Guideline for Safe and Eco-friendly Biomass Gasification

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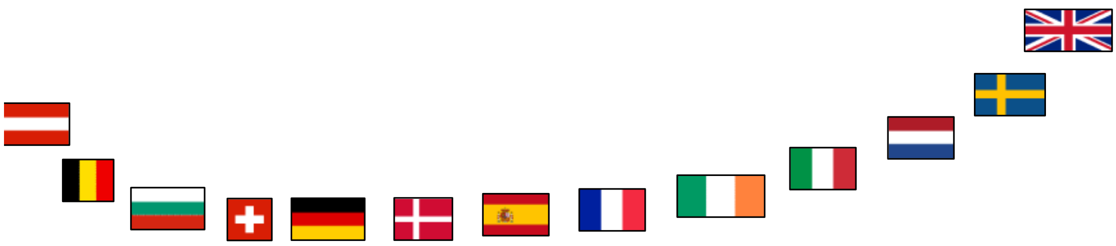

I. Preface

Biomass gasification is a promising, energy-efficient technology that can contribute significantly to renewable energy generation. This technology has to advance and is close to commercialisation, but large-scale implementation is hampered for various reasons. Leading gasification experts from around the world have identified Health, Safety and Environmental (HSE) issues as an important barrier to marketing the technology. In several cases, the lack of awareness and understanding of the HSE issues results in neglecting these issues, in long and complicated procedures, high costs and sometimes cancellation of the initiative. For the same reasons authorities tend to have unrealistic and costly requirements for gasification plants. A broadly accepted HSE guideline would effectively tackle this barrier and then significantly contribute to the development of a safe and environmentally-friendly technology.

With the support of the Intelligent Energy for Europe programme (contract number EIE-06-078), an international team developed a methodology for easy risk assessment. The main result is this GUIDELINE, aiming at safe best practice of biomass gasification. The Gasification Guide project team believes that guidance to stakeholders on Health, Safety and Environment will contribute to this aim.

Risk assessment in biomass gasification activity is becoming increasingly important all over the world. It is an effective means of identifying process safety risks and determining the most cost-effective ways to reduce risk. Manufacturers and users of gasification plants recognise the need for risk assessment, but most do not have the tools, experience and resources to assess risk quantitatively.

This GUIDELINE is based on an accepted methodology, science, common sense and wherever possible, measurable parameters from existing biomass gasification plants and those under development or construction. They also take account of the chemical industry and petroleum refinery practice. This guideline provides a general overview, and is not intended to be comprehensive in every aspect.

The existence of a practical biomass gasification guideline will assist different target groups such as manufacturers, operators, scientists, authorities, advisors and end-users/investors in assessing the potential HSE risks and imposing realistic measures for risk reduction and fair HSE requirements.

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III. Table of Contents

IV. Abbreviations and Definitions

Abbreviations

ABV	Anti backfiring valve
ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
ATEX	ATmosphères EXplosibles(French)
BGP	Biomass Gasifier Plant
CEN	Comité Européen de Normalisation
CHP	Combined Heat and Power
COMAH	COntrol of MAjor accident Hazards
DS	Dansk Standard
EC	European Community
EEC	European Economic Community
FMEA	Failure Modes and Effects Analysis
FR	Fire Resistance
HAZOP	HAZard and OPerability
HAZID	HAZard IDentification
HSE	Health, Safety and Environment
IC	Internal Combustion
IPPC	Integrated Pollution Prevention and Control
INF	Informationshæfte (DK)- [Short note]
O&M	Operation and Maintenance
PI	Piping and Instrumentation
PLC	Programmable Logic Controller
ppm	parts per million
PSV	Pressure Safety Valve
RA	Risk Assessment
RP	Recommended Practice
SIL	Safety integrity level
SME	Small and Medium Enterprises (KMU in German)
VDI	Verein Deutscher Ingenieure

Definitions

Biomass: Material of biological origin, excluding material embedded in geological formations and transformed to fossil (Note: This definition is the same as the definition of biomass in CEN TC 335 Solid Biofuels. Biomass is the only non-fossil carbon source.).

Gasification: Thermal conversion of carbon-based materials into a product gas composed primarily of CO, H_2, methane and light hydrocarbons in association with CO_2, H_2O and N_2, depending on the specific gasification process considered.

Producer gas: The mixture of gases produced by the gasification of organic material such as biomass at relatively low temperatures (700 to 1000ºC). Producer gas is composed of carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2), nitrogen (N_2) and typically a range of hydrocarbons such as methane (CH_4). Producer gas can be burned as a fuel gas, e.g. in a boiler for heat, or in an internal combustion gas engine for electricity generation or CHP. The composition of the gas can be modified by choice of gasification parameters to be optimised as a fuel gas (producer gas) or synthesis gas, which contains almost exclusively CO and H_2 and is suitable for synthesis of liquid biofuels.

Synthesis gas: A mixture exclusively of carbon monoxide (CO) and hydrogen (H_2). Following clean-up to remove any impurities such as tars, synthesis gas (syngas) can be used to synthesise organic molecules such as synthetic natural gas (SNG - methane (CH_4)) or liquid biofuels such as synthetic diesel (via Fischer-Tropsch synthesis).

Environmentally-sound: The maintenance of a healthy environment and the protection of life-sustaining ecological processes. It is based on thorough knowledge and requires or will result in products, manufacturing processes, developments, etc which are in harmony with essential ecological processes and human health.

Deflagration: An explosion that has a pressure wave below the speed of sound.

Detonation: An explosion that has a pressure wave above the speed of sound.

CE-mark: The CE marking symbolises the conformity of a product to the Community requirements incumbent on the manufacturer of the product. It indicates that the product conforms with all the Community provisions providing for its affixing.

Zoning: These are the ‘official’ definitions for zones 1, 2, and 22 from directive 1999/92/EC:

Zone 1 A place in which an explosive atmosphere consisting of a mixture with air or flammable substances in the form of gas, vapour or mist is likely to occur occasionally in normal operation.

Zone 2 A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Zone 22 A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

Note: Categories like ‘II2G’ refer to the quality of equipment and should not be mixed with zone classification.

Terms for "Authorisation" and "Declaration"

Official terms and synonyms for "authorisation/permit" and "declaration" (with regard to classified installations) are listed below for different EU countries.

State	Authorisation / Permit	Declaration
Austria	Bewilligung	
Belgium	Permis (d'environnement) / (milieu)vergunning	Déclaration / aangifte
Denmark	Godkendelse	Anmeldelse
France	Autorisation	Déclaration
Germany	Genehmigung, Erlaubnis, Bewilligung, Zulassung	Anzeige, Anmeldung
Ireland	Licence, permit, permission	
Italy	Autorizzazione	Comunicazione
Netherlands	Vergunning (wet milieubeheer)	Aangifte
Spain	Autorización	Notificación
Sweden	Tillstånd	Anmälan
Switzerland	Bewilligung, (Plan-) Genehmigung	Anzeige, (Emissions-) Erklärung
United Kingdom (England and Wales)	Authorisation, permit, license, (planning) consent	Notification, declaration

1 Introduction

1.1 Objective

The objective of the Gasification Guide **project** is to accelerate the market penetration of small-scale biomass gasification systems (< 5 MW fuel power) by the development of a Guideline and Software Tool to facilitate risk assessment of HSE aspects.

The Guideline may also be applied in retrofitting or converting old thermal plants in the Eastern European countries – with rich biomass recourses – to new gasification plants.

The objective of this **document** is to guide key target groups identifying potential hazards and make a proper risk assessment. The software tool is an additional aid in the risk assessment.

1.2 Target groups

During the project cycle of developing and implementing a biomass gasification plant, different organisations, institutes, industries and/or private bodies are engaged at some stage. Stakeholders include: project developers, engineers, legislation and permitting authorities, investors, consultancy/advisors, manufacturers and operators. In principle, they all belong to the target group. Furthermore, host communities and policy makers also play a key role.

The views and needs of these target groups regarding biomass gasification technology may differ. In some cases, members of the target groups may even have conflicting interests, for instance manufacturer versus plant owner, end-user and permitting authorities. For the implementation and commercialisation of biomass gasification, there are several major target groups:

- Manufacturers;
- Operators, technicians and plant owners;
- Permitting authorities;
- Investors or advisors to the investors; and
- HSE experts.

1.3 Scope of the Guideline

This guideline is intended to be a training tool and a resource for workers and employers to safely design, fabricate, construct, operate and maintain small-scale biomass gasification facilities. The Guideline is applicable with the following constraints:

- The maximum scale of the gasification plant was agreed to be about 1 MW_e. The reason is that large companies do have normally their safety rules in place;
- This means in principle only fixed bed gasifier designs. However, most parts are also valid to other designs and even other thermal conversion processes;
- The use of contaminated biomass is beyond the scope of this Guideline.

Biomass gasification is a fairly complex technology, and biomass gasification plants (BGP) need to comply with various European guidelines and national laws. The different process steps and potential HSE aspects in a typical BGP are illustrated in Figure 1-1. Each process step has to be carefully considered for its HSE constituents during the planning, engineering, construction and operation stage. In this Guideline less emphasis is placed on gas engines as these are commercially available and already come with a CE mark and Declaration of Conformity.

