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Report on possible Health, safety and environmental (HSE) hazards from biomass gasification plants

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Legal Disclaimer

Foreword

The present **Report on possible HSE Hazards** was created in 2007 within the "Gasification Guide" project, which is supported by the Intelligent Energy for Europe programme under contract no. EIE-06-078.

Biomass gasification is a promising technology, which can contribute to the overall EU-policy to develop future energy systems which are efficient, safe in design and operation as well as environmental friendly and increase the share of renewable energy. Gasification technology is near to commercialisation but today large-scale introduction is hampered by various reasons.

Poor awareness and lack of understanding of the health, safety and environment (HSE) hazards in the project development, planning, design, construction stage and during operation and maintenance of gasification plants is recognized as a major non-technical obstacle. The project "Guideline for Safe and Eco-friendly Biomass Gasification" aims to effectively tackle this barrier.

The objective is to accelerate the market penetration of relatively small scale biomass gasification systems (< 5 MW fuel power) by the development of a Guideline and Software Tool for easy and simple risk assessment of HSE.

The project homepage can be reached at **http://www.gasification-guide.eu**.

1. Process of Biomass Gasification

1.1. Introduction

Biomass gasification provides a possibility for an efficient conversion process for the supply combined heat and power in small scale systems by producing a burnable wood gas from solid biomass. By utilizing such a burnable gas e.g. with internal combustion (IC) engines a high total electrical efficiency (approx. 25 - 30%, [1]) can be reached.

A full assessment of risks and hazards coming from the burnable gas atmosphere requires information on explosion characteristics of possible gas/oxidizer mixtures in and around the plant and awareness of possible reasons such as leakages, failures of plant parts (e.g. rotary valves), damages of the piping, casings etc. Therefore a comprehensive risk assessment is required to cover all possible risks from plant site and to reduce danger and risk potentials respectively. The properties of the produced treated/converted gaseous secondary fuel with its toxicity, hot plant utilities, burnable explosive gas mixtures, etc. as well as the plant with its mechanical components, reactors and aggregate cause a lot of risks, which has to be considered in a detailed hazard evaluation and analysis and enclosed risk assessment procedure to provide a technology which is stable and safe in design and operation.
Furthermore a broad data pool must be available for explosion characteristics of different producer gas compositions referring to different operation modes of the plant (start-up, shut-down, normal operation, emergency shut down) to develop and provide safe plant concepts according to different European directives and guidelines as well as national guidelines and laws.

From statutory authorization frame the risk assessment systematic for the development of safe plants is required without any restrictions on the used technology in general. For example a detailed risk assessment is required in the

- Machinery Directive 2006/42/EC [2]
- Pressurized Equipment Directive 97/23/EC (PED) [3]
- ATEX Directive (94/9/EC) [4]
- Electromagnetic Compatibility (EMC) – Directive 89/336/EC and 2004/108/EC [5]
- Low Voltage Directive 2006/95/EC [6]

Providing a technological documentation of the risk assessment is not only required by the directives mentioned above – for the placing a product/machinery into the market it also protects the manufacturer/employees/operators in principle from prosecutions regarding negligence. When a comprehensive risks assessment was done and nevertheless an accident would occur, which has not been taken into account at the well developed, argued and documented risk assessment, manufacturers/operators cannot easily be accused for negligent behaviour.

The procedure of risk assessment is not generally standardized and is only supported by a huge amount of case studies from different other branches of the industry (e.g. food industry, chemical industry, metal industry, etc.). These given examples can only give guidance for finding a systematic and have to be modified for the application of biomass gasification plants.

This document presents a possible approach to hazard identification and risk assessment for biomass gasification plants in the lower and middle class of power.

1.2. Process Description – Overview

Biomass gasification deals with the thermo-chemical conversion of solid biomass to a burnable gas which can finally be used in gas utilisation units, like internal combustion engines, gas turbines or fuel cells, for the combined heat and power (CHP) production. The plants are normally operated with woody natural biomass, but can principally also be operated with wood residues, waste wood or short rotation crops. The latter kinds of feed stock are not covered by the present project and therefore this document does not include additional impacts on possible HSE issues caused by different solids fuels from woody biomass.
The process chain of biomass gasification plants includes different process stages, which have different specific functions for a reliable generation of producer gas of defined quality for safe and eco- and environmental-friendly heat and power production in the gas utilisation module.
The biomass enters the plant over a fuel feeding system, which conveys the biomass in required mass stream and quality (fuel treatment maybe included: sieve, dryer, etc.) to the gasifier, where the biomass is converted to a gaseous secondary fuel. The produced wood gas usually leaves the gasifier with in temperature between 500 and 800°C and a specific heating value and organic and inorganic gaseous and a particulate matter pollutants (tars, dusts, soot, ammonia, chlorine, alkali metals, chlorine and sulphurous compounds). The specific load on particulate matter strongly depends on the gasification principle (fixed bed, moving bed, circulating systems, etc. For a detailed description see Deliverable 8 "Report - Description of Biomass Gasification Technologies". After gasification the produced gas has to be cooled, cleaned from pollutants, condensate water has to be separated in order to be able to utilize the gaseous fuel utilised for instance in internal combustion engines. The limiting values for producer gas pollutants as well as producer gas quality parameters (temperature, gas flow, supply pressure, moisture content, etc.) are defined by manufactures of the utilisation aggregates. The produced heat and power from the gas engine is supplied to local energy grids - district heating systems or local electricity grid respectively. A CHP-plant is usually operated according to the heat demand (base heat load operation), which means that allows produced heat is used in the local district heating system. Figure 1-1 gives an overview on typical biomass gasification installation with its process steps as well as in- and output streams.

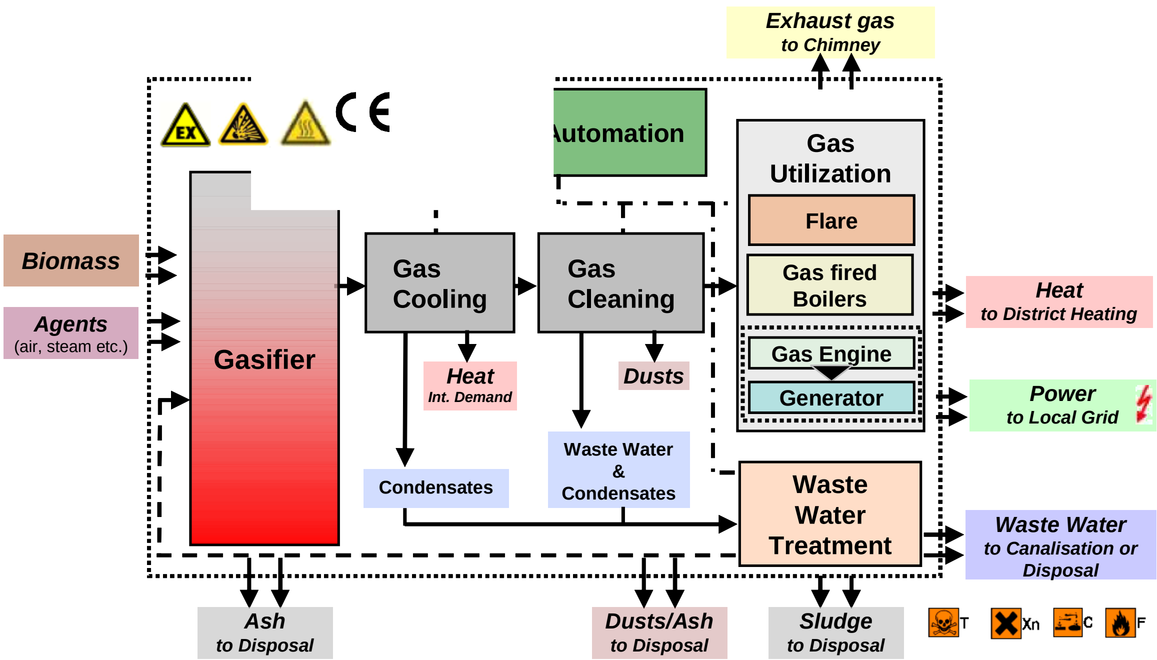

Figure 1-1: Typical process chain of a biomass gasification plant [7]

Basis for the year-round base load operation is the plants load design, which has to include load characteristic of the present district heating system as well as seasonal fluctuation with part load in summer month, where it should be possible, that the CHP-plant can also be operated in full load or in slightly part load.
The operation of biomass gasification plant causes different plant emission streams in gaseous, liquid and solid phase – especially liquid and gaseous emission stream often need to be treated due to the legal frame of existing limiting values. Emission stream in solid phase (majority of the accumulated mass are ashes out of gasification) have to be classified with respect to solid carbon content and contamination with organic compounds (e.g. sludge from gas cleaning) for the selection of usage or disposal type (see also limiting values for solids out of biomass combustion).

