risk clustering

Quality risk	Technical and/or equipment risk
(Re-)Moistening of wood chips (> 30 % WC)	Equipment damage
Impure wood chips	Cracking pipes
Reduced caloric value	Failure of filter systems
Fire hazard (triggered by high moisture content)	Uncleaned tanks
Impure straw bales	Leakage of tanks
Quality degradation	

3 Conclusion

This report focuses on identifying risks along a supply chain dedicated to biomass-based energy carrier production. Through reviewing existing studies and consulting experts, hazards associated with logistics and decentral conversion processes were detected. By means of this data set different analysis were conducted in order to extract the most important risks and, finally, actions for mitigating severe threats were identified. The previous chapters showed that most important risks are represented by the security of supply, reducing moisture content as well as preventing re-moistening, observing biological degradation and considering traffic induced by decentral conversion plant. For these hazards actions for risk mitigation are, if necessary, proposed.

4 List of References

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5 Annex

5.1 Definition of keywords for search of relevant articles

Used Keywords
biomass transport
biomass transport risk
biomass transport hazard
biomass storage transport
biomass storage transport risk
biomass storage transport hazard
pyrolysis oil transport
pyrolysis oil transport risk
pyrolysis oil transport hazard
pyrolysis oil storage transport risk
pyrolysis oil storage transport hazard
bio char transport
bio char transport risk
bio char transport hazard
bio char storage transport risk
bio char storage transport hazard
bio coal transport
bio coal transport risk
bio coal transport hazard
bio coal storage transport risk
bio coal storage transport hazard
bio oil transport
bio oil transport risk
bio oil transport hazard
bio oil storage transport risk
bio oil storage transport hazard

5.2 Results of scientific database search (EBSCO, Emerald, ScienceDirect)

Number	Keywords	searched as:	Database					
			EBSCO		Emerald		Science Direct	
			Results	Selected	Results	Selected	Results	Selected
1	biomass risk	*biomass*+*risk*	533	0	287	1	57204	0
		biomass+*risk* in Title	4	0	0	0	23	0
		biomass+*risk* in Abstract	133	0	2	0	1051	0
2	biomass transport, storage, handling hazard	*biomass*+*hazard*	35	0	43	0	24991	0
		biomass+*hazard* in Title	4	0	0	0	4	0
		biomass+*hazard* in Abstract	18	0	0	0	146	0
3	pyrolysis oil transport, storage, handling risk	*pyrolysis*+*risk*	8	0	39	0	12254	0
		pyrolysis+*risk* in Title	0	0	0	0	2	0
		pyrolysis+*risk* in Abstract	5	0	0	0	96	0
4	pyrolysis oil transport, storage, handling hazard	*pyrolysis*+*hazard*	6	0	23	0	9941	0
		pyrolysis+*hazard* in Title	0	0	0	0	2	0
		pyrolysis+*hazard* in Abstract	6	0	0	0	55	0
5	bio char transport, storage, handling risk	*char*+*risk*	13	0	94	0	29915	0
		char+*risk* in Title	0	0	0	0	1	0
		char+*risk* in Abstract	3	0	0	0	36	0
6	bio char transport, storage, handling hazard	*char*+*hazard*	21	0	29	0	11309	0
		char+*hazard* in Title	0	0	0	0	1	0
		char+*hazard* in Abstract	2	0	0	0	23	0
7	bio coal transport, storage, handling risk	*coal*+*risk*	4673	0	1965	0	59793	0
		coal+*risk* in Title	40	0	0	0	129	0
		coal+*risk* in Abstract	656	0	9	0	885	0
8	bio coal transport, storage, handling hazard	*coal*+*hazard*	1173	1	407	0	31858	0
		coal+*hazard* in Title	8	0	0	0	96	0
		coal+*hazard* in Abstract	142	0	3	0	359	0
9	bio oil transport, storage, handling risk	*oil*+*risk*	9510	0	7916	0	200930	0
		oil+*risk* in Title	338	0	0	0	221	0
		oil+*risk* in Abstract	5624	0	76	0	2762	0
10	bio oil transport, storage, handling hazard	*oil*+*hazard*	1964	0	0	0	68943	0
		oil+*hazard* in Title	16	0	0	0	40	0
		oil+*hazard* in Abstract	358	0	11	0	488	0
11	biomass risk assessment	*biomass*+*risk*+*assessment*	58	0	192	0	37261	0
		biomass+*risk*+*assessment* in Title	0	0	0	0	5	0
		biomass+*risk*+*assessment* in Abstract	13	0	0	0	184	0
12	biomass risk evaluation	*biomass*+*risk*+*evaluation*	25	0	152	0	32156	0
		biomass+*risk*+*evaluation* in Title	0	0	0	0	1	0
		biomass+*risk*+*evaluation* in Abstract	2	0	0	0	62	0