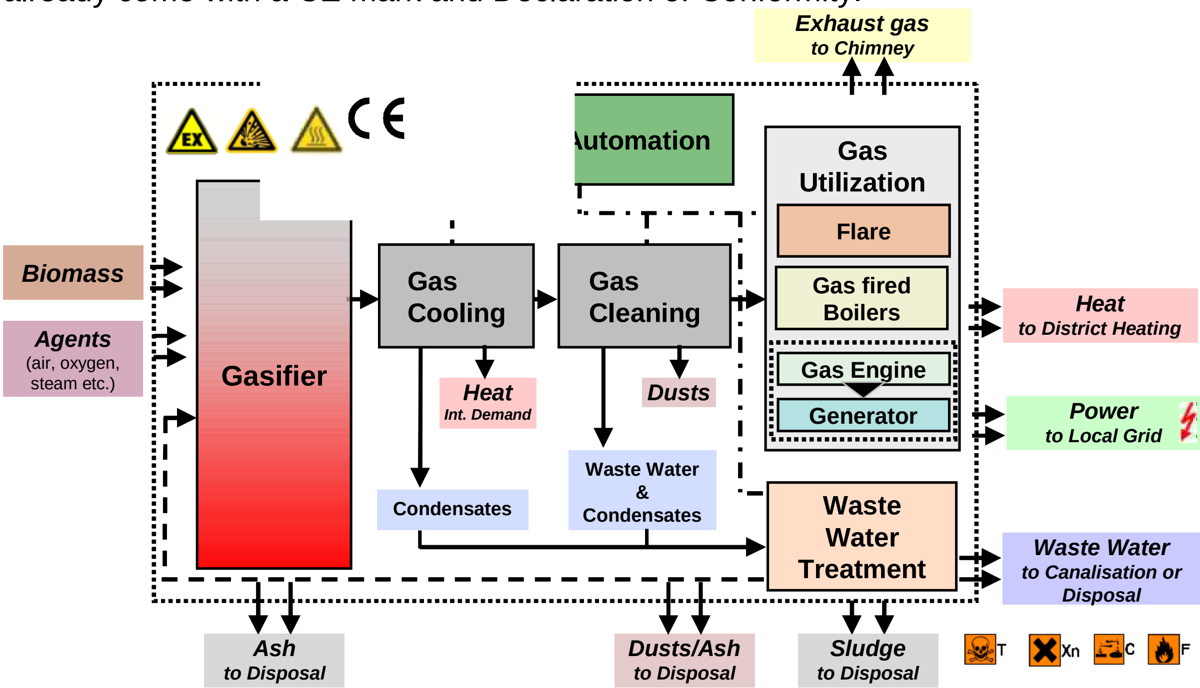

Figure 1-1 : Potential Health, Safety and Environmental aspects of gasification plants

In the formulation of this HSE Guideline, the following process steps and system components have been considered:

- Fuel storage and handling on site;
- Fuel conveyance and feeding;
- Gasification reactor;
- Gas conditioning (cleaning and cooling);
- Gas utilisation (gas engine);
- Automation and control; and
- Auxiliaries and utilities

1.4 Reading Guide

The Guideline contains four major chapters; each chapter can be read on its own without knowing the content of previous chapters.

Chapter 2 briefly describes the gasification technology in general.
Chapter 3 gives an overview of major legal framework issues on plant permission and operation. The legal frame is changing and the description is based on the situation by the end of 2007.
Chapter 4 explains the *theory* behind the risk assessment method and risk reduction measures

Chapter 5 is the heart of the Guideline and gives *practical* examples of good design, operation and maintenance principles. The practical examples and feedback have been received throughout the project and the description is based on mid-2009.
Chapter 6 describes the best techniques currently available for emission abatement which are used in biomass gasification plants.

The following important information can be downloaded from the project website **www.gasification-guide.eu**:

1. Software Tool “Risk Analyzer” for easy risk assessment of biomass gasification plants. The software tool is java-script based and the associated manual can also be downloaded
2. A checklist for permitting authorities to make a quick risk assessment
3. Several comprehensive reports as deliverables from the project.

2 Technology Description

2.1 Introduction

This chapter gives a brief overview of the different process steps applied in biomass gasification plants (BGP). The chapter is an abbreviated version of the technology description report given by *Deliverable 8: Biomass gasification: State-of-the-art description*, where a more comprehensive description is given on:

- general information (e.g. design, information on plant emissions, etc.);
- technology details (e.g. fundamental description of basic technologies); and
- important health, safety and environmental relevant issues.

Biomass gasification with a downstream gas engine is particular suitable for decentralised biomass utilisation and high efficient combined heat and power production. Figure 2-1 presents a simplified diagram of a BGP illustrating the main components, which describe and classify the process.

The fuel is normally fed into the gasification reactor through an air/gas-tight closure (an exception is an open top gasifier) by appropriate fuel conveying systems. The conversion of the fuel into a producer gas takes place in the gasification reactor, where the thermo-chemical conversion steps of drying, pyrolysis, partial oxidation and reduction as well as ash formation take place. For relatively small scale units – which is the scope of this Guideline –air is normally used as the gasification agent.

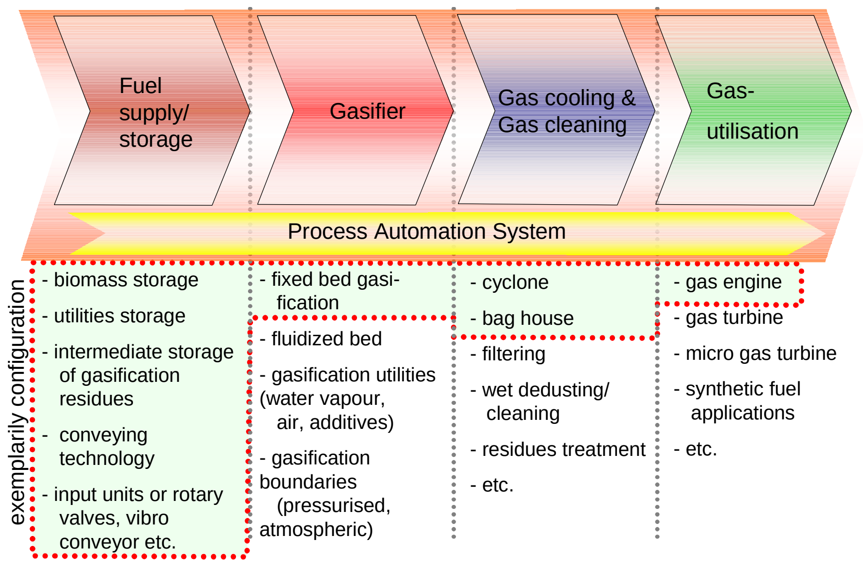

Figure 2-1: Typical process chain of a biomass cogeneration plant (compare [1])

The producer gas leaves the reactor at elevated temperatures (600-800°C) with a certain heating value and pollutant load. In the subsequent steps of the process chain, sensitive heat contained in the producer gas can be used for the provision of internal process heat, drying of the fuel and/or for district heating purposes. In various cleaning and cooling concepts the producer gas is subjected to dry (hot) and/or wet cleaning to achieve the required specifications for the gas engine. Note: in the case of wet gas cleaning, often the sensible heat can not be utilised.

During operation of a biomass gasification plant there is an increased hazard potential due to the fact that a potentially explosive, toxic and combustible gas mixture is produced and consumed. The producer gas and residues (ash, liquids, exhaust gases) may cause the following major hazards/risks:

- an explosion and/or fire;
- health damage to humans (poisoning, danger of suffocation, noise, hot surfaces, fire and explosion); and
- pollution of the environment and plant vicinity.

To counteract these adverse effects, appropriate measures must be taken to meet the requirements for successful market introduction of a safe and eco-friendly biomass gasification technology.

2.2 Fuel storage, pre-treatment, transport and feeding

Fuel storage, transport and pre-treatment may influence the fuel quality (e.g. drying during storage), as well as the gasification process stability (e.g. producer gas quality, stability of heat and power production, etc). Fuel is normally stored in a separate building adjacent to the main gasifier building. In most cases, the size of the storage building is chosen based on 2-3 days operation (to overcome a weekend) without fuel delivery. From here, fuel is transported to the pre-treatment section. The main technologies available to meet the requirements of the gasification system are drying, sizing or compacting, depending on the origin of the fuel. After pre-treatment the fuel may be transported to a daily storage bunker. The most common means of transport or conveyance is belt conveying and screws. From the daily storage bunker the fuel is further transported to the feeding system, which mostly is equipped with a dosing unit. The fuel conveyor may have integrated features like sieving, a magnetic belt, removal of contaminants and foreign material, and/or a drying unit. The actual feeding into the gasification reactor is usually done by a speed-controlled screw, the double-sluice lock hopper system or the rotary valve.