2. Hazards identification and analysis

The present report gives an overview on possible HSE hazards at biomass gasification plants. Hereby a systematic method is presented for the investigation of dangers from plant operation and their possible consequences. The outcome of this analysis is given within the next chapter specific for each process step of the process chain. The applied approach follows in principle the model of HAZOP analysis and is adapted on the special requirement of biomass gasification plant analysis with the boundary condition to provide a simplified method, which can easily used by plant manufacturers and operators [8, 9].
HAZOP analysis starts in principle with the definition of functions of units or parts of the plant installation in operation and uses simple key words for the investigation of valid or not valid plant operation states (too high/to low, more/less, etc.). The team, which is conducting the HAZOP analysis has to ask for events, consequences and reasons (caused by events) due to theoretical abnormal operation states of the plant and evaluates therefore the possible HSE hazards.
An accurate and suitable technology description is fundamental for the risk evaluation and assessment covering the plant operation details as well as basics for possible HSE hazards. Figure 2-1 presents a simplified process configuration of a gasification plant. For detailed analysis of dangers it is helpful to subdivide the process chain into different plant sections, were operation modes, temperatures, pressures, used and treated plant utilities can be defined more easily for manageable plant section than in an overall analysis of the whole plant at one step. Interfaces between the process sections have to be defined for an overall analysis and assessment in a second step to unite the different analyses of possible events and their consequences from the different process sections.

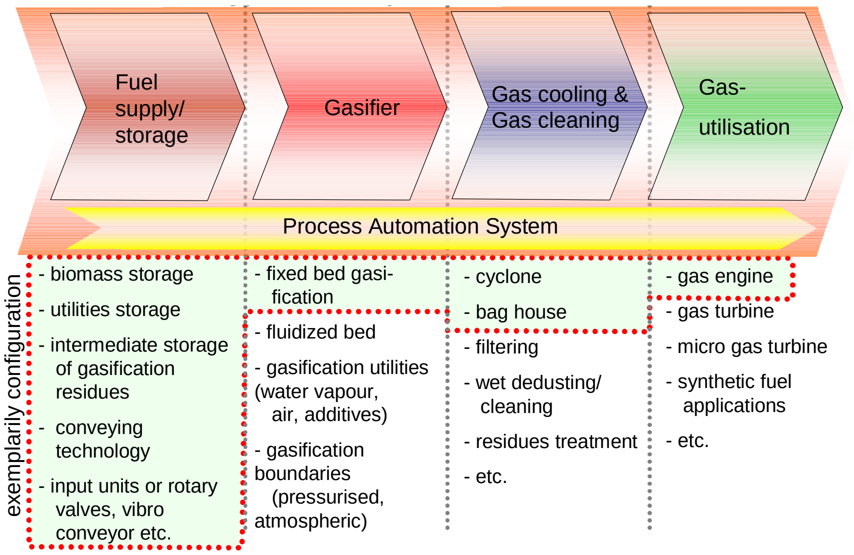

Figure 2-1: Typical process configuration of a gasification plant [9]

The red framed area in the figure above gives an exemplarily configuration of a gasification plant. Based on this exemplarily configuration the used aggregates, electrical drives, reactors, etc. are investigated within a detailed analysis to define the operation mode of the plant sections.

In that stage of the analysis it is a big challenge to combine possible HSE hazards with part, units, modules and its function to get a complete list of possible HSE dangers in the plant concept, which have finally be assessed to their risk potential, whether counter measures have to be applied or not. Figure 2-2 gives a structure for the risk evaluation in biomass gasification plants.

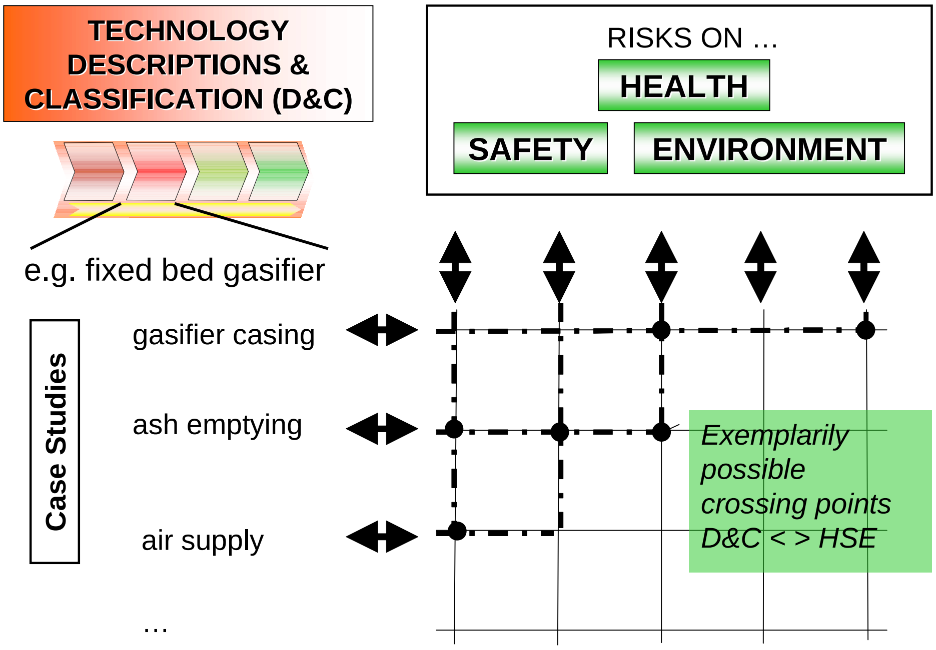

Figure 2-2: Hazard evaluation of technical plant concepts [7]

Each process step with is functions unit and parts should be taken into consideration for the hazard evaluation. The first step is to define process units and their functions. In many cases the risk evaluation deals with very complex system, which contains a huge number of mostly independent functions and plant parts. By defining process units the complex system is simplified and a separate analysis of each function is possible. Based on this an analysis on possible hazards can be applied, asking for abnormal operation conditions as well as impact of a possible electronics, part or aggregate failure and their consequences.
The following tables (Table 2-1and Table 2-2) are checklists for possible hazardous events and their consequences, which can occur at biomass gasification plants. These checklists were circulated and agreed upon within the project team with experts on HSE. Nevertheless these lists cannot be considered to be exhaustive (no claim to completeness is made), but gives good guidance for the conduction of hazard identification and the preparation of a risk assessment.

Completeness of the information and data provided in the given cases and examples is excluded. Other cases and examples are feasible.

The identification of possible hazardous events and their consequences should basically be conducted in team work. The team has to prepare all necessary technical information (technology description, information about plant media and utilities, process schemes, etc.) to have a good basis for the hazards analysis of the particular process or process unit. For elaborating the specific details it is helpful to subdivide the whole process chain into sub

units, e.g. a biomass gasification plant consists of the units fuel supply, gasifier, gas cooling, and so on. The sub units themselves can be itemised into functions and functional groups (part based), which allows an easier investigation of possible hazards or failure cases – see Figure 2-3 for the preparation of the hazards identification and risk assessment.
The detailed and itemised technology description (recommendable in tabular form) provides the basis for a step-wise analysis of events and their possible consequences, which might be relevant relating unacceptable risks. For giving an example the analysing team has to ask for the possibility of leakages (see Table 2-2 of events) in the present investigated functional group “scrubber packing tower”, as shown later on.
According to the estimations of the team there could be the fact, that sealing from flange connectors (part of the functional group scrubber packing tower) could be safety relevant, where gas leakages can occur.
The next step based on the awareness of possible hazardous events is the combination of this circumstance with possible consequences. It is important to point out, that an identified hazardous event can also possess more than one possible consequence. Possible consequences are summarised in Table 2-2.

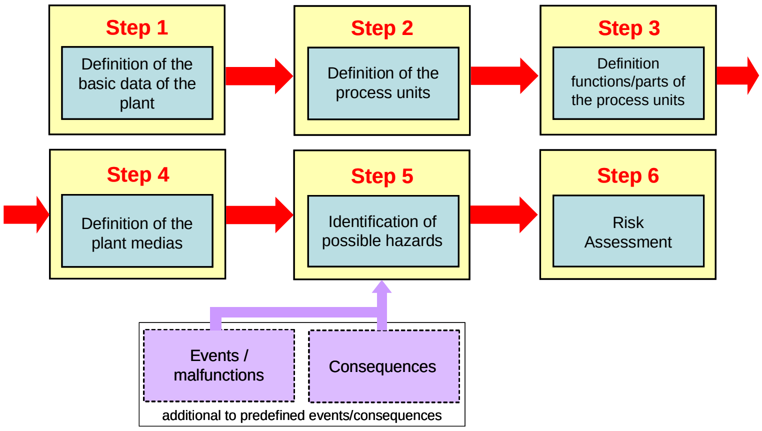

Figure 2-3: Preparation of the hazards identification and risk assessment

Table 2-1: Checklist for possible hazardous events in biomass gasification plants (without the claim to completeness)