Rem: Despite the large number of search results only very few of them related to operational risks in connection with biomass and logistics. See also 2.2.1.

5.3 Results of Google Scholar search

Number	Keywords	searched as:	Selected	Link	Date
1	biomass risk	biomass risk	0		27.01.2014
		Biomasse Risiko	1	http://inis.iaea.org/search/search.aspx?orig_q=RN:43004108#page=231	27.01.2014
2	biomass transport, storage, handling hazard	biomass transport hazard	0		27.01.2014
		biomasse transport gefahr	0		27.01.2014
		biomass storage hazard	0		27.01.2014
		biomasse lagerung gefahr	0		27.01.2014
		biomass handling hazard	0		27.01.2014
3	pyrolysis oil transport, storage, handling risk	pyrolysis oil transport risk	0		27.01.2014
		pyrolyse öl transport risiko	0		27.01.2014
		pyrolysis oil storage risk	0		27.01.2014
		pyrolyse öl lagerung risiko	0		27.01.2014
		pyrolysis oil handling risk	0		27.01.2014
4	pyrolysis oil transport, storage, handling hazard	pyrolysis oil transport hazard	0		27.01.2014
		pyrolyse öl transport gefahr	0		27.01.2014
		pyrolysis oil storage hazard	0		27.01.2014
		pyrolyse öl lagerung gefahr	0		27.01.2014
		pyrolysis oil handling hazard	0		27.01.2014
5	bio char transport, storage, handling risk	bio char transport risk	0		27.01.2014
		bio kohle transport risiko	0		27.01.2014
		bio char storage risk	0		27.01.2014
		bio kohle lagerung risiko	0		27.01.2014
		bio char handling risk	0		27.01.2014
6	bio char transport, storage, handling hazard	bio char transport hazard	1	https://www.nrdc.org/energy/files/biochar_paper.pdf	27.01.2014
		bio kohle transport gefahr	0		27.01.2014
		bio char storage hazard	0		27.01.2014
		bio kohle lagerung gefahr	0		27.01.2014
		bio char handling hazard	0		27.01.2014
7	bio coal transport, storage, handling risk	bio coal transport risk	0		27.01.2014
		bio coal storage risk	0		27.01.2014
		bio coal handling risk	0		27.01.2014
8	bio coal transport, storage, handling hazard	bio coal transport hazard	0		27.01.2014
		bio coal storage hazard	1	http://gisceu.net/PDF/U918.pdf	27.01.2014
		bio coal handling hazard	0		27.01.2014
9	bio oil transport, storage, handling risk	bio oil transport risk	0		27.01.2014
		bio öl transport risiko	0		27.01.2014
		bio oil storage risk	0		27.01.2014
		bio öl lagerung risiko	0		27.01.2014
		bio oil handling risk	0		27.01.2014
10	bio oil transport, storage, handling hazard	bio oil transport hazard	0		28.01.2014
		bio öl transport gefahr	0		28.01.2014
		bio oil storage hazard	0		28.01.2014
		bio öl lagerung gefahr	0		28.01.2014
		bio oil handling hazard	0		28.01.2014
11	biomass risk assessment	biomass risk assessment	0		28.01.2014
		biomasse risiko bewertung	0		28.01.2014
12	biomass risk evaluation	biomass risk evaluation	0		28.01.2014
		biomasse risiko evaluierung	0		28.01.2014