An important aspect is to avoid the escape of gas through the feeding section during the actual feeding and/or the air ingress during the same period. Anti-backfiring systems can be used or purging using inert gases to avoid this risk of potentially explosive atmospheres, as well as physically separating the fuel storage and gasification reactor, minimising fire risks potentials.

2.3 Auxiliary fuel and plant utilities

Auxiliary media/fuels and plant utilities may be needed during O&M to ensure the stable plant operation. A summary is given in Table 2-1.

Table 2-1: Example of auxiliaries and utilities

Media	Purpose
Natural gas / propane gas	Auxiliary firing, like start-up
(Bio)-diesel	Auxiliary firing, pilot injection gas engine
(Bio)-oils	Lubricating oils, scrubbing emulsions
Nitrogen,	Inertisation media, purge media
Water, steam	Gasification media supply, cooling media
Air and pressurized air	Gasification agent supply, operating medium for plant actuating elements
Electricity	Blowers, conveyors, fans, etc.

2.4 Gasification reactor

The thermo-chemical conversion of solid biomass into raw producer gas takes place in the gasification reactor (gasifier). At small scale, the updraft and downdraft type gasifiers are mostly used, see Figure 2-2. The sequence of the biomass conversion steps of drying, pyrolysis, partial oxidation and reduction depends on the type of gasifier. Recently, concepts are developed and implemented where the different zones are physically separated, mostly the pyrolysis and partial oxidation. The main reason behind this separation is the optimisation of each step and minimisation of the tar production. At the exit, the producer gas contains desired products and by-products:

- desired products: permanent gas (H_2, CO, CH_4, CO_2, N_2) and ashes with low remaining carbon content;
- undesired products: particulate matter, dust, soot, inorganic (alkali metals) and organic pollutants (tars or PAH, Polycyclic Hydro Carbons).

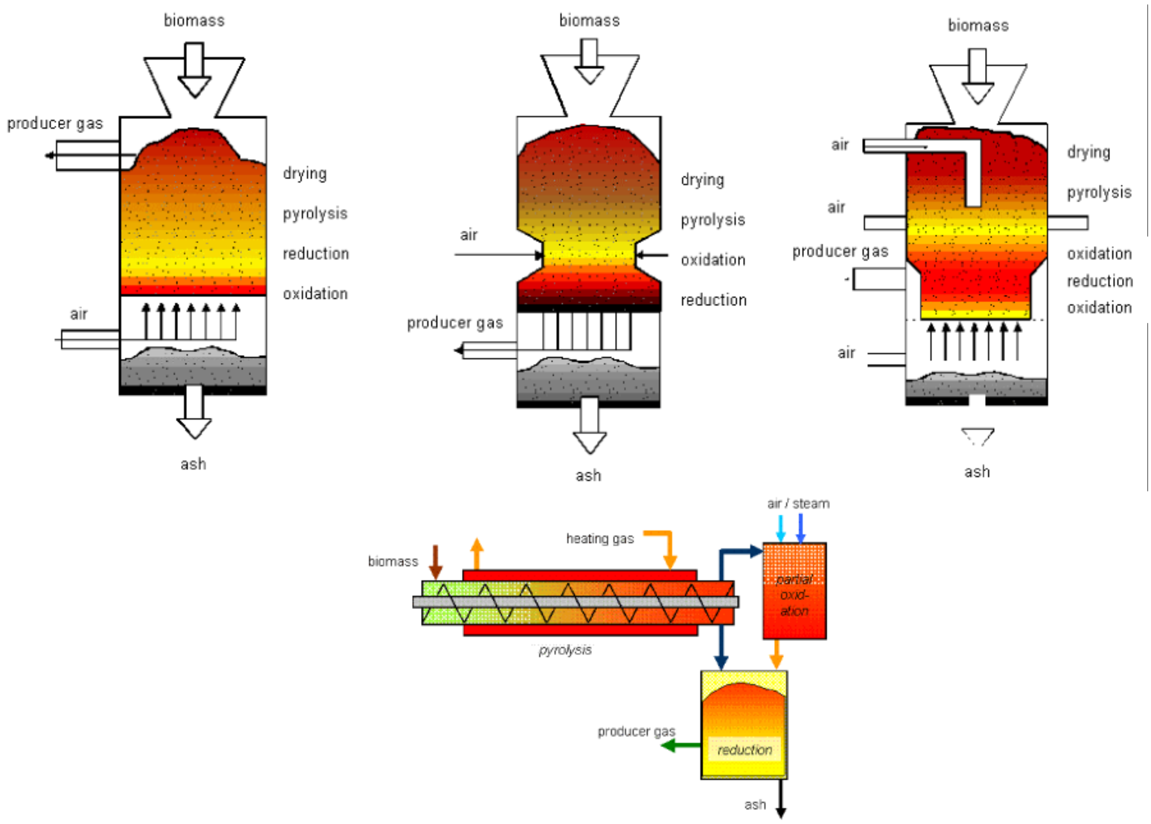

Figure 2-2: Typical gasifier reactor configurations at small to medium scale (updraft, downdraft double fire and two-stage)

2.5 Gas cooling

The purpose of gas cooling is to decrease gas temperatures to a certain level for:

- producer gas treatment (e.g. gas cleaning in bag filters); or
- utilisation in the gas engine; cooling increases the energy density of the gas.

It is recommended to recover the sensible heat in the gas, which allows the supply of:

- internal process heat (steam supply, evaporation energy, etc.);
- process heat to districted heating systems.

Corresponding to the process chain configuration of Figure 2-1, producer gas temperatures can be decreased in different stages, see
Table 2-2.

Table 2-2: Examples for typical temperature levels provided by gas cooling

Temperature range	Process step
600-800 °C	Cyclone, ceramic filters
90-250 °C	Fabric filters
90-400 °C	Gas scrubbing, final cooling
Close to ambient	Gas engine

Note: in case fabric bag filters are used, the tar and water dewpoint need to be considered. The dewpoint is the temperature where the molecules start condensing. This should be avoided, because they will block the filter, leading to increased pressure drop.

2.6 Gas cleaning

Gas cleaning is required to meet the specifications set by the engine supplier, even under varying conditions like gas flow, producer gas compositions, level of contamination, etc.. Major contaminants in the raw producer gas are particulate matter (soot, dust) and tar. Other impurities may include ammonia (which will be converted to NO_x during combustion in the engine), HCl, H_2S, alkalies, and acids, all dependent much on the process conditions, fuel and type of gasifier. The following dry and/or wet gas cleaning devices are applied (or a combination):

- cyclone - primary de-dusting (prior to gas cooling);
- hot gas filter - fine de-dusting (prior to gas cooling);
- bag filter system - fine de-dusting (after gas cooling);
- other filters (sand bed filter, active coke bed); and
- scrubbers – tar and dust removal with a liquid agent (water, oil, emulsions).

2.7 Gas Utilisation

This Guideline is focused on small scale BGP's producing combined heat and power (CHP) plant. The gas engine entails a conditioning of the biomass derived gas, providing gas parameters determined by the specifications of the engine (nearly constant producer gas temperature, sufficient heating value, purity level, humidity as well as a gas engine inlet pressure). Gas engines are a commercial commodity, which means that the gasifier manufacturer has to fulfil the requirements set by the engine supplier. There are only a few cases known, where the engine suppliers adapted the engine design for using biomass derived producer gas.

The major HSE issue to be considered here are the exhaust emissions. Products from incomplete combustion or from producer gas slip (predominantly CO and C_xH_y) and high-temperature or fuel-nitrogen combustion (NO_x) necessitate the operation of secondary treatment systems with regard to stipulated emission limits insofar, engine-specific measures being insufficient for minimising pollutants in the exhaust gas. Treatments with various techniques involving catalytic converters or post-combustion techniques, which guarantee compliance with emission limits, are possible in principle. Long-term experience regarding the effectiveness and service life of catalytic converters is presently not yet available. Service life is influenced substantially by catalyst poisons, e.g. heavy metal compounds, alkali compounds, etc., which in part reduce the activity of the catalytic coating very quickly.

2.8 Exhaust gas cleaning

Dependent on the emission requirements, exhaust gas must be cleaned from too high values of CO, C_xH_y, NO_x or particulates. The amount is dependent on the oxygen level in the exhaust gas. Some engines are operating in lean-burn mode, meaning a relatively high oxygen level, to reduce the CO emission.
There are very limited detailed data on the exhaust gas composition. Recently, the concentration of benzene (C_6H_6) appeared to be a problem and a solution for this has still not been found.

2.9 Producer gas properties regarding HSE aspects

2.9.1 Typical gas composition and physical gas properties

Small-scale biomass gasifiers operate normally with air as a gasification agent. This results in a certain gas composition that differs largely from other gases like biogas or natural gas. Typical characteristics of producer gas are given in Table 2-3.