EVENTS

1	Leakage (gas escape / air intake)	The term leakages includes the types of unpredictable loss of containment of plant media and plant utilities. Plant media could be biomass, producer gas, scrubbing agent, etc. Plant utilities are possibly pressurised air, cooling agents, inertisation media like nitrogen, etc.
2	Leakage steam	
3	Leakage liquids (escape)	
4	Leakage scrubbing agents	
5	Leakage solids	
6	Temperature too high/low	Physical/chemical parameters gives defined operation conditions of the particular investigated functional group - an exceeding or undershooting of this normal operation conditions could principally lead to hazards and should therefore be investigated as for "too high" or "too low".
7	Pressure too high/low	
8	Plant flows too high/low	
9	Plant fill level too high/low	
10	Concentration too high/low	
11	Failure - mechanical stress	Part or functional group failure can have various shape, depending on operation conditions or mechanical, thermal or chemical stress.
12	Failure - thermal stress	
13	Failure - corrosion	
14	Failure - icing	
15	Failure - ware out	
16	Failure - blocking	
17	Failure - sealing	
18	Failure - welding	
19	Failure - fitting or flange	
20	Hot surfaces	Thermal conversion plants possess system immanent hot surfaces, which have to be analysed due to possible hazards, f.i. gasifier, gas engine exhaust gas system, etc.
21	Failure - electric power supply	Failure in electrical installations, devices or plant steering and control system could be a initial points for a huge number of possible hazards in fully automated plant concepts. Therefore a comprehensive analyse on that topic have to be applied according to the listed points of this rubric.
22	Failure - electric plant steering and control	
23	Failure - electrical device	
24	Failure - sensor	
25	Failure - plant media/utility supply and disposal	The reliable supply with plant medias and plant utilities is necessary for the safe and stable plant operation. Failures within the supply chain could lead to transient operation states (shut down) or failure of safety functions.
26	Harmful plant media and utilities	Biomass Gasification plants process different medias and utilities, which could be harmful for human health and environment. A possible loss of containment (see also leakage) could directly result in health or environmental impairment.
27	Transient operation - start-up	Transient plant operation states includes start-up, shut down and changes of plant power load, where grave intervention into the plant control parameters, applied by the operator or automatic routines, take place.
28	Transient operation - shut-down	
29	Transient operation - increase plant power load	
30	Transient operation - emergency shut-down	
31	Operating error	Operating error are frequent reasons for hazardous consequences within plant operation, so the plant concept should therefore be analysed on such possibilities and further improvement to prevent maloperation (process automation, technical precaution - fail-safe)
32	Maintenance	
33	Force of nature - flooding	Forces of nature have generally to be considered and focuses on the reliability of the process chain under such environmental influences.
34	Force of nature - stroke of lightning	
35	Force of nature - storm/thunderstorm	
36	Force of nature - earthquake	

Table 2-2: Checklist for possible hazardous consequences in biomass gasification plants (without the claim to completeness)

Consequences

1	Abnormal operation conditions	Abnormal operation conditions are typically described by exceeding/undershooting of normal operation conditions and physical/chemical media properties and can have various reason.
2	Mechanic failure	This term contains various types of possible failure and failure reasons - see also event list.
3	Danger from electricity	Danger from electricity includes hazards, where electrical installation and their possible malfunctions are involved.
4	Failure gas engine / Emergency stop	Biomass conversion plants (gasification, combustion) process solid, liquid and/or gaseous fuels and have to guarantee a safe utilisation of varying feedstock and under different plant operation states (normal operation, start up, shut down, etc.)
5	Failure of combustion system	
6	Failure of flare / Emergency gas utilisation	
7	Failure of automation system	The stable operation of the automation system assume a functioning process electric system; f.i.: unpredictable failure from plant sensor could lead to an total or part-wise failure of the automation system.
8	Danger to health	Possible dangers to health and impact on environment are summarised within this rubric.
9	Danger to health - skin burns	
10	Danger to health - irritation of skin mucous membrane	
11	Noise pollution, ototoxic noise	
12	Immission (exhaust, flue gas and smell/odour)	
13	Poisoning	
14	Smouldering fire	Fire and explosion are, apart from danger to health or environment, consequences with an almost always high severity. This type of consequence requires in most of cases counter measures and an extended safety concept for successful risk reduction - see risk assessment.
15	Fire	
16	Explosion	
17	Failure of function	Functions failure means the occurance of and specific function of the investigated unit or sub unit, which leads to fatal errors in the process chain.
18	others	

Potential hazardous events cause dangerous consequences on occurrence during plant operating. The effects from these consequences have to be minimized by applying safety measures to keep off damages on human life, environment and the plant itself.
The combination of the possible events and consequences gives good guidance for the conduction of the risk identification. Following this approach it is possible to prepare a list of hazards for any plant concepts or process units, which can further be used within risk assessment. The assessment creates specific numbers for the risk potential of the presents investigated hazardous event and their consequences by using the following coherence:

risk = severity * frequency Equation 2-1

Together, severity and frequency, of an event results in a risk. The terms severity and frequency are usually based on estimation of the assessing team. The severity is typically subdivided into classes (e.g. inessential, marginally, critical, and disastrous). Severity classes are used to assess the danger potential. Frequencies or failure rates are almost available for different process configuration or plant parts [10] and can be used for the determination of a possible failure rate within the unit function or of the investigated part or aggregate. Both figures, frequency and severity, can be combined in a risk matrix to conclude the existing risk – as shown in Figure 2-4: Risk matrix of frequency vs. severity [8, 11-14]

The risk matrix is subdivided into three areas, named “acceptable”, “ALARP” (As Low As Reasonably Practicable) and “unacceptable”. Acceptable and ALARP together mark the area of principally low or arguable remaining risk. The area “unacceptable” is recognized as an area of too high risk, so that a counter measure for reducing this specific risk has to be applied compulsory in any case. Counter measures generally help to reduce existing risks on lower level. It has to be kept in mind, that counter measures may change the technical concept, which consequently makes a reassessment of the investigated process unit necessary, so that no additional hazards arise, due to the counter measures themselves.

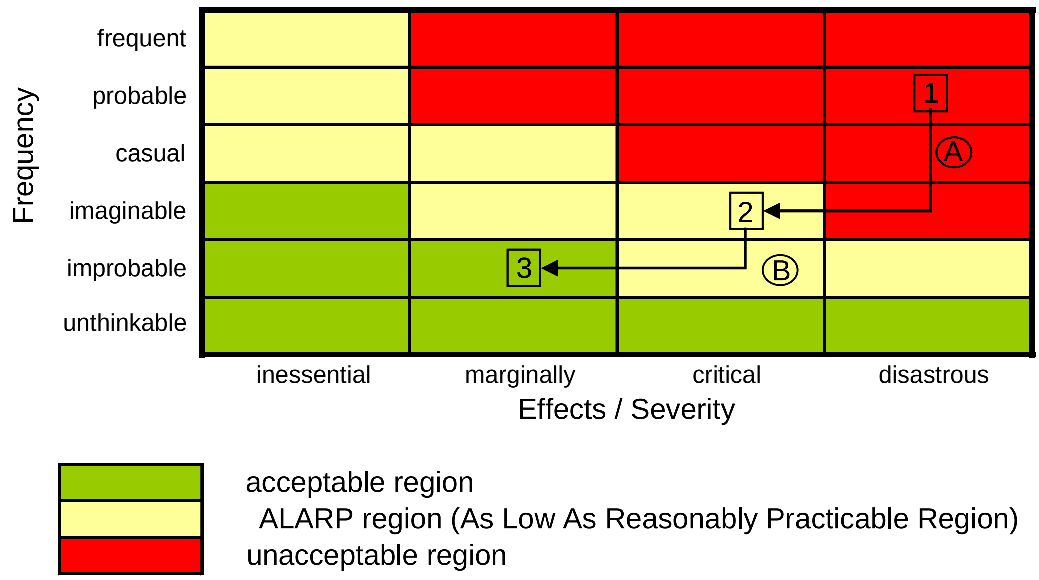

Figure 2-4: Risk matrix of frequency vs. severity [8, 11-14]

For the case, that the existing risk is within the Acceptable or ALARP region, principally no additional counter measure has to be applied. The risk assessment team decides, whether the specific remaining risk in the ALARP region is acceptable or not. Further safety measures are often not economically justifiable or would not bring a good improvement relating process safety and would therefore not applied. An ALARP case can be principally regarded to be acceptable, but the approval of a higher remaining risk potential has to be argued optionally in the following way:

- Why is the remaining risk acceptable?
- Why do additional counter measures not allow reducing remaining risk?
- Are there any negative feedback effects from additional counter measures, which do not allow risk minimisation?

The documentation of the risk assessment is very essential for the traceability. It is commonly done in tabular form, i.e. in structured lists of events and their possible consequences. Such a method can be carried out with the assistance of a computer software, which helps considerably with the structuring of the documentation and with placing of cross-references to recurring events and consequences.
As one main outcome of this project a risk assessment software tool called "RISK ANALYSER" was developed, which covers the features of the technology description, hazards identification and risk assessment as well as the documentation with detailed print layout. The part risk assessment is also discussed within the draft guideline and in more detail in the manual to the risk assessment software tool – see deliverable D11 Software tool for Risk Assessment regarding HSE.

Example for hazard identification method

The hazards identification is specific for each plant concept, so a general list of possible hazards can be carried out for an exemplarily plant unit only, which is shown for a scrubber unit in the following. Figure 2-5 shows its separation into four functions, i.e. (A) gas scrubbing and transport, (B) Scrubbing media circulation, (C) Scrubbing media treatment, and (D) Scrubbing media recirculation and waste water treatment.

The total case study for these examples is given in Annex B of this document.