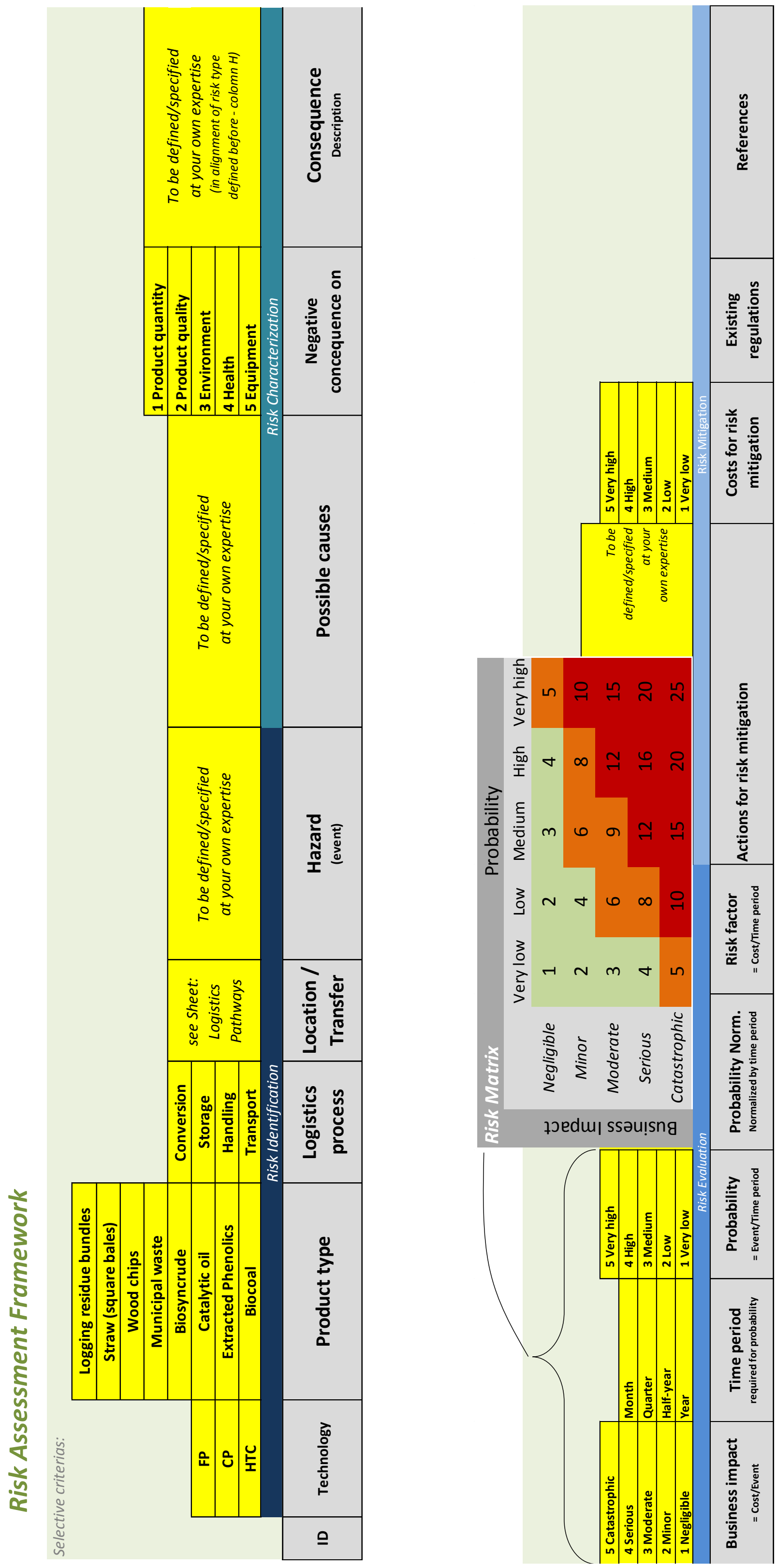
Rem: Results from Google Scholar are less scientifically oriented than those from scientific databases.