Table 2-3: Typical characteristics of producer gas compared to other gases

Parameter	Producer gas	Biogas	Natural gas
CO (vol %)	12-20	<1	<0.5
H_2 (vol %)	15-35	<1	<0.5
CH_4 (vol%)	1-5	50-75	90-99
CO_2 (vol %)	10-15	20-50	<1
N_2 (vol%)	40-50	<1	<1
Heating value MJ/Nm^3	4.8-6.4	18-26	35
Explosion range (vol%)	5-59	8-18	4.5-15
Air to gas ratio	1.1-1.5	5-7.5	10

2.9.2 Explosion levels and combustion pressure

The following analysis of gases comes from a two-stage gasification plant. The first stage is evaporation and pyrolysis of wood chips by indirect heating. The second stage is pyrolysis of gases by direct heating with combustion products.

Table 2-4: One example of the explosion levels and pressures

Gas composition	Pyrolysis gas (1st stage)	Production gas (2nd stage)
CO_2	0.15 mole/mole	0.13 mole/mole
CO	0.15 mole/mole	0.09 mole/mole
H_2O	0.46 mole/mole	0.29 mole/mole
H_2	0.13 mole/mole	0.22 mole/mole
CH_4	0.07 mole/mole	0.01 mole/mole
N_2	0.00 mole/mole	0.23 mole/mole
Tar components	0.04 mole/mole	0.02 mole/mole
Mole weight	24.3 kg/kmol	22.3 kg/kmol
Stoïchiometric combustion air mole air/ mole gas	3.00 mole air/ mole gas	1.59 mole air/ mole gas
LEL	0.104	0.12
UEL	0.395	0.62
Deflagration pressure from 15°C	6.6 barg	6.1 barg
Flame temperature from 15°C	1695 °C	1575 °C
Deflagration pressure from 500 °C	3.4 barg	2.5 barg
Flame temperature from 500°C	2480 °C	1820 °C

2.10 Automation and control

Under the current economic conditions, a BGP needs to be fully automated, allowing for unmanned operation. Full automation has the advantage that safety procedures can be included in the automated control system. Basically, any plant needs an automation and control system, so for small-scale systems, the part becomes relatively expensive. The following items are mostly automated:

- Fuel feeding (rotational speed controllers, or opening of valves);
- Fuel level in the gasifier reactor;
- Oxygen supply to the gasifier reactor (linked to the fuel feeding);
- Cleaning sequence of filters (dependent on pressure drop);
- Air-gas ratio to the gas engine.

3 Legal Framework for Biomass Gasification Technologies

3.1 Introduction

Planning, building, commissioning, and operation of biomass gasification plants are activities that are subject to European and national regulations. In order to determine the relevant legal framework for small and medium biomass gasification plants, it is useful to draw a rough distinction between those requirements applying to the design and manufacturing of BGPs (as products that are to be placed on the European market) and those applying to ownership and operation; in simple terms, to distinguish between the manufacturer's and the operator's duties.

The underlying legal background is different for the two parties. While the legal framework with regard to the safety of products placed on the market is rather homogeneous throughout Europe, the legal framework for plant operation displays many variations across the European member states. The aim of this chapter is to give a general overview of the legal areas that apply to biomass gasification plants, both from the manufacturer's and the operator's point of view. The focus is on legal requirements towards health, safety and environment (HSE).
Hazard identification and risk assessment are among those legal HSE requirements that have to be met both by the manufacturer and the operator.

3.2 Manufacturing and placing on the market

The manufacturer's HSE duties related to biomass gasification plants arise from European directives according to Article 95 of the EC Treaty, which define essential health and safety requirements that have to be fulfilled by products intended for the European market. Directives that may be particularly relevant for BGPs are listed in Table 3.1.

Table 3.1: European Directives (providing for the CE marking) that may be applicable to biomass gasification plants or to parts thereof

Directive: Number, Scope	Examples of application (BGP equipment)
73/23/EEC: Low voltage equipment [2006/95/EC]	Electrical instruments, drives, control systems, generator
89/336/EEC: Electromagnetic compatibility [2004/108/EC]	Electrical instruments, drives, control systems
98/37/EC: Machinery [2006/42/EC]	Drives, pumps, blowers, moving mechanical parts, gas engine, fuel feeding system, ash removal system
94/9/EC: Equipment for use in potentially explosive atmospheres (ATEX directive)	Blowers, measuring devices, flame arrestors
97/23/EC: Pressure equipment	Heat exchangers/boilers, compressed air system
2000/14/EC: Noise emission by outdoor equipment	Conveyor belts

Common elements of these directives include the assessment of conformity with the essential health and safety requirements set out in the directives. Technical specifications of products meeting the essential requirements are laid down in harmonised standards. Application of harmonised or other standards remains voluntary, and the manufacturer may always apply other technical specifications to meet the requirements.

A comprehensive reference to New Approach directives and to harmonised standards can be found at the website below:
<http://www.newapproach.org/Directives/DirectiveList.asp>.

While manufacturers are required to assess and declare the conformity of their products, they may choose between different conformity assessment procedures provided for in the applicable directive(s).

It is evident that certain parts of a BGP will be in the scope of directives from Table 3.1. The question is sometimes raised as to whether a biomass gasification plant as a whole can be in the scope of any one of these directives, and therefore requires CE marking, conformity assessment and declaration of the entire plant. This issue is also treated in Deliverable D6 ("Listing of actions to harmonise the legal frame for biomass gasification"), which is available on the Gasification Guide website.

The following quotation from the European guide on New Approach directives may give some guidance on this matter:

"It is the responsibility of the manufacturer to verify whether or not the product is within the scope of a directive.
A combination of products and parts, which each comply with applicable directives, does not always have to comply as a whole. … The decision whether a combination of products and parts needs to be considered as one finished product has to be taken by the manufacturer on a case-by-case basis."[1]

A BGP manufacturer will have to identify those units or pieces of equipment in the biomass gasification plant that are devices or assemblies covered by New Approach Directives, and to supply the required CE marking and declarations of conformity (DoC) for these parts. The manufacturer may choose to install pieces of equipment from third-party suppliers that already bear CE marking and that come with declarations of conformity.

[1] Guide to the implementation of directives based on the New Approach and the Global Approach, European Commission, Luxembourg, 2000

There is no requirement for a manufacturer to deliver an all-inclusive declaration of conformity for an entire biomass gasification plant. Nevertheless, the manufacturer has to supply operating instructions, possibly in the form of an operating manual, which cover all hazards of the plant and all safeguards and precautions that are required for safe operation, including start-up, shut-down, and maintenance.

Discussion with experts from various European countries has revealed that different opinions exist concerning the application of some of the directives listed in Table 3.1 and on the consequences of their application.

With a view to the Machinery Directive, it has been argued that a biomass gasification plant as a whole should to be treated as an assembly of machines, resulting in a DoC according to the Machinery Directive for that assembly. A point in favour of that notion is the fact that risk assessment according to the Machinery Directive covers different types of hazards, including mechanical hazards as well as electricity, extreme temperatures, fire, explosion, noise, vibration, and emission of hazardous substances.

On the other hand, it has been argued that general product safety and liability requirements already demand a comprehensive hazard identification and risk assessment from the manufacturer, without any need to subject the entire product to a single New Approach directive. Furthermore, the official ‘Comments on Directives 98/37/EC’[2] published by the European Commission state that "...there is no point, for example, in extending [the Machinery Directive] to complete industrial plants such as power stations...". Therefore, it may be regarded as a viable solution for biomass gasification plants to employ hazard assessment procedures related to machinery (e.g. according to European standards EN 1050/EN 14121-1), but without classifying the entire BGP installation as machine (or assembly of machines) and without issuing a DoC related to the entire installation.

It has been a subject of discussion whether a piece of equipment (e.g. a gasification reactor) that could become pressurised to more than 0.5 bar only in case of an internal explosion should be regarded as pressure equipment in terms of the Pressure Equipment Directive (PED), combined with the question of which design

[2] http://ec.europa.eu/enterprise/mechan_equipment/machinery/guide/guide_en.pdf

specification should be used for such equipment[3]. This seems to be an issue that still needs to be resolved between competent bodies at European level. A more detailed discussion can be found in Deliverable D6 ("Listing of actions to harmonise the legal frame for biomass gasification"), which is available on the Gasification Guide website.

Biomass gasification plants in terms of this Guideline are supposed to be professional equipment, operated on a commercial scale. It cannot be precluded, however, that future development of small biomass gasifier plants may result in equipment that can be operated far more easily, turning such BGPs into an alternative for standard heating equipment which is made available to consumers.

Therefore, it may become necessary in future to apply directive 2001/95/EC on general product safety to BGPs if they are intended for, or likely to be used by, consumers. Health and safety requirements for consumer products are generally more demanding than those for commercially operated products.

3.3 Construction and operation of biomass gasification plants

Construction and commercial operation of a biomass gasification plant are affected by various regulations that may have a direct impact on the design of the plant and its operation mode.

The areas that appear to be the most important in terms of environmental protection and occupational safety and health regulations have been compiled in Table 3.2 below.

Table 3.2: Legal areas that may be relevant for the construction, putting into service, and operation of biomass gasification plants

Main subject	Subject	Relevance for biomass gasification plants
Environmental impact	Permit requirements (Integrated pollution prevention and control)	Although BGPs are not in the scope of the IPPC directive, national regulations may require integrated permits or special permits, cf. table 3.3.
	Environmental impact assessment (EIA)	BGPs may be classified as a type of development that requires EIA screening.