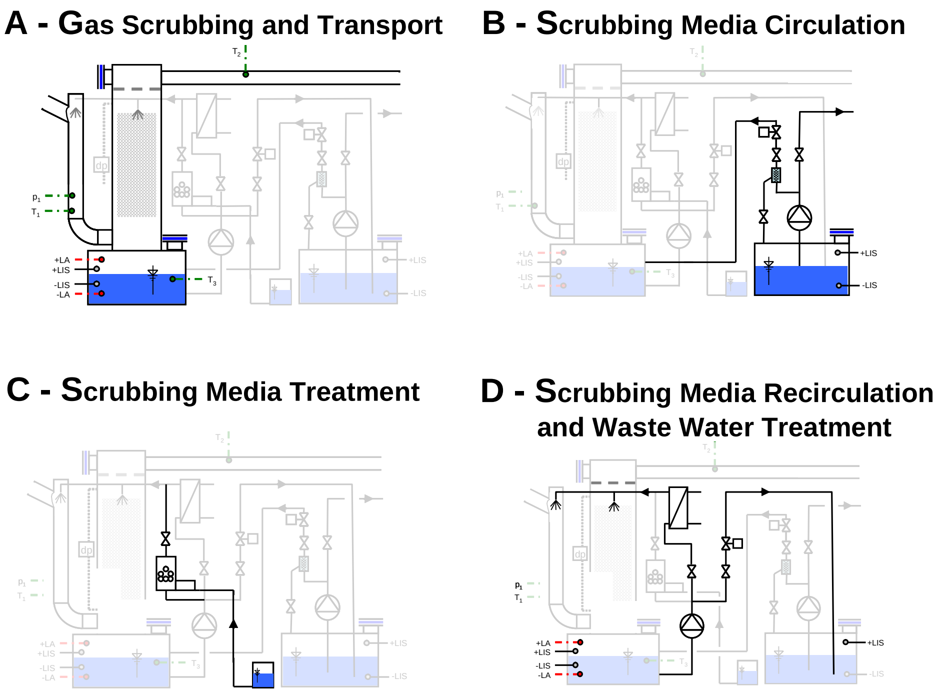

Figure 2-5: Definition of functions for an exemplarily process unit (scrubber)

The hazard identification considers abnormal operation conditions (within defined hazardous events, e.g. of Table 2-1: Checklist for possible hazardous events in biomass gasification plants) and their possible consequences (see e.g. Table 2-2). These abnormal conditions can be caused by failure of parts or units of the function blocks as well as external effects (up- and down stream of the investigated system). The investigation delivers results on different hazards, analysed with the approach already shown in Figure 2-2 for the example sub unit “Gas Scrubbing and Transport” (for the other sub units see Annex B):

1. **Listing of objectives of the process functions**
   The process function “gas scrubbing and transport (A)” comprises fundamental objectives, which are part of the operation description. These are:
   - gas scrubbing and gas cooling (particulate removal),
   - tight producer gas transport and
   - observation of the scrubber tank level (condensate removal)
   - observation of the pressure drop (blocking effect).

2. **Listing of parts and apparatuses of the investigated function** (optionally including design parameters, etc.)
   The involved apparatuses/parts of “Gas scrubbing and transport” are:
   - quench pipe,
   - scrubber water tank,
   - column with packing material,
   - off-gas piping,
   - hand holes.

3. Identification of possible hazards (tabular form)

The usage of the events and consequences list allows for a stepwise analysis of the present investigated sub unit. Within the preparation of the risk assessment it is helpful to use tabular form for the creation of the hazards list, to get clear arranged summary charts of each sub unit function. Table 2-3 give an exemplarily layout for such a hazards list including examples for sub unit "gas scrubbing and transport".

Table 2-3: Example for hazards identification using the lists of events and consequences – tabular form

1 GAS SCRUBBER
Gas Scrubbing and Transport

EVENTS (E1 up to E34)	CONSEQUENCES (C1 up to C17)	DESCRIPTION	REFERENCE TO
Pos.	Pos.	Pos.	Pos.
1 Leakage (gas escape / air intake)	1 Failure gas engine / Emergency stop	1 The air intake and exceeding of the oxygen concentration limit above a limiting value (e.g. 10% of UFL) leads to an automatically emergency shut down of gas engine.	
	1 Failure of flare / Emergency gas utilisation	1 Air intake in case of vacuum pressure in the gas piping or apparatuses causes explosive atmosphere and could possibly endanger the flare operation, due to flame flash back effects.	
	1 Danger to health	1 Producer gas constituents (carbon monoxide) and pollutants (organic and inorganic) can expose human health to danger - poisoning, carcinogen effects.	
	1 Poisoning	1 Main gas component of the producer gas is carbon monoxide, which is a toxic gas and could entail death or heavy poisoning.	
	1 Explosion	1 Gas escapes and air intakes from/in scrubber housing leads to an explosive atmosphere inside/around the process unit and has to be avoided by different measurements.	
2 Leakage steam	2	2 no steam pipes in this sub unit	
3 Leakage liquids (escape)	3	3 only liquid is scrubbing media	3 Leakage scrubbing agents (Pos. 4)
4 Leakage scrubbing agents	4 Mechanic failure	4 Leakages of liquid phase can cause corrosion of metal parts. A major leakage could deactivate gas scrubbing or cooling function due to loss of cooling liquid in the system.	
	4 Danger from electricity	4 A discharge of scrubbing media could possibly spray onto electrical plant parts, which could therefore cause dangers from electricity (body or earth contact).	
	4 Failure of automation system	4 The failure of the automation system could be dedicated to failure of instrumentation.	
	4 Danger to health - irritation of skin mucous membrane	4 Skin contact of condensate water has to be avoided due to irritant condensate substances (e.g. BTX, phenoles) - personal safety measures have to be applied (safety gloves and eyeglasses, etc.)	
	4 Immission (exhaust, flue gas and smell/odour)	4 Liquids from gas scrubbing are usually environmental relevant plant emissions. Especially uncontrolled loss of oil based scrubbing agents leads to unacceptable smell/odour or ground contamination respectively.	
	4 Poisoning	4 Poisoning from scrubbing agents could occur from unacceptable high contamination in the scrubbing liquid.	4 Leakage (gas escape / air intake) (Pos. 1)
5 Leakage solids	5	5 no solid streams in this sub unit	

The layout of Table 2-1 gives an overview on the considered events and their possibly dedicated hazardous consequences. Events, not applicable to the investigated sub unit, have to be skipped. The punctuation shows, that each event has usually more than one consequence. For documentation matter it is useful to give a short description on facts and basics, which underlie the estimation of the hazardous events-consequence combination. For the description of similar combinations or for the emphasis of coherences between different event-consequence combinations (different functions or/and parts) it is furthermore helpful to add references, exemplarily given within the right column.

The completion of this events list delivers fundamentals for the conduction of the risk assessment. The hazards identification can be carried out independently from the risk assessment, due to complexity and completeness reason. It is suggested that an extensive brainstorming phase on the topic of hazards identification is done prior to the detailed assessment of severity and frequency.

The itemisation of the analysis is up to the performer of the hazards identification. The approach is principally structured into sub unit and functions, which means, that secondary process units can be analysed in less deepness than the main process units and functions of the process. The division of the process into major and minor functions as well as its detailing is decision of the performing group.

The hazards identification should be established as dynamic analysis within the plant planning, plant construction and plant operation phase. Each phase can bring essential innovations to the plant (changes in conceptual design or operation routines), which have to be treated within updating of the events and consequences lists. The continuous improvement of the overall plant concept is duty on behalf of the manufacturer and/or operator to guarantee plant operation, with regard to health, safety and environmental issues.

3. Report summary and conclusions

The present report gives an overview on possible hazards in biomass gasification plants. The recommendation of the project team is the application of an identification method, which uses events and consequences lists for the evaluation of possible hazards in biomass gasification plants. The method is described within the report. An example of use is given in annex A.

The risk identification for the technical application of biomass gasification requires very detailed information of the process, the plant and its different operation modes etc., which have to be prepared before starting the risk identification. The following points have to be taken into consideration during the risk identification procedure:

- technology description and classification (process schemes, balances, etc.)
- event and consequence lists, which can describe possible HSE hazards
- hazards identification and risk assessment
- continuous updating of the hazard identification during plant operation due to process modifications or originally unconsidered hazards
- support of the systematic by case studies (see for e.g. BGR 104, [15])

The event and consequence lists result from the expert opinion of the different project partners in the consortium for the Gasification-Guide Project. The first draft of the lists were circulated within the project team, updated with the feedback of the partners, and finally agreed upon by the project partners.

A clear arranged analysis is essential for the comprehensible risk identification documentation. Consequently templates are given in Annex A in support for an accelerated preparation of the risk identification.

The aim of hazards identification is the usage of the compiled data within risk assessment, where a weighting of identified hazards has to be conducted. The height of the existing risk is the basis for the decision, whether the remaining risk is acceptable or not. If it is unacceptable, counter measures have to be applied to reduce the specific risk. The risk assessment (method, examples etc.) is part and chapter of the draft guideline.

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Appendix A – General Hazards in Biomass Gasification Plants on Health Safety and Environment

The appendix A gives an overview on general hazards to be taken under consideration at biomass gasification plants. The hazard lists are structured along the typical process chain configuration described in Figure 2-1.

Completeness of the information and data provided in the given cases and examples is excluded. Other cases and examples are feasible.