5.4 Results of Google search (rather practically oriented)

Number	Keywords	searched as:	Selected	Link	Date
1	biomass risk	biomass risk	0		29.01.2014
		Biomasse Risiko	0		29.01.2014
2	biomass transport, storage, handling hazard	biomass transport hazard	3	http://www.nachhaltigwirtschaften.at/iea_pdf/reports/iea_bioenergy_health_and_safety_report_(final).pdf http://www.pyne.co.uk/Resources/user/docs/TRANSPORT,%20STORAGE%20AND%20HANDLING%20OF%20BIOMASS%20DERIVED%20FAST%20PYROLYSIS%20LIQUIDS.pdf http://www.ieabcc.nl/workshops/task32_Dublin_SSC/07%20Koppejan.pdf	29.01.2014
		biomasse transport gefahr	1	http://www.aelf-mn.bayern.de/erwerbskombination/44274/linkurl_30.pdf	29.01.2014
		biomass storage hazard	1	http://www.cea.org.uk/files/4313/7502/0795/Biomass_HS_final_071211.pdf	29.01.2014
		biomasse lagerung gefahr	1	http://www.bam.de/de/service/publikationen/publikationen_medien/fb284_vt.pdf	29.01.2014
		biomass handling hazard	0		29.01.2014
3	pyrolysis oil transport, storage, handling risk	pyrolysis oil transport risk	0		29.01.2014
		pyrolyse öl transport risiko	0		29.01.2014
		pyrolysis oil storage risk	1	http://www.pyne.co.uk/Resources/user/docs/CIRAD_MSDS-Final.pdf	29.01.2014
		pyrolyse öl lagerung risiko	0		29.01.2014
		pyrolysis oil handling risk	0		29.01.2014
4	pyrolysis oil transport, storage, handling hazard	pyrolysis oil transport hazard	0		29.01.2014
		pyrolyse öl transport gefahr	0		29.01.2014
		pyrolysis oil storage hazard	0		29.01.2014
		pyrolyse öl lagerung gefahr	0		29.01.2014
		pyrolysis oil handling hazard	0		29.01.2014
5	bio char transport, storage, handling risk	bio char transport risk	0		29.01.2014
		bio kohle transport risiko	0		29.01.2014
		bio char storage risk	0		30.01.2014
		bio kohle lagerung risiko	0		30.01.2014
		bio char handling risk	0		30.01.2014
6	bio char transport, storage, handling hazard	bio char transport hazard	0		30.01.2014
		bio kohle transport gefahr	0		30.01.2014
		bio char storage hazard	0		30.01.2014
		bio kohle lagerung gefahr	0		30.01.2014
		bio char handling hazard	0		30.01.2014
7	bio coal transport, storage, handling risk	bio coal transport risk	0		30.01.2014
		bio coal storage risk	0		30.01.2014
		bio coal handling risk	0		30.01.2014
8	bio coal transport, storage, handling hazard	bio coal transport hazard	0		30.01.2014
		bio coal storage hazard	0		30.01.2014
		bio coal handling hazard	0		30.01.2014
9	bio oil transport, storage, handling risk	bio oil transport risk	0		30.01.2014
		bio öl transport risiko	0		30.01.2014
		bio oil storage risk	0		30.01.2014
		bio öl lagerung risiko	0		30.01.2014
		bio oil handling risk	0		30.01.2014
10	bio oil transport, storage, handling hazard	bio oil transport hazard	0		30.01.2014
		bio öl transport gefahr	0		30.01.2014
		bio oil storage hazard	0		30.01.2014
		bio öl lagerung gefahr	0		30.01.2014
		bio oil handling hazard	0		30.01.2014
11	biomass risk assessment	biomass risk assessment	2	http://np-net.pbworks.com/f/Holmlund+(2005)+Risk+Assessment+Bio+-+presentation+IEA+Task+40,+UNEP.pdf http://www.gasification-guide.eu/gsg_uploads/documenten/D12%20Risk%20assessment%20-%20Health%20Safety%20and%20Environment.pdf	30.01.2014
		biomasse risiko bewertung	0		30.01.2014
12	biomass risk evaluation	biomass risk evaluation	0		30.01.2014
		biomasse risiko evaluierung	0		30.01.2014