[3] For explosion resistant equipment, design and test principles based on explosion protection demands have been specified in EN 14460. This standard is in the list of harmonised standards to the ATEX Directive 94/9/EC, however, but not to the PED.

	Emissions to atmosphere: gases, dust, smell	Emissions in normal operation from engines, flares, or from storage; start-up and shutdown may also cause relevant emissions
	Noise emission	Noise from equipment (gas engines, blowers, coolers), from material handling and vehicles
Environmental impact	Major Accident Hazards	Could become relevant if large amounts of hazardous substances are stored on site
	Waste production and treatment	Waste from plant operation may include ashes, tar, and contaminated cleaning fluids. Special considerations may be required if intermediates are recirculated (e.g. tar from the gas cleaning system)
	Waste water discharge	Process waste water may require special treatment to meet requirements for discharge to sewer
	Handling of substances hazardous to water / protection of water bodies	Tar, cleaning liquids, water treatment chemicals; use of cooling water
	Soil protection	Tar, cleaning liquids, water treatment chemicals
Occupational safety and health	Health and safety at work, general	Risk assessment, protective measures, operating instructions, personal protective equipment, emergency procedures
	Substances hazardous to health	Intermediates: producer gas (CO), tar; handling of chemicals used in the plant, e.g. cleaning liquids, water treatment chemicals, biological agents (storage of feedstock)
	Fire and explosion hazards; explosion protection	Flammable producer gas; special precautions for gasifier start-up and shutdown; assessment of areas at risk from hazardous explosive atmospheres (zone classification)
	Installations subject to monitoring	Special monitoring may be required for certain types of equipment and installations
	Pressure equipment	Requirements towards installation and maintenance, (regular) testing
	Electrical equipment	Requirements towards installation and maintenance, (regular) testing
	Machinery	Requirements towards installation and maintenance, (regular) testing
Other Regulations	Renewable energies and biomass	Possible effects of plant design, type of feedstock, and mode of operation: feed-in tariffs, combined heat and power, guarantee of origin (renewables) distinction: (natural) biomass / waste
	Energy feed-in	Requirements towards feeding electrical energy to the power grid
	Land use planning	Selection of appropriate site (industrial activity)
	Safety of buildings	Fire safety, building stability

Table 3.2 can be used as a checklist to determine the statutory obligations that may become relevant for a specific BGP installation in a European state. The regulations pertaining to the subjects from Table 3.2 need to be determined individually for BGP installations. It is recommended to consult the competent local authority or authorities at an early stage in order to identify the regulations and procedures that apply.

A basic question that needs to be answered at an early stage of planning concerns the type of permit(s) that will be required for an individual BGP installation. For small and medium BGPs, an environmental permit will be necessary in many cases, and limit values for emissions of noise and substances to the atmosphere and water will be fixed in the permit.

Classification criteria which have the most significant impact on legal requirements towards BGP construction and operation, including the decision on whether or not a permit is required and what type of permit is needed, are listed below:

- Type of gasifier feedstock: natural biomass or (biomass) waste; [4]
- Thermal input rating (thermal capacity) of the BGP with regard to gasifier feedstock;
- Thermal output rating (thermal capacity) of the BGP with regard to the produced gas;
- Is the BGP operated as a stand-alone unit or as part of a larger installation;
- Electrical rating of the CHP gas engine;
- Gas engine type (e.g. compression ignition, spark ignition);
- Operating time per year of the gas engine (peak load operation or continuous operation);
- Date of putting the plant into service;
- Properties of the site and its surroundings (e.g. industrial, commercial, agricultural, or residential area);
- Does the BGP require the discharge of waste water?

The above criteria apply to formal requirements (is a notification of the regulatory authority or an environmental permit required?) and to substantive requirements and consequences (emission limits, electricity feed-in tariff).

Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (the ‘IPPC Directive’) lays down measures designed to

[4] Gasification of waste within the scope of the Waste Incineration Directive 2000/76/EC is not considered in this guideline.

prevent or, where that is not practicable, reduce emissions in the air, water and land from certain industrial activities to achieve a high level of protection of the environment as a whole.

The situation of licensing (permit) requirements for biomass gasification plants resulting from national or regional legislation transposing the IPPC Directive and defining integrated permit procedures is given in Table 3.3 for a number of European countries.

Table 3.3: National regulations transposing the IPPC Directive; pertaining permit requirements for small and medium BGPs using natural biomass

State	Regulation(s) transposing the IPPC directive	Permit requirements for biomass gasification plants
(Europe)	(Directive 96/61/EC concerning integrated pollution prevention and control – IPPC directive)	(According to Annex I, BGPs are not in the scope of the IPPC directive.)
Austria	Trade, Commerce and Industry Regulation Act 1994, last amended 2006 [Gewerbeordnung GewO 1994, zuletzt geändert 2006]	Yes, but specific requirements for IPPC installations do not apply to BGPs
	Immission Protection Act - Air [IG-L Immissionsschutzgesetz - Luft]	Yes
Belgium (Example: Brussels)	Environmental Permit Order [Ordonnance du 5 juin 1997 relative aux permis d'environnement du Ministère de la Région de Bruxelles-Capitale]	
	Schedule of classified installations [Arrêté du Gouvernement de la Région de Bruxelles-Capitale fixant la liste des installations de classe IB, II et III]	Yes, for gasification of carbonaceous material (< 500 t/d) (No. 39, class IB)
Bulgaria	Environmental Protection Act (SG 91/2002) [Закон за опазване на околната среда (ДВ 91/2002)]	Yes
	Regulation №5 on risk assessment (SG 47/1999) [Наредба №5 за оценка на риска (ДВ 47/1999)]	
Denmark	Environmental Protection Act 2006 Statutory Order no. 1640 of 13 December 2006 from the Ministry of the Environment on Approval of Listed Activities (Approval Order) [BEK nr 1640 af 13/12/2006 (Godkendelsesbekendtgørelsen)]	Yes, if thermal rating is > 1 MW (Annex 2, G 202)
France	Environmental Act [Code de l'environnement]	
	Schedule of classified installations [Nomenclature des installations classées pour la protection de l'environnement]	Yes, for production of flammable gas (1410) and for combustion of non-standard fuel if thermal rating is > 0.1 MW (2910)
	[Arrêté du 2 février 1998 relatif aux prélèvements et à la consommation d'eau	

	ainsi qu'aux émissions de toute nature des installations classées pour la protection de l'environnement soumises à autorisation]	
Germany	Federal Immission Control Act [Bundesimmissionsschutzgesetz, BImSchG] Ordinance on Installations Requiring a Permit [4. BImSchV]	Yes, if thermal rating of the produced gas is > 1 MW (Annex, No. 1.4 and 1.13)
Ireland	Protection of the Environment (PoE) Act 1992 and 2003	(BGPs not in the scope)
Italy	IPPC Act 2005 [Decreto Legislativo 18 febbraio 2005, n. 59 "Attuazione della direttiva 96/61/CE relativa alla prevenzione e riduzione integrate dell'inquinamento"] Environmental Protection Ordinance [Decreto Legislativo 152 del 3 aprile 2006 recante norme in materia ambientale]	(BGPs not in the scope) Yes (Art. 269)
Netherlands	Environmental Act [Wet milieubeheer, Wm] Ordinance on Installations and Permits [Inrichtingen- en vergunningenbesluit milieubeheer (Ivb)] Water Act [Wet verontreiniging oppervlaktewateren, Wvo]	Yes (internal combustion engines > 1.5 kW) (Cat. 1, 1.1b)
Spain	IPPC Act [Ley 16/2002 de 1 de julio de Prevención y Control Integrados de la Contaminación (Ley IPPC)] Air Quality Act [LEY 34/2007, de 15 de noviembre, de calidad del aire y protección de la atmósfera]	(BGPs not in the scope) Needs to be discussed with competent authority: dry distillation of wood (annex IV, 1.1.3, group A); conventional heat and power stations < 50 MW thermal (2.1.1, group B); gasifiers (3.1.2, group C)
Sweden	The Environmental Code [SFS 1998:808 Miljöbalk] Ordinance on environmentally hazardous activities [Förordning (1998:899) om miljöfarlig verksamhet och hälsoskydd]	No, for gasifiers and gas engines < 10 MW, but notification required (40-5 and 40.1-2) [from 01/01/2008: yes, if more than 150.000 m^3 flammable gas per year is produced – 40.10 (B)]
Switzerland	(No Swiss transposition of IPPC directive!) Environmental Protection Act [Bundesgesetz über den Umweltschutz (Umweltschutzgesetz, USG)]	Yes; building laws of the Swiss cantons determine the authorization procedure
United Kingdom (England and Wales)	The Environmental Permitting (England and Wales) Regulations 2007	Needs to be discussed with the Environment Agency, cf. Part 2 (Activities) / Chapter 1 (Energy activities) / Section 1.1 (Combustion Activities) and Section 1.2 (Gasification, Liquefaction and Refining Activities)

In some European states, Annex 1 of the European IPPC Directive (categories of industrial activities) has been transposed into national law on a 1:1 basis, which means that BGPs are not in the scope of these national regulations. Other European states have combined the obligations from the IPPC Directive with their national schedules for plants and activities subject to licensing.