Table 4-1: General Hazards at Biomass Gasification Plant Concepts

Common hazards for all gasification plant parts	
1	Leakages of gaseous shape at the gasifier with respect to gas escape (producer gas, pyrolysis gas, plant utilities, etc.)
2	Leakage and unwanted air intake at the gasifier resulting in hot spots inside the gasifier and leakage growth
3	Health hazard (danger of suffocation, contamination with residues and condensates) due to possible leakages from downstream plant section (gas generation and/or gas cleaning)
4	Danger of fire and explosion
Storage of fuel and auxiliary fuel	
1	Foreign (non-fuel) material within the delivered biomass (steel parts, stones, etc.)
2	Unacceptable odour/smell from the storage of wet biomass/ wood chips
3	Exceeding of maximal allowable temperature limits in the area of biomass storage
4	Health hazard (danger of suffocation, contamination with residues and condensates) due to possible leakages from downstream plant section (gas generation and/or gas cleaning)
5	Danger of fire and explosion (gas explosions; dust explosions depending on the processed biomass and typical fuel particle size)
Fuel conveyance	
1	Foreign material in the used biomass (steel parts, stones, etc.) from fuel delivery
2	Exceeding of maximal allowable temperature limits in the area of fuel feeding
3	Health hazard (danger of suffocation, contamination with vapours and condensates) due to possible leakages from downstream plant section (gas generation and gas cleaning)
4	Danger of fire and explosion
5	Leakages of gaseous and liquid shape around the gasifier (producer gas, pyrolysis gas, cooling media and plant utilities)
6	Backfiring (firebrands, low-speed deflagration, etc.)
7	Failure of the anti-backfiring system (valve-, rotary valve system, double sluice) due to unexpected foreign material within fuel feeding stream or failure in the fuel dosing routines and apparatus
8	Failure or blocking of the fuel dosing system
9	Appearance of potential explosive atmospheres, its detection and activation of safety routines (gas inertisation systems - nitrogen, emergency stop plant, etc.)
Gasification reactor	
1	Leakages of gaseous shape at the gasifier with respect to gas escape (producer gas, pyrolysis gas, plant utilities, etc.)

2	Leakage and unwanted air intake at the gasifier resulting in hot spots inside the gasifier and leakage growth
3	Failure in fuel feeding system - emptying of the gasifier combined with possible tremendous temperature increase due to combustion mode
4	Fuel feeding blocking, tunnelling and dead space formation due to insufficient reactor geometry and inner reactor surface structuring, which do not promote the gradual sinking of the fuel filling
5	Inhomogeneous and unstable reaction conditions in the certain reaction zones, leading to a degradation of the producer gas quality, resulting in problems in subsequent gas cooling, cleaning and utilisation
6	Failure in the gasification agents supply to the individual reaction zones
7	Temperature and chemical stability (reducing conditions) of the reactor body (reactor shell, brick lining and hot gas components)
8	Hot surfaces at gasification reactors
9	Health hazard (danger of suffocation, contamination with residues and condensates) due to possible leakages
10	Danger of fire and explosion
Gas cooling	
1	Blocking, corrosion or fouling effects from particulate matter due to tarry compounds, dusts, soot, aerosols, chlorine etc. can cause failure in gas cooling sections
2	Exceeding of maximal allowable temperature limits in the area of gas cleaning
3	Observance of the certain gas quality parameters (ash- and dust loading, tar loading, etc.) with regard to regeneration facilities and design on erosive properties of the producer gas
4	Increasing of pressure drop in heat exchangers on producer gas side - see also blocking
5	Health hazards (danger of suffocation, contamination with residues and condensates)
6	Danger of fire and explosion
Gas Cleaning	
1	Toxicity of the cleaned materials and the materials separated from the raw producer gas
2	Degradation of gas cleaning efficiencies due to heavy tar or dust loaded producer gas
3	Increasing pressure drop on producer gas side due to surface fouling effects
4	Exceeding of residues disposal limiting values due to failure of waste product treatment
5	Compliance of operation parameters of the respective technology concept to guarantee certain disposal limiting values for the accumulated plant residues
6	Health hazards (danger of suffocation, contamination with residues and condensates)
7	Danger of fire and explosion
Hot gas cleaning	
1	Failure of thermally stressed components close to the hot gas transport and hot primary de-dusting process prior to gas cooling
2	Blocking, corrosion or fouling effects from particulate matter due to tarry compounds, dusts, soot, aerosols, chlorine etc. can cause failure in hot gas cleaning section
3	Failure on temperature control before the dust filter (too high temperature: damage to filter units; insufficient temperature: tar condensation)
4	Health hazards (danger of suffocation, contamination with residues and condensates)
5	Danger of fire and explosion
Cold/wet gas cleaning	
1	Chemical resistance of the used materials to the various agents (condensates, aromatic/non-aromatic hydrocarbon compounds, alcoholic/acidic organic compounds, alkaline and/or acidic producer gas components and regulatory chemicals)

2	Failure within the gas treatment, gas transport and residues disposal functions - e.g. temperature control of scrubbing agents, observation and control of agents contamination by organic and inorganic matter, observation of pressure drop and flooding effe
3	Health hazards (danger of suffocation, contamination with residues and condensates)
4	Danger of fire and explosion

Gas utilization

1	Efficiency of upstream gas cooling before utilization/gas engine and filling level of the cylinder respectively [in combination with gas cleaning and cooling]
2	Control of gas inlet pressure - Gas pressure regulation upstream from the engine
3	Gas/air mixing system - condensation and blocking effect in the intake system, which may lead to deactivation of the safety chain (gas valves, pressostats, etc.)
4	Supercharging with intercooler needs extensive producer gas conditioning to avoid condensation effect from gas humidity and tars/hydrocarbons (e.g. naphthalene)
5	Safety precautions against a condensate failure in the gas mixing system
6	Health hazards (danger of suffocation, contamination with residues and condensates)
7	Danger of fire and explosion

Treatment of exhaust gas

1	Deactivation of the exhaust gas treatment system, caused by alkali metals due to insufficient gas cleaning
2	Noise problems
3	Compliance with emission limiting values (Carbon monoxide CO, nitrogen oxides NO_x)
4	Safety measures against hot surfaces in the area of secondary treatment of exhaust gas
5	Design of the exhaust gas system due to the possibility of potentially explosive atmospheres
6	Health hazards (danger of suffocation, contamination with residues and condensates)
7	Danger of fire and explosion (engine control system with suitable control of load shedding and emergency stop functions)

Heat usage from CHP plants

1	Failure in district heating system (heat sink) results in failure of gas cooling, if no adequate auxiliary cooling is available
2	Hot surface
3	Chemicals for the pre-treatment of district water - personnel protective equipment
4	Health hazards (contamination with chemicals, residues and condensates from system heating water)
5	Danger of fire and explosion

Auxiliary and emergency gas flare facilities

1	Suitability of the gas devices for the application wood gas and plant utility treatment
2	Suitable load and throughput regulation for the entire plant in the case of multiple gas use (e.g. combination of IC engine and gas heated boiler)
3	Flame- and/or temperature monitoring in the gas modules and in the flares
4	Availability of auxiliary firing (selection of flare geometry and auxiliary fuel; suitable pre-mixing of the producer gas with air
5	Start procedure for the emergency gas flare (igniting the flare or a flare with a permanent standby flame
6	Contingency procedure for the failure of the producer gas emergency flare (pollution, auxiliary firing failure)

	7	Health hazards (danger of suffocation, contamination with residues and condensates)
	8	Adequate design and construction of auxiliary units for the supplying auxiliary plant media und energy streams
	9	Danger of fire and explosion
	10	Compliance of limiting values for flue gas emissions (including smells, odour)
Disposal of residues and emission streams		
	1	Compliance with the relevant regulations when dealing with residues to protect health, safety and the environment
	2	Pollutant concentration in gaseous, solid and liquid residues and their HSE effects
	3	Conditioning of condensates and waste water streams
	4	Health hazards (danger of suffocation, contamination with residues and condensates)
	5	Danger of fire and explosion of solid residues (ash and dust material from gasification have high carbon content and a very fine particle size, therefore they are highly inflammable)

Appendix B – Hazards Identification for an exemplarily Gas Scrubbing Unit

The following example of use gives an overview on the method for the risk identification within gas scrubbing unit of a biomass gasification unit. The described gas scrubbing unit can be seen as one unit of a complete biomass gasification plant, consisting of the fuel storage und conveyance, the gasifier, a gas cooling and the gas cleaning section, subdivide in dry (fabric filter) and wet gas cleaning (gas scrubber) with an downstream gas utilisation module (compare with Figure 2-1). The following example of use only represents the hazards identification of the gas scrubbing unit, which analogues can be used within all other processing steps of the process chain.

Completeness of the information and data provided in the given cases and examples is excluded. Other cases and examples are feasible.

Technology Description

The given gas scrubbing unit of Figure 4-1 fulfils various functions of gas treatment. The main parts, reactors and aggregates of the scrubbing unit are described in the caption of the figure.