Rem: useable results from Google search are larger since practitioners' reports are returned, too

5.5 Risk assessment framework



5.6 UN classification of relevant substances

UN No.	Name and description	Class	Classifi-cation code	Packing group	Labels	Special provi-sions	Limited and quantities		Packaging			Portable tanks and	
									Packing instruc-tions	Special packing provisions	Mixed packing provisions	Instruc-tions	Special provisions
	3.1.2	2.2	2.2	2.1.1.3	5.2.2	3.3	3.4	3.5.1.2	4.1.4	4.1.4	4.1.10	4.2.5.2 7.3.2	4.2.5.3
(1)	(2)	(3a)	(3b)	(4)	(5)	(6)	(7a)	(7b)	(8)	(9a)	(9b)	(10)	(11)
1361	CARBON, animal or vegetable origin	4.2	S2	II	4.2		0	E2	P002 IBC06	PP12	MP14	T3	TP33
2924	FLAMMABLE LIQUID, CORROSIVE, N.O.S.	3	FC	III	3 +8	274	5 L	E1	P001 IBC03 R001		MP19	T7	TP1 TP28
3265	CORROSIVE LIQUID, ACIDIC, ORGANIC, N.O.S.	8	C3	II	8	274	1 L	E2	P001 IBC02		MP15	T11	TP2 TP27
2312	PHENOL, MOLTEN	6.1	T1	II	6.1		0	E0				T7	TP3

ADR tank		Vehicle for tank carriage	Transport category (Tunnel restriction code)	Special provisions for carriage				Hazard identifi-cation No.	UN No.	Name and description
Tank code	Special provisions			Packages	Bulk	Loading, unloading and handling	Operation			
4.3	4.3.5, 6.8.4	9.1.1.2	1.1.3.6 (8.6)	7.2.4	7.3.3	7.5.11	8.5	5.3.2.3		3.1.2
(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(1)	(2)
SGAN	TU11	AT	2 (D/E)	V1 V13				40	1361	CARBON, animal or vegetable origin
L4BN		FL	3 (D/E)	V12			S2	38	2924	FLAMMABLE LIQUID, CORROSIVE, N.O.S.
L4BN		AT	2 (E)					80	3265	CORROSIVE LIQUID, ACIDIC, ORGANIC, N.O.S.
L4BH	TU15 TE19	AT	0 (D/E)			CV13	S9 S19	60	2312	PHENOL, MOLTEN

5.7 Risk list for each conversion technology

Fast Pyrolysis	Probability Normalized by Time Period	Business Impact (Scale)	Business Impact (Scope)	Negative Consequence on...
Risk factor 1				
(Re-)Moistening of straw	1	1	3	2,3
Destructed bales	1	1	2	1,2
Risk factor 2				
Crashing pile	2	1	1	1
Disadvantageous bale size	2	1	1	5
Fire hazard	1	2	2	1
Leakage of pipes and vessels	1	2	2	1
Low bulk density	2	1	2	1,2
Pest infestation (insects)	1	2	1	1
Poor load securing	1	2	1	1
Risk factor 3				
(Re-)Moistening of straw	1	3	1	4
Fire hazard	1	3	5	1,3,5
Instability of handling equipment	1	3	1	5
Leakage of pipes and vessels	1	3	2	5
Overloaded transport vehicle	1	3	1	5
Pest infestation (insects)	1	3	1	4
Risk factor 4				
Crashing pile	1	4	1	4
Destructed bales	1	4	1	4
Fire hazard	1	4	4	4,5
High moisture content (> 15 % WC)	2	2	1	2
Impure straw bales	2	2	1	1
Instability of handling equipment	1	4	1	4
Leakage of pipes and vessels	1	4	4	3,4
Overloaded transport vehicle	1	4	1	4
Poor load securing	1	4	1	4
Uncleaned tanks	2	2	1	5
Risk factor 6				
Equipment damage	2	3	1	5
Impure straw bales	2	3	2	2,5
Risk factor 10				
Supply shortage	2	5	1	1
Risk factor 10.5				
Quality degradation	3,5	3	2	1,1
Risk factor 16				
Heavy transport traffic	8	2	1	3