Even if a BGP is not in the scope of national regulations transposing the IPPC Directive, individual permits for construction and operation (e.g. building permits) or notification of regulatory authorities may still be required due to other national or regional regulations.

Therefore, when planning to build and operate a biomass gasification plant, it is recommended that discussions are held with the local regulator at an early stage and advice is sought on the specific statutory regulations.

National regulations on occupational safety and health (for the subjects listed in Table 3.2) require the employer to prevent or minimise occupational risks, to provide information and training, and to provide the necessary organisation and means. To this end, the employer needs to perform hazard identification and risk assessment, and draw up documents on the results of this assessment and on the protective measures and safeguards that need to be used.

With regard to biomass gasification plants, these documents have to include:

- a registry of hazardous substances used on the premises;
- an explosion protection document; and
- written company-specific operating instructions.

In addition to statutory regulations, it is necessary to take account of HSE requirements set out by insurers in order to obtain liability or damage insurance for a biomass gasification plant.

3.4 Permit procedures for biomass gasification plants

If a permit is required for the construction and operation of a biomass gasification plant, the applicant has to provide detailed information on the planned activity. The procedures are country-specific e.g. in terms of

- the competent authorities;
- the information that has to be provided in the written application for permit;
- application forms to be used; and
- the number of copies to be provided by the applicant.

In Table 3.4, official sources of information (web_links) and search strategies for relevant official information on permit procedures and application forms have been compiled for a number of European states.

Table 3.4: Overview of sources of information concerning the required specifications in applications for permits

State	**Scope / type of installation;** **source of information regarding application for (environmental) permit**
Austria	Commercially operated BGP installations: Sections 353 and 353a of the Trade, Commerce and Industry Regulation Act (GewO 1994): **http://www.ris2.bka.gv.at/Bundesrecht/** Detailed information on permit procedures has been compiled in the Austrian "Guideline on safety and authorisation of biomass gasification plants" [Leitfaden - Anlagensicherheit und Genehmigung von Biomassevergasungs-anlagen]: http://www.nachhaltigwirtschaften.at/edz_pdf/leitfaden_biomassevergasungsanlagen.pdf
Belgium (Example: Brussels)	Permit procedures for classified installations: **http://www.ibgebim.be/Templates/Professionnels/Informer.aspx?id=1210&langtype=2060**
Denmark	Heat and power plant, gas turbine or gas engine installation in the 1–5 MW (thermal) range: Annex 5 Section 3 of the Approval Order (BEK No. 1640 of 13/12/2006) **https://www.retsinformation.dk/Forms/R0710.aspx?id=13040**
France	Permit procedures for classified installations: **http://installationsclassees.ecologie.gouv.fr/-Regime-d-autorisation-.html** Information on details required in the permit application: **http://installationsclassees.ecologie.gouv.fr/Comment-constituer-le-dossier-de.html**
Germany	Gasifiers and gas engines > 1 MW (thermal): Ordinance on Permit Procedures (9. BImSchV), Sections 3, 4 and 4a) to 4e) **http://bundesrecht.juris.de/bundesrecht/bimschv_9** Additional information and application forms can be found on the websites of *Laender* Environmental Ministries. (Search keywords: "Antrag Genehmigung Immissionsschutz <*Land*>") e.g. for Northrhine-Westphalia: **http://www.umwelt.nrw.de/umwelt/immissionsschutz/genehmigungsverfahren/index.php**
Ireland	General information on licensing: Environmental Protection Agency (Ireland) **http://www.epa.ie/downloads/advice/**
Italy	Installations subject to environmental permits: Environmental Agencies of the provinces (Search keywords: "autorizzazione ambiente <province>")
Netherlands	Installations subject to environmental permits: Application forms for environmental permits can be downloaded from community websites in the Netherlands. (Search keywords: "aanvraag vergunning milieubeheer <community>")
Spain	General information: Spanish Ministry of the Environment: **http://www.mma.es/portal/secciones/** (New authorisation requirements have been imposed by the Air Quality Act of 15/11/2007.)
Sweden	Installations subject to environmental permits: General information on permit procedures can be downloaded from the

	Swedish Environmental Ministry website **http://www.naturvardsverket.se/sv/Verksamheter-med-miljopaverkan/Tillstand-och-anmalan-for-miljofarlig-verksamhet/** Additional information and application forms can be found on the websites of county administrative boards [länsstyrelsen]. (Search keywords: "tillstånd miljöfarlig verksamhet <county>")
Switzerland	Industrial installations: Building permits, declarations on emissions, permits for industrial installations: Special application forms and guidelines can be found on the websites of the Swiss cantons. (Search keywords: "Baugesuch Industrie <canton>"; "Plangenehmigung Betriebsbewilligung <canton>")
United Kingdom (England and Wales)	Planning process for renewable energy: **http://www.berr.gov.uk/energy/sources/renewables/planning/process/page18680.html** Energy from solid biomass plants (background document): **http://publications.environment-agency.gov.uk/pdf/GEHO0706BLBH-e-e.pdf?lang=_e** Understanding the meaning of regulated facility: **http://www.environment-agency.gov.uk/static/documents/Business/epr2_v1.0_2000543.pdf** How to comply with your environmental permit, Additional guidance for Combustion Activities: http://publications.environment-agency.gov.uk/pdf/GEHO0209BPIN-e-e.pdf

Typically, the application for a permit to construct and operate a biomass gasification plant will have to include the items listed below:

- information on the applicant (name, address),
- specific reference to the relevant regulations, e.g. classification of the installation and of the type of industrial activity according to national schedules,
- description of the plant location, supplemented with maps and site plans in different scales,
- description of plant layout and plant operation (text, flowsheets, equipment lists, layout plans),
- mass and energy balances of the entire plant (feedstock, emissions, waste, auxiliary materials, energies that are used and delivered), demonstrating that all emission streams have been considered,
- description of general occupational safety measures,
- description of special hazards (fire, explosion, hazardous substances) and precautionary measures,
- description and assessment of potential effects on the environment (e.g. noise emissions, emissions to atmosphere),
- description of waste and waste-water management.

Occasionally, additional third-party certificates and expert opinions may be required, e.g. on noise emissions and on fire and explosion protection.

3.5 Special aspects of permit procedures for biomass gasification plants in European states

Austria

A detailed presentation of the legal framework for construction and operation of biomass gasification plants in Austria, of the documents required for the permit procedures and of the competent authorities can be found in chapter 4 of the "Guideline on safety and authorisation of biomass gasification plants" (Leitfaden - Anlagensicherheit und Genehmigung von Biomassevergasungs¬anlagen), cf. table 3.4. Small BGPs operated on a commercial basis will be covered by the Trade, Commerce and Industry Regulation Act [Gewerbeordnung]. Production of electricity is subject to Austrian electricity law.

Denmark

Permit procedure requirements for BGPs in the 1 – 5 MW thermal range are detailed in Annex 5 Section 3 of the Approval Order (BEK No. 1640 of 13/12/2006). This order contains a detailed description of the information that needs to be presented when applying for a permit.

Germany

For BGPs with less than 1 MW thermal rating of the produced gas and/or the CHP engine, only a building permit from the local building authority will be required. For larger plants or if an environmental impact assessment is necessary (for site-specific reasons), the activity will be subject to an environmental permit procedure, which will include other relevant permits. Noise emission from BGP operation can be an important factor for the choice of a suitable site for the plant.

Netherlands

Permits for small-scale biomass plants are issued by local government, mostly the municipality or province. Building permit includes the need for a declaration of clean soil as it is prohibited to build on polluted soil.

Municipality and municipal Fire department evaluate proposed fire protection and safety measures, as stipulated in the Building Decree.

BAT is important to obtain environmental and building permit.

Switzerland

Issues of environmental protection (emissions, waste) and occupational safety are treated as part of building permit procedures. The application for a building permit [Baugesuch] must include a declaration on emissions [Emissionserklärung] and an application for permits according to occupational law for planning and operation of an industrial installation [Plangenehmigung, Betriebsbewilligung].

Building authorities of the “cantons” are the competent authorities for building permit procedures.

Fire safety of the installation has to be described when applying for fire insurance at the building insurance of the canton [Kantonale Gebäudeversicherung], which is compulsory.

3.6 Legal background of "best available techniques" requirements

According to Article 2 of the IPPC Directive, "best available techniques" (BAT) shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole:

- ‘techniques’ shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- ‘available’ techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the member state in question, as long as they are reasonably accessible to the operator;
- ‘best’ shall mean most effective in achieving a high general level of protection of the environment as a whole.

Article 9 of the IPPC Directive requires that emission limit values (or equivalent parameters and technical measures) for activities in the scope of that directive shall be based on the "best available techniques", without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions.