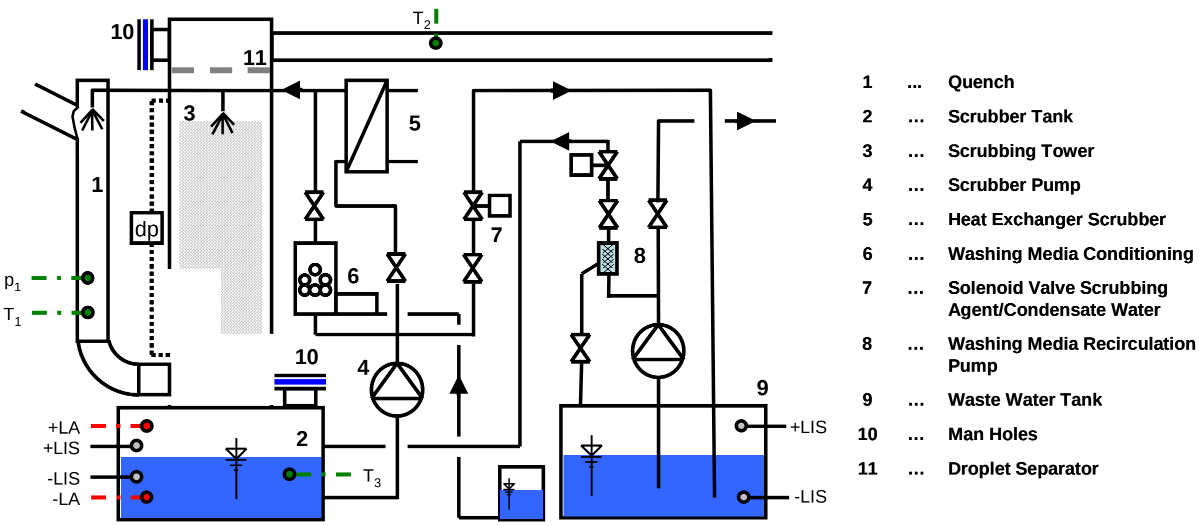

Figure 4-1: Gas Scrubbing unit within a biomass gasification concepts including auxiliary units for waste water and scrubbing agent processing

The process scheme shows a process concept with a high level of complexity, which is not helpful for the hazards identification, so it is recommended to subdivide the process in its sub functions with dedicated parts, which allow an easier and structured technology description as well as hazard identification, due to a restricted area for the analysis.
The suggestion of the itemisation of the process unit is given in the Figure 4-2, where the following process functions with is dedicated parts are fixed:

- A – Gas scrubbing and transport
- B – Scrubbing media circulation
- C – Scrubbing media treatment
- D – Scrubbing media recirculation and waste water treatment

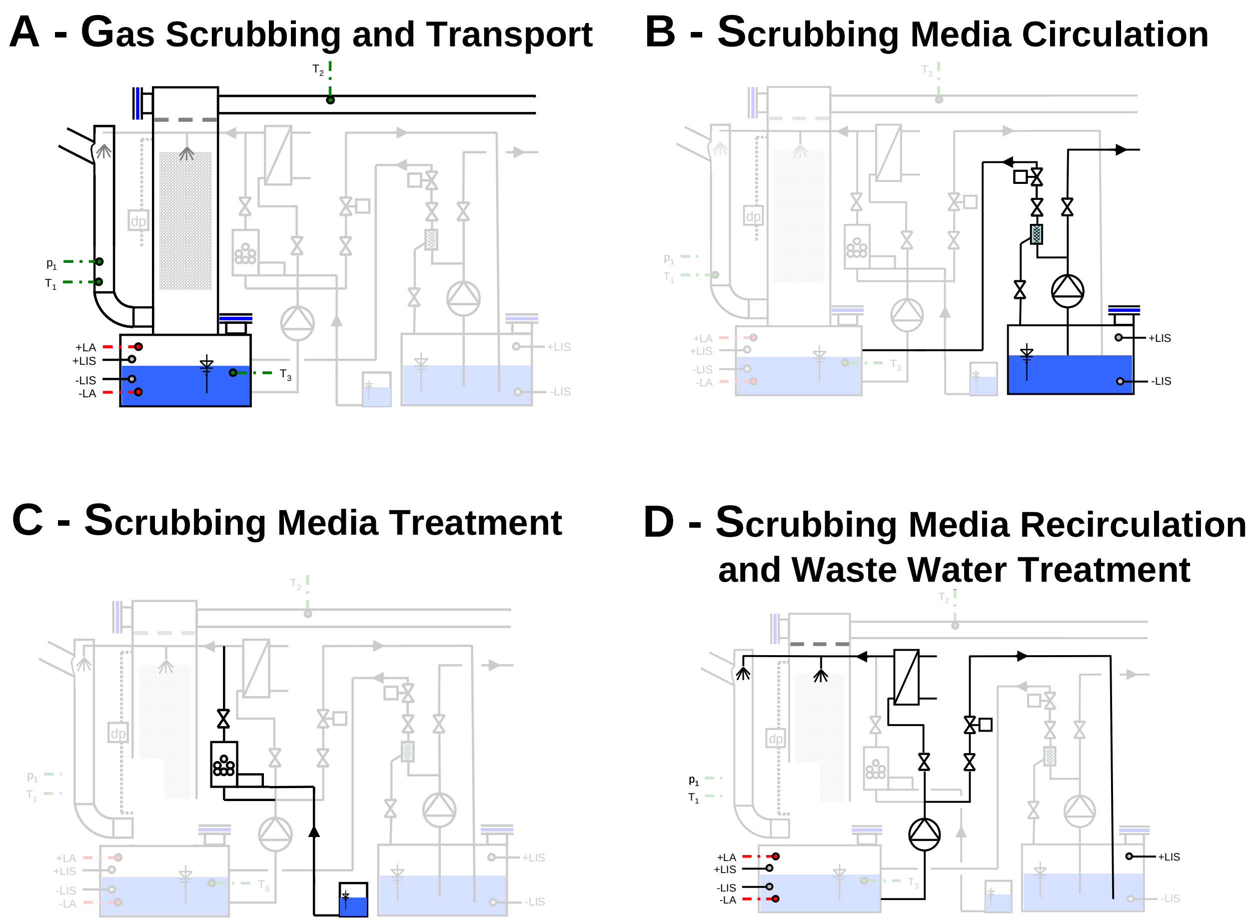

Figure 4-2: Definition of process functions and sub units for the gas scrubbing unit

A- Gas scrubbing and transport:

The wood gas enters the gas scrubbing unit through the quench pipe (1), with an temperature of about 150°C and moisture content corresponding to the operation state of the gasifier, depending on biomass moisture and steam addition in the gasifier (10-40 Vol.%$_{dry}$). The quench pipe allows a temperature decrease combined with a fall below the due point by scrubbing agent injection. The gas is normally cooled down to a temperature below 60°C (Temperature and gas vacuum pressure indication and control applied), which allow the further processing of the gas within the packing material tower (3). The condensed water phase from humidity condensation is accumulated in the scrubber tank (2). The scrubbing tower allows the enlargement of surface area by the usage of scrubbing agent moistened packing material, which results in improved mass transfer and scrubber efficiency. The pressure drop in the packing material is monitored to observe a possible blocking and flooding of the scrubber tower. The treated producer gas leaves the scrubber through a droplet separator (11) and the outlet pipe, where the outlet temperature is controlled. The top of the scrubbing tower possess a man hole (10), where maintenance work on droplet separator and packing tower material during downtime of the plant can be applied.

B- Scrubbing Media Circulation:

The condensed water phase from the producer gas humidity is accumulated together with the scrubbing agent biodiesel in the scrubber tank, where scrubber tank level is controlled between high and low (+LIS and –LIS; **L**evel-**I**ndicator-**S**witch). The indication of high scrubber tank level starts the down pumping of the scrubber agent mixture (biodiesel and

water) to the waste water tank by activating the magnetic valve Scrubbing agent and Condensate water (7) during normal operation of the scrubber pump (4). The maximum level of the waster water tank is controlled. The exceeding or falling below of a certain scrubber tank levels of the normal operation levels (+LIS or -LIS) lead to the indication of too high or too low scrubber tank level by given an alarm from –LA or +LA (**L**evel **A**larm). The alarm routine provides counter measures for the described alarms from exceeding or falling below of a certain scrubber level.
The scrubber pump provides beside the function of scrubbing agent removal the function of the scrubbing media circulation for the operation of the quench (1) and the scrubbing tower (3). Therefore the scrubbing agent is cooled in the heat exchanger (5), to be able to dissipate the sensitive heat from gas cooling in the quench and scrubbing tower.

C – Scrubbing media treatment
The utilisation of the biodiesel/water mixtures in the present gas scrubbing units needs a conditioning of the agent with regard to the pH-value for the removal of ammonia from the producer gas. The control of the pH-value is applied by the injection of chemicals and controlled by sensors (temperature und pH-value, 6).

D – Scrubbing media recirculation and waste water treatment
The accumulation of the incident biodiesel/condensate water mixture is provided by waste water tank (9), where a decomposition of the biodiesel and water phase takes place. The oil phase of the separating waste water tank is filtered and recirculated in the scrubber tank (8), to increase the mass fraction of biodiesel for gas scrubbing in the circulating scrubbing agent. The remaining waste water is transported to waste water disposal tanks or a waste water treatment system.