Explanation: *Business Impact (Scale)* refers to the assessment scale presented as a selective criteria (from 1 to 5), whereas *Business Impact (Scope)* defines how often the hazard was attributed to a potential risk factor. The last column indicates by numbers, which particular consequences each risk has (1…Product quantity, 2…Product quality, 3…Environment, 4…Health, 5…Equipment). Risks might result in more than one consequence, which is indicated by a sequence of numbers.

Catalytic Pyrolysis	Probability Normalized by Time Period	Business Impact (Scale)	Business Impact (Scope)	Negative Consequence on...
Risk factor 2				
Leakage of pipes	1	2	1	3
Overloaded transport vehicle	1	2	4	1,3,4,5
Risk factor 3				
(Re-)Moistening of wood chips (> 30 % WC)	1,5	2	1	2
Fire hazard	3	1	1	5
Incorrect installation of the pump tubing	1	3	3	1,3,4
Leakage of pipes	1	3	1	1
Quality degradation	1	3	1	2
Toxication	1	3	1	4
Risk factor 4				
Heavy transport traffic	4	1	1	3
Incorrect installation of the pump tubing	1	4	1	1
Inreasing pressure in tanks	1	4	4	1,3,4,5
Instability of handling equipment	2	2	2	4,5
Leakage of pipes	2	2	1	4
Leakage of tanks	2	2	2	1,3
Not properly locked lids	1	4	1	1
Risk factor 5				
Fire hazard	1	5	4	1,3,4,5
Risk factor 6				
Cracking pipes	2	3	1	5
Fire hazard	3	2	1	4
Leakage of pipes	2	3	4	1,3,4,5
Leakage of tanks	2	3	4	1,3,4,5
Risk factro 8				
Cracking pipes	2	4	4	1,3,4,5
Uncleaned tanks	4	2	1	2
Risk factor 9				
(Re-)Moistening of wood chips (> 30 % WC)	3	3	1	3
Impure wood chips	3	3	1	2
Overloaded transport vehicle	3	3	2	4,5
Reduced caloric value	3	3	1	2
Supply shortage	3	3	1	1
Risk factor 12				
(Re-)Moistening of wood chips (> 30 % WC)	3	4	1	2
Biological degradation	3	4	1	2
Equipment damage	3	4	2	2,5
Heavy transport traffic	4	3	1	3
High moisture content	3	4	1	2
High share green state (needles, leaves)	3	4	2	1,2
Not properly locked lids	6	2	3	1,2,4
Traffic accident	4	3	4	1,3,4,5
Wrong particle size	3	4	1	2
Risk factor 18				
(Re-)Moistening of wood chips (> 30 % WC)	4,5	4	1	4
Fire hazard	4,5	4	2	1,2
Supply shortage	4,5	4	1	1

Hydrothermal Carbonization	Probability Normalized by Time Period	Business Impact (Scale)	Business Impact (Scope)	Negative Consequence on...
Risk factor 1				
(Re-)Moistening of biocoal	1	1	2	2
High water content (biocoal > 55 % WC)	1	1	2	2,4
Released emissions (mold formation, sewage water)	1	1	1	2
Risk factor 2				
Quality degradation	1	2	2	1,2
Risk factor 3				
Blocking of municipal waste by walking floors (truck)	1	3	1	5
Risk factor 4				
Dust explosion	1	4	1	1
Risk factor 5				
Fire hazard	1	5	1	1
Risk factor 7				
Failure of filter systems	3,5	2	2	3,4
Risk factor 15				
Municipal waste containing impurities	5	3	3	2,3,4

Negative concequence on
1 Product quantity
2 Product quality
3 Environment
4 Health
5 Equipment