Due to the thermal rating and to the type of feedstock used, biomass gasification plants as considered in this project are clearly not in the scope of Annex I, Category 1 (Energy Industries) of the IPPC Directive. Neither can these BGPs be classified as any of the "Other activities" listed in Category 6 of Annex I to the IPPC Directive. Therefore, there is currently no requirement at the European level from the IPPC directive to apply emission limit values or emission abatement requirements based on BAT. As has been pointed out in chapter 3.2, however, small and medium BGPs are in the permit scope of some national regulations transposing the IPPC Directive. Therefore, some national permit procedures for BGPs include the requirement that emission limit values (or equivalent parameters and technical measures) shall be based on BAT.

In the BREF document of July 2006 on large combustion plants , for example, gasification of biomass is described as an ‘emerging technique’ that is currently performed in demonstration units only. This is an indicator that the techniques for exhaust gas cleaning of biomass gasification plants, large-scale or small-scale, are in the stage of development, too. The questions

- which emission abatement techniques from standard combustion applications can be successfully transferred to small biomass gasification plants; and
- which emission values can thus be achieved,

still need to be answered, taking both environmental and economic considerations into account.

A brief description of techniques for emission abatement that are currently used in small-scale biomass gasification plants is presented in chapter 6 of this Guide.

4 Theoretical Aspects of Risk Assessment

4.1 Introduction

The technology of biomass gasification differs from other energy conversion technologies based on renewable energy sources (e.g. biomass combustion) because it inherently involves the production, treatment and utilisation of flammable and toxic gas mixtures, plant media and utilities. Therefore, an adequate risk assessment is strongly recommended and is often a legal requirement for placing the plant into the market and running it.

A risk assessment is aimed at protecting the workers and the plant itself. Manufacturers/operators have to keep in mind that accidents and ill health can ruin lives and can affect the business too if output is lost, machinery is damaged, insurance costs increase or there is the possibility of prosecution *[Ref 16]*.

A risk assessment consists of a careful examination of what could cause harm to the people and environment in the plant, and the adoption of reasonable control measures. The manufacturers/operators have to produce a complete and well-documented assessment of the risk relative to:

- Health – e.g. hazards to human health, dangers from toxic gases, etc;
- Safety – e.g. explosion hazards, fire hazards, etc;
- Environment – e.g. plant emissions, loss of containment relating to toxic substances, etc.

A risk assessment has to be carried out during the planning phase (for manufacturers) in order to improve the plant's conceptual design. In existing plants, a risk assessment allows the reduction of the remaining risks by continual updating of the original risk assessment (for manufacturers and operators).
Different methods for risk assessment are available, but procedures for risk assessment are not generally standardised for biomass gasification plants. Some guidance on risk assessment can be found in different case studies from other branches of the industry (e.g. food industry, chemical industry, metal industry, etc.). These examples can only give guidance for finding a methodology and often have to be adapted to be used for biomass gasification plants.

4.2 Applied risk assessment procedure for biomass gasification plants

Assessing the risks is an extensive task for which comprehensive knowledge of the process and the operational behaviour, as well as the risk assessment methodology itself, is needed. A team that has various expertise is recommended for the risk assessment. The following information is necessary:

- Plant data (process schemes, piping and instrumentation diagram (P&I), reference designation and plant documentation, apparatus design, etc.);
- Predefined plant operation modes (knowledge about start-up, shut-down and normal operation mode), process control strategies;

- Data on plant media, gas mixtures and plant media streams (e.g. waste water, gas cleaning residues, dusts, exhaust gas), as well as their corresponding safety characteristics (toxicity, explosion characteristics etc);
- Desired operation conditions (temperature, pressure, flows and gas compositions);
- Machinery lists, details on construction design;
- Mass and energy balances, process stream information (temperature, pressure, composition and pollutant load, etc);
- Information on the plant's surroundings (geographical aspects, environmental aspects, etc).

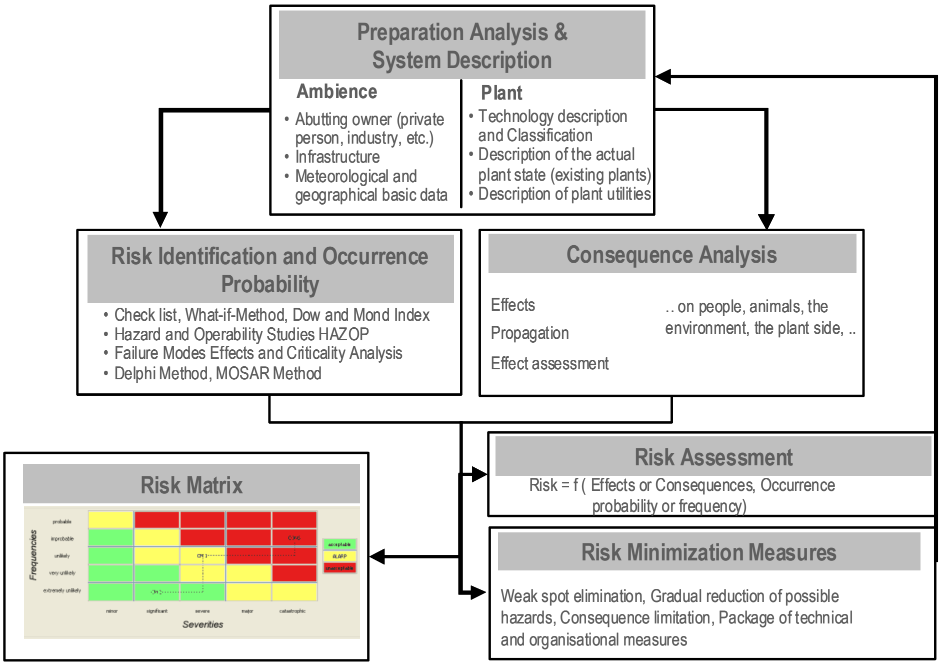

Figure 4-1 Systematic approach for the risk assessment of biomass gasification plants

Small-scale biomass gasification being a unique and relatively new technology, no specific risk assessment technique or guidance is available. This guide recommends a risk assessment methodology which is practicable and sufficient to be applied to such plants. The chosen approach is based on functional analysis of the plant *[Ref 10-12].* It follows principally the Hazard and Operability Studies (HAZOP) *[Ref 13, 20]* and Failure Modes Effects and Criticality Analysis (FMEA) *[Ref 14]* methods, as well as recommendations given by an expert commission *[Ref 13, 15].*

In many cases, the risk assessment deals with a very complex system, which contains a huge number of mostly independent functions and plant parts. By subdividing the process into process units *[Ref 1, 17]* (e.g. fuel storage, handling, feeding, gasifier, gas cooling, gas cleaning, gas conditioning and gas utilisation), the complex system is simplified, and a separate analysis of each function (e.g. for the gasifier: fuel supply, gasification utilities supply - i.e. steam and air, temperature control in the gasifier, ash removal, etc) is possible.

On each investigated function, the risk evaluation team has to *[Ref 21]*:

- Identify the possible hazards and their associated occurrence probability;
- Identify the consequences arising from these possible hazards and their severity;
- Evaluate the risks;
- Apply the suitable reduction/mitigation measures;
- Review and update the risk assessment on a regular basis.

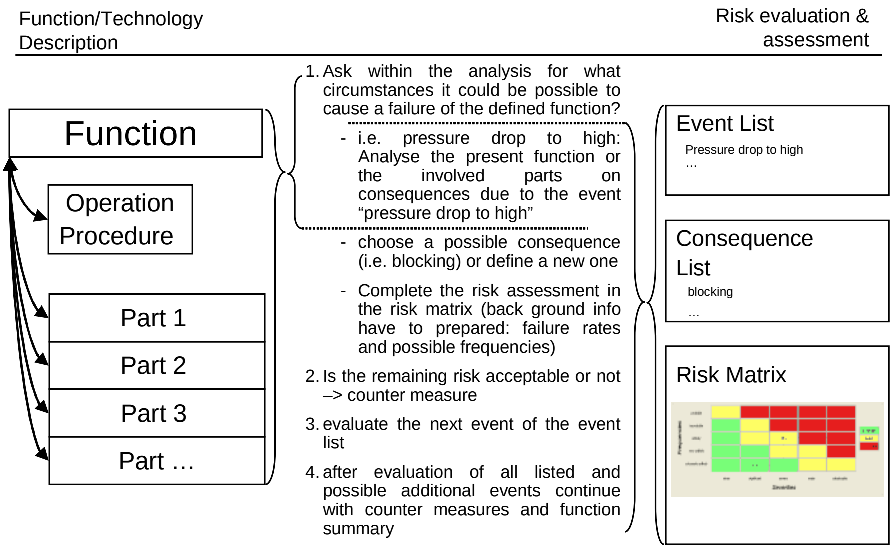

Figure 4-2 Description scheme for the risk evaluation and assessment within one investigated function

Figure 4-2 gives a general overview of the principles and methodology underlying a risk assessment. All steps of the assessment must be well-documented to allow traceability.
The following sections give the basis for conducting the hazard identification (Hazard-ID), the risk assessment (RA) itself and implementing concrete risk reduction (RR) measures.
An example of a risk assessment carried out on a whole model process configuration will be given in the software tool manual (D11 – Software tool and Manual).