Hazards identification for a gas scrubbing unit

The present described Technology concept is analysed on possible HSE hazard, following an approach developed by the Gasification Guide project. Within a the following pages a complete hazards analysis for the sub unit A-Gas Scrubbing and Transport was applied.

Completeness of the information and data provided in the given cases and examples is excluded. Other cases and examples are feasible

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)		**CONSEQUENCE** (C1 - C17)		**DESCRIPTION**		**REFERENCE TO**
Pos.		Pos.		Pos.		Pos.
1	Leakage (gas escape / air intake)	1	Failure gas engine / Emergency stop	1	The air intake and exceeding of the oxygen concentration limit above a limiting value (e.g. 10% of UFL) leads to an automatically emergency shut down of gas engine.	
		1	Failure of flare / Emergency gas utilisation	1	Air intake in case of vacuum pressure in the gas piping or apparatuses causes explosive atmosphere and could possibly endanger the flare operation,	

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)	**CONSEQUENCE** (C1 - C17)	**DESCRIPTION**	**REFERENCE TO**
Pos.	Pos.	Pos.	Pos.
		due to flame flash back effects.	
	1 Danger to health	1 Producer gas constituents (carbon monoxide) and pollutants (organic and inorganic) can expose human health to danger - poisoning, carcinogen effects.	
	1 Poisoning	1 Main gas component of the producer gas is carbon monoxide, which is a toxic gas and could entail death or heavy poisoning.	
	1 Explosion	1 Gas escapes and air intakes from/in scrubber housing leads to an explosive atmosphere inside/around the process unit and has to be avoided by different measurements.	
2 Leakage steam	2	2 no steam pipes in this sub unit	
3 Leakage liquids (escape)	3	3 only liquid is scrubbing media	3 Leakage scrubbing agents (Pos. 4)
4 Leakage scrubbing agents	4 Mechanic failure	4 Leakages of liquid phase can cause corrosion of metal parts. A major leakage could deactivate gas scrubbing or cooling function due to loss of cooling liquid in the system.	
	4 Danger from electricity	4 A discharge of scrubbing media could possibly spray onto electrical plant parts, which could therefore cause dangers from electricity (body or earth contact).	
	4 Failure of automation system	4 The failure of the automation system could be dedicated to failure of instrumentation.	
	4 Danger to health - irritation of skin mucous membrane	4 Skin contact of condensate water has to be avoided due to irritant condensate substances (e.g. BTX, phenoles) - personal safety measures have to be applied (safety gloves and eyeglasses, etc.)	

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)		**CONSEQUENCE** (C1 - C17)		**DESCRIPTION**		**REFERENCE TO**	
Pos.		Pos.		Pos.		Pos.	
		4	Immission (exhaust, flue gas and smell/odour)	4	Liquids from gas scrubbing are usually environmental relevant plant emissions. Especially uncontrolled loss of oil based scrubbing agents lead to unacceptable smell/odour or ground contamination respectively.		
		4	Poisoning	4	Poisoning from scrubbing agents could occur from unacceptable high contamination in the scrubbing liquid.	4	Leakage (gas escape / air intake) (Pos. 1)
5	Leakage solids	5		5	no solid streams in this sub unit		
6	Temperature too high/low	6	Abnormal operation conditions	6	Too high temperatures could be caused by failure of scrubbing agent pumping or blocking in the pipes for scrubbing agent transport. Too low temperature leads to changed scrubbing properties regarding solubility, kinematics viscosity etc. and gives therefore different characteristics as considered within design parameters		
		6	Mechanic failure	6	Mechanic failure could be a consequence of exceeding of maximum temperatures for used material of the apparatus (sealing, iron materials, plastics for packing tower material, etc.) which could lead to various secondary consequences.	6	Leakage (gas escape / air intake) (Pos. 1)
						6	Leakage scrubbing agents (Pos. 4)
		6	Failure gas engine / Emergency stop	6	Increased producer gas temperatures could lead to malfunction in the gas utilisation in the gas engine, due to exceeding of maximum allowed entrance gas temperatures (gas engine or possibly also flare system affected).		
		6	Danger to health - skin burns	6	High temperatures leads to skin burn from hot surfaces - appropriate safety measures like protection plates for avoiding		

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)		**CONSEQUENCE** (C1 - C17)		**DESCRIPTION**		**REFERENCE TO**	
Pos.		Pos.		Pos.		Pos.	
					danger to health are recommended.		
		6	Smouldering fire	6	The combination of too high temperatures und hot surfaces could be relevant for the occurrence of fire or smouldering fire, due to prohibited contact or too little distance of/to burnable substances or materials.		
7	Pressure too high/low	7	Abnormal operation conditions	7	Too high or too low pressure could be a originated from a failure of the pressure control system (pressure sensor and/or frequency controlled producer gas fan) or from blocking effects, which could cause leakages in different kinds as well as restrictions of functions of the process unit or other sub units, which results in different consequences.	7	Leakage (gas escape / air intake) (Pos. 1)
						7	Leakage scrubbing agents (Pos. 4)
		7	Mechanic failure	7	Mechanic failure could be a consequence of exceeding of maximum allowed pressures for used material of the apparatus (sealing, iron materials, plastics for packing tower material, etc.) which could lead to various secondary consequences.		
		7	Failure gas engine / Emergency stop	7	The gas engine is usually secured by pressure controller. Overpressure and vacuum pressure results in engine shut down.		
8	Plant flows too high/low	8	Abnormal operation conditions	8	The scrubber and packing tower have a design point, where performance parameters like cooling load and gas cleaning requirements can be guaranteed - plant flow out of this design point could cause flooding of the packing tower or too high temperatures at scrubber outlet	8	Temperature too high/low (Pos. 6)

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)	**CONSEQUENCE** (C1 - C17)	**DESCRIPTION**	**REFERENCE TO**
Pos.	Pos.	Pos.	Pos.
		for too high flows.	
		A trend of decreasing (too low) plant flows and high pressure drop could indicate dangers from blocking, where the function of the apparatus fails.	8 Failure - blocking (Pos. 16)
9 Plant fill level too high/low	9 Abnormal operation conditions	9 High liquid level in the gas scrubber tank will bring blocking of gas transport due to flooding of the packing tower. Low scrubber tank level will cause failure in scrubber media transport as well as failure of sub unit function.	9 Failure - blocking (Pos. 16)
	9 Mechanic failure	9 Falling below a defined liquid level will cause a dry-run of the scrubber pump followed by a possible break down of the pump.	
	9 Failure of function	9 Too low liquid level and therefore loss of scrubbing media causes failures in the sub unit functions gas cooling and gas cleaning, due to failure of scrubbing or cooling media.	
10 Concentration too high/low	10 Abnormal operation conditions	10 The term concentrations means in this connexion prohibited high contamination of the producer gas with either condensable/soluble organic or inorganic matter or solid particulate matter respectively, which could lead to increased failure rates of technical parts and within sub units function.	
	10 Mechanic failure	10 Possible consequence of prohibited high concentration could be apparatus blocking within quench, packing tower and apparatus piping or a failure of the washing media pump.	

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)		**CONSEQUENCE** (C1 - C17)		**DESCRIPTION**		**REFERENCE TO**	
Pos.		Pos.		Pos.		Pos.	
		10	Failure gas engine / Emergency stop	10	The removal of pollutants guarantees stable operation of the utilisation aggregate. Too high concentration of producer gas (inlet and outlet concentration) pollutants could lead to a failure of down stream aggregates and pipes, when producer gas purification fails, due to concentrations out of design specification.	10	Failure - blocking (Pos. 16)
		10	Failure of flare / Emergency gas utilisation	10	Too high concentration of pollutants could endanger the producer gas utilisation with regard to stable operation of gas control and instrumentation.	10	Failure - blocking (Pos. 16)
		10	Immission (exhaust, flue gas and smell/odour)	10	High concentration of pollutants could lead to increased concentration in plant emission streams (exhaust gas engine - possible higher emissions of unburned compounds, condensate water - possible overload of the waste water treatment or smell/odour from waste water or residues).		
11	Failure - mechanical stress	11		11	in normal operation not relevant for this process unit, see ref.	11	Leakage (gas escape / air intake) (Pos. 1)
12	Failure - thermal stress	12		12	not relevant due to low temperatures < 100°C		
13	Failure - corrosion	13	Mechanic failure	13	Different producer gas pollutants and scrubbing agents compounds could contain substances that lead to corrosion and decrease of material thickness, which could lead to increased ware out, mechanic failure, or leakages and/or function failure.	13	Leakage (gas escape / air intake) (Pos. 1)
						13	Leakage scrubbing agents (Pos. 4)
						13	Failure - welding (Pos. 18)
14	Failure - icing	14		14	not relevant for this process unit		
15	Failure -	15		15	not relevant for this process unit		

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)	**CONSEQUENCE** (C1 - C17)	**DESCRIPTION**	**REFERENCE TO**
Pos.	Pos.	Pos.	Pos.
ware out			
16 Failure - blocking	16 Abnormal operation conditions	16 Blocking could lead to increasing of the pressure drop and tunnel flows within in scrubbing tower packing in the apparatus - effect from this could be decreasing scrubbing and cooling efficiencies.	16 Pressure too high/low (Pos. 7)
			16 Plant flows too high/low (Pos. 8)
17 Failure - sealing	17 Danger from electricity	17 Failure of sealing could be linked with consequences of the event leakages and abnormal operation conditions.	17 Leakage (gas escape / air intake) (Pos. 1)
	17 Danger to health		17 Leakage scrubbing agents (Pos. 4)
	17 Immission (exhaust, flue gas and smell/odour)		17 Temperature too high/low (Pos. 6)
	17 Explosion		17 Pressure too high/low (Pos. 7)
18 Failure - welding	18	18 gas leakage, see Ref.	18 Leakage (gas escape / air intake) (Pos. 1)
19 Failure - fitting or flange	19	19 gas leakage, see Ref.	19 Leakage (gas escape / air intake) (Pos. 1)
20 Hot surfaces	20	20 not relevant for this process unit (temperatures < 100°C)	20 Temperature too high/low (Pos. 6)
21 Failure - electric power supply	21	21 failure of pump and consequently of scrubbing media circulation (see own sub unit B and D)	
22 Failure - electric plant steering and control	22 Abnormal operation conditions	22 Operation conditions cannot further be controlled and could bring dangers with regard to exceeding of temperature, pressures, etc.	
	22 Failure of automation system	22 The gas scrubber is operated by measurement, steering and control function, which are realised by different instrumentation. Failure results in hazards related to improper scrubber tank level, temperature as well as pressure control.	

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)	**CONSEQUENCE** (C1 - C17)	**DESCRIPTION**	**REFERENCE TO**
Pos.	Pos.	Pos.	Pos.
23 Failure - electrical device	23	23 no electrical device in this sub unit	
24 Failure - sensor	24 Mechanic failure	24 Sensors that are exposed to producer gas or scrubbing liquids (temperature, pressure and level switches) could be blocked or corroded due to chemically aggressive or abrasive streams.	24 Failure - corrosion (Pos. 13)
			24 Failure - blocking (Pos. 16)
	24 Danger from electricity	24 Sensor failure could directly lead to dangers from electricity due to electric shocks from sensor error or possible electrical short-circuit, which could deactivate process steering and control.	24 Failure - electric plant steering and control (Pos. 22)
	24 Failure of automation system	24 Sensor failure/deactivation delivers wrong data to the process steering and control, which could therefore fail.	24 Failure - electric plant steering and control (Pos. 22)
	24 Failure of function	24 High scrubber tank level could block producer gas flow through the apparatus. Uncontrolled temperature und pressure leads to abnormal operations conditions, which causes various dangerous operation conditions.	24 Temperature too high/low (Pos. 6)
			24 Pressure too high/low (Pos. 7)
			24 Plant fill level too high/low (Pos. 9)
25 Failure - plant media/utility supply and disposal	25 Abnormal operation conditions	25 The stable operation of the process unit needs a reliable supply and disposal of plant utilities or process output streams. Errors in the supply and disposal chain lead to an shut down of the plant.	25 Plant fill level too high/low (Pos. 9)
	25 Immission (exhaust, flue gas and smell/odour)	25 Errors in the disposal chain of wastes from the sub process could result in overfilling and possible leakages around the scrubber tank.	25 Leakage scrubbing agents (Pos. 4)
			25 Failure -

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)	**CONSEQUENCE** (C1 - C17)	**DESCRIPTION**	**REFERENCE TO**
Pos.	Pos.	Pos.	Pos.
			blocking (Pos. 16)
26 Harmful plant media and utilities	26 Danger to health	26 The apparatuses of the investigated sub unit treats producer gas mixtures and scrubbing agents, which contains a water-oil mixture and condensable and water-oil-soluble fraction from producer contaminants. The mixture is principle posed a risk to health with depending on its composition.	26 Leakage (gas escape / air intake) (Pos. 1)
			26 Leakage scrubbing agents (Pos. 4)
			26 Maintenance (Pos. 32)
	26 Danger to health - irritation of skin mucous membrane	26 see above	
	26 Poisoning	26 see above	
27 Transient operation - start-up	27 Abnormal operation conditions	27 Transient operation can bring deviation from set point values (between allowed values), therefore control limits during start up should consider broader control limits than during normal operation - temperature, pressure with broader fluctuation.	27 Temperature too high/low (Pos. 6)
			27 Pressure too high/low (Pos. 7)
	27 Failure of flare / Emergency gas utilisation	27 During plant start-up higher producer gas contamination with pollutants have to be expected.	27 Concentration too high/low (Pos. 10)
	27 Explosion	27 Plant start-up often causes explosive atmospheres, due to exchange of air and producer gas during the start-up of the gasifier, which leads potentially high risks..	

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)		**CONSEQUENCE** (C1 - C17)		**DESCRIPTION**		**REFERENCE TO**	
Pos.		Pos.		Pos.		Pos.	
28	Transient operation - shut-down	28	Abnormal operation conditions	28	Transient operation can bring deviation from set point values (between allowed values), therefore control limits during start up should consider broader control limits than during normal operation - temperature, pressure with broader fluctuation.	28	Temperature too high/low (Pos. 6)
						28	Pressure too high/low (Pos. 7)
		28	Failure of flare / Emergency gas utilisation	28	During plant shut-down higher producer gas contamination with pollutions have to be expected.	28	Concentration too high/low (Pos. 10)
		28	Explosion	28	Plant shut-down and plant purge with air may cause explosive atmospheres, due to exchange of producer gas and air during the shut down of the gasifier, which leads potentially high risks..		
29	Transient operation - increase plant power load	29	Failure gas engine / Emergency stop	29	Flooding of the packed column (scrubber) may causes entrainment of water to the engine and must be avoided		
30	Transient operation - emergency shut-down	30		30	no critical consequences found		
31	Operating error	31	Abnormal operation conditions	31	Operation errors are in principle possible during engagement in the process control, which could lead to various technical problems. Principally variable set points are scrubber operation temperatures und the pressure, predominant in the apparatus.		
		31	Danger to health	31	Danger to health relating operating error can be present during manual sampling of producer gas (e.g. tar and particle concentration) or scrubbing agent for the determination of process quality parameters as well as during	31	Leakage (gas escape / air intake) (Pos. 1)

1 GAS SCRUBBER **Gas Scrubbing and Transport**							
EVENT (E1 - E34)		**CONSEQUENCE** (C1 - C17)		**DESCRIPTION**		**REFERENCE TO**	
Pos.		Pos.		Pos.		Pos.	
					improper handling at man holes, valves and measurement points (temperature, pressure, level indication).		
						31	Leakage scrubbing agents (Pos. 4)
						31	Failure - blocking (Pos. 16)
						31	Harmful plant media and utilities (Pos. 26)
		31	Immission (exhaust, flue gas and smell/odour)	31	Faulty operation of the gas scrubber can lead to decreased gas cleaning efficiencies or improper clean gas qualities, due to wrong process intervention or wrong plant operation.	31	Failure - plant media/utility supply and disposal (Pos. 25)
		31	Explosion	31	Handling with burnable gas needs the consideration of operation rules for gas treating plants in general. Possible source of danger could be connectors and the hand holes as well as measurements ports where leakages (gas escape, air intake) for the occurrence of explosive mixtures can happen.	31	Leakage (gas escape / air intake) (Pos. 1)
						31	Maintenance (Pos. 32)
32	Maintenance	32	Danger from electricity	32	Opening or inspection of the apparatus could cause danger from electricity, when damaging electrical wire or electrical devises.	32	Leakage (gas escape / air intake) (Pos. 1)
		32	Failure of automation system	32	Maintenance is in general a possible source for malfunctions in process automation in the subsequent plant operation. E.g. sensors could be mismatched, put into the wrong place, or left uninstalled. Safety routines and check lists have to be implements after maintenance work to reduce the risk of human	32	Failure - sensor (Pos. 24)

1 GAS SCRUBBER

Gas Scrubbing and Transport

EVENT (E1 - E34)		**CONSEQUENCE** (C1 - C17)		**DESCRIPTION**		**REFERENCE TO**	
Pos.		Pos.		Pos.		Pos.	
					errors.		
		32	Danger to health	32	Maintenance is accompanied by various measures from process automation (plant stop, observation of temperature, pressure and gas composition in and around the plant, etc.). Process control has to consider safe plant maintenance routines.		
					Opening or inspection of the apparatus could cause danger to health, due to contact with or escapes and leakages of plant media and utilities.	32	Harmful plant media and utilities (Pos. 26)
		32	Immission (exhaust, flue gas and smell/odour)	32	Escapes and leakages possibly lead to prohibited plant emissions (flue gas contamination, smell/odour, etc.).		
		32	Fire	32	Maintenance could be accompanied by various modification work, where welding work, measures from process		
		32	Explosion				
33	Force of nature - flooding	33	Failure of automation system	33	Level indication sensors have to be protected and water-resistant.	33	Failure - sensor (Pos. 24)
34	Force of nature - stroke of lightning	34	Failure of automation system	34	Sensor error possible (temperature, level indication)	34	Failure - sensor (Pos. 24)
35	Force of nature - storm/thunderstorm	35		35	not relevant for this sub unit		
36	Force of nature - earthquake	36		36	possible consequence: mechanic failure, see ref.	36	Failure - mechanical stress (Pos. 11)
						36	Leakage (gas escape / air intake) (Pos. 1)