4.3 Hazards Identification and Consequences

For each defined function, the risk assessment team has to carry out a hazard identification. This consists of identifying all situations or events that could cause harm to people and environment. These hazardous events can be of different natures:

- Abnormal operation conditions (temperature and pressures);
- Equipment failures;
- Leakage;
- Operator failure;
- Loss of containment;
- Etc.

The approach proposed in this guide follows principally the HAZOP and FMEA analysis, but different hazard identification techniques are available and could be used (see Annex A).

The occurrence probability of each identified hazardous event has to be assessed (e.g. using failure rates of equipment, existing data) *[Ref 23, 26]*. The investigated hazardous event can itself be caused by different events or situations that have to be taken into account in the calculation of the overall occurrence probability.
All these possible hazardous events have to be analysed to determine their possible consequences, such as fire, explosion, emissions, etc. *[Ref 26]* (see Figure 4-3).

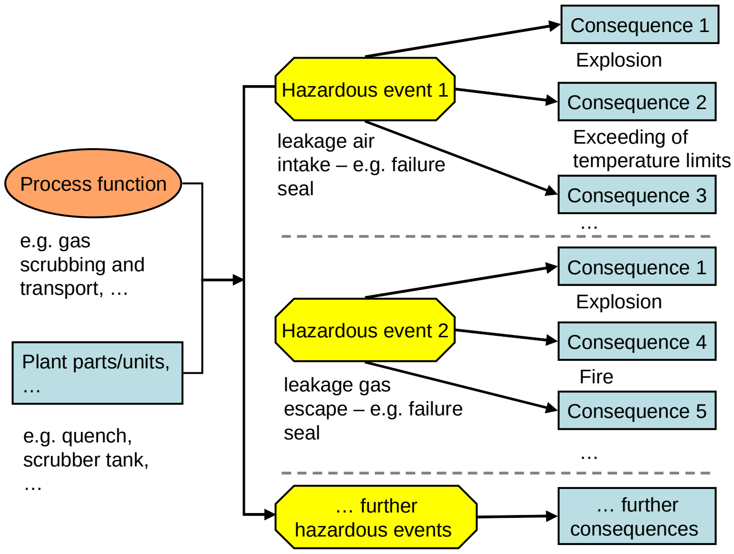

Figure 4-3 Structure of hazard identification

The identification of possible hazardous events and their consequences should be conducted by expert teams consisting of different disciplines. Realistic figures for the estimation of frequency and the severity should be used.

4.4 Risk assessment

The next step of the procedure consists of evaluating the risk associated to the identified hazardous events. Risk is interpreted as the combination of consequence (severity) and likelihood (frequency). A risk matrix enables this combination to be represented graphically (see Figure 4-4) *[Ref 21, Ref 27, Ref 28]*. It is an easy method to visualise the spread of risk, to screen hazards, or to conduct a simple risk analysis. The main advantage of the matrix is its easy representation of different risk levels, and the avoidance of more time-consuming quantitative analysis where this is not justified.

For the implementation of the risk matrix, the occurrence probability and the severity determined in the previous step can be classified in several categories. Table 4-1 and Table 4-2 propose a structure that can be used. The risk assessment team can choose a different classification, e.g. by having more categories. However, the chosen classification should not overcomplicate the risk matrix *[Ref 28]*.

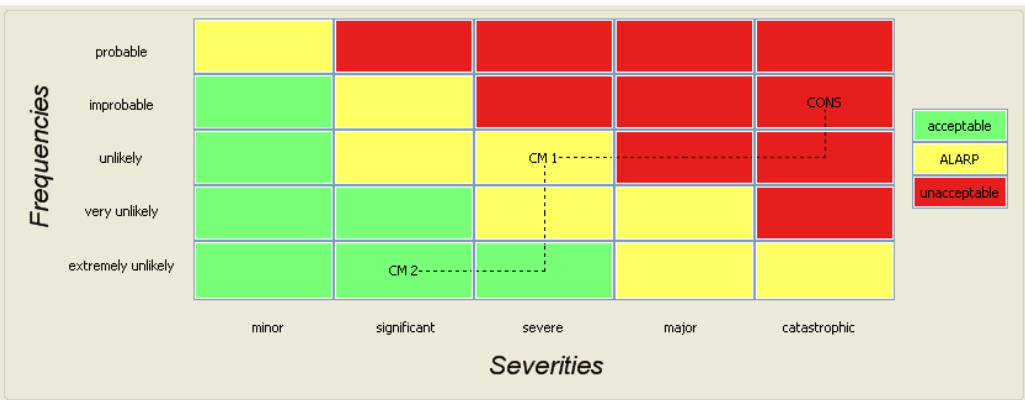

Figure 4-4 Risk matrix for the characterisation and visualisation existing and/or remaining risk potentials

Table 4-1 Example for risk characterisation – Probabilities

Notation	Frequency range
Extremely unlikely	**<10^{-6} per year**
Very unlikely	**10^{-6} to 10^{-4} per year**
Unlikely	**10^{-4} to 10^{-2} per year**
Improbable	**10^{-2} to 1 per year**
Probable	**> 1 per year**

Table 4-2 Example for risk characterisation – Severities

CONSEQUENCES					
Category	**minor**	**significant**	**servere**	**major**	**catastrophic**
Human beings	light injury	injury	severe injury	disablement, death	death
Environment	olfactory pollution, elevated emissions (short time)	long lasting olfactory pollution, slightly increased emissions	emission of toxic substances of little amounts	emission of toxic substances of amounts	emission of toxic substances of huge amounts
Property/goods	no plant shut down, online reparation possible, little costs	plant stop, warm start possible, standstill of the plant < 2 days	plant damage, cold start necessary, standstill of the plant 1 to 3 weeks	critical plant damage concerning the whole plant or plant sections, standstill of plant > 8 weeks	enormous plant destruction/damag e concerning the whole plant

The risk matrix is subdivided into three areas *[Ref 27]*:

- *Acceptable region*

  Risks falling into this region are generally regarded as insignificant and adequately controlled. The levels of risk characterising this region are comparable to those that people regard as insignificant or trivial in their daily lives. These risks are typically from activities that are inherently not very hazardous or from hazardous activities that can be, and are, readily controlled to produce very low risks. Further action to reduce risks is often not required.

- *As Low As Reasonably Practicable (ALARP) region*

  Risks in this region are typically activities that people are prepared to tolerate in order to secure benefits, provided that the nature and level of the risks are properly assessed and the results used properly to determine *control measures*. If the hazardous events fall into the ALARP region, this does not mean that the total risk for the installation is ALARP, but that it should be considered whether further risk reductions are needed.

  For the remaining risk in the ALARP region, further safety measures might not be economically justifiable and reasonable. In all cases, the risk assessment team must discuss the following points:

  - Is the remaining risk acceptable?
  - Can additional countermeasures be taken to reduce the risk level?

  The risk falling in this region should be reviewed on a regular basis to make sure that they still meet the ALARP condition.

- *Unacceptable region*

  The risks in this region are unacceptable and **must** be reduced to an ALARP region by the application of countermeasures.

4.5 Risk reduction measures

An unacceptable risk requires the implementation of risk reduction measures to move it to the ALARP region of the risk matrix. Practically, this consists of decreasing the frequency and/or the severity of a hazardous event or concern.

The bow-tie diagram shown in Figure 4-5 can be used for this purpose. The column 'Top event' in the bow-tie diagram marks the failure of the currently investigated function. This technique is flexible, and any event can be used as a top event. The columns on the left and on the right of the top event contain initiators and consequences of the 'top event'. The bow-tie diagram can help in determining what can be done to reduce the risk to an acceptable level. Indeed, on the diagram, safety barriers are represented (Figure 4-5):

- The safety barriers between the 'Hazardous Events' column and the 'Top Event' correspond to *prevention measures* that act towards the reduction of likelihood/frequency of the top event.
- The safety barriers between the 'Top Event' and the 'Consequences' columns correspond to the *mitigation measures* that act to reduce the severity of consequences and/or the likelihood of those consequences.

Different types of countermeasures can be applied:

- *Technical countermeasures:* These consist of the implementation of technical modifications such as change in the process design, addition or replacement of some process parts, etc.
- *Process control countermeasures:* These refer to any changes of the control system routine. This may be the addition of new control devices on the process chain (e.g. temperature sensors, pressure gauges, CO sensors, etc) with the suitable alarm system. The implementation of these new control devices must include setup of the adequate emergency management system.
- *Organisational countermeasures:* These refer to various activities relative to the organisation of the work.

All these countermeasures have to be recorded in the O&M manual.

Therefore, the risk assessment procedure should not be taken as a straightforward process [22]. Indeed, the implementation of countermeasures may change the original process. Additional hazardous events may appear. A re-evaluation of risks for the modified process may be necessary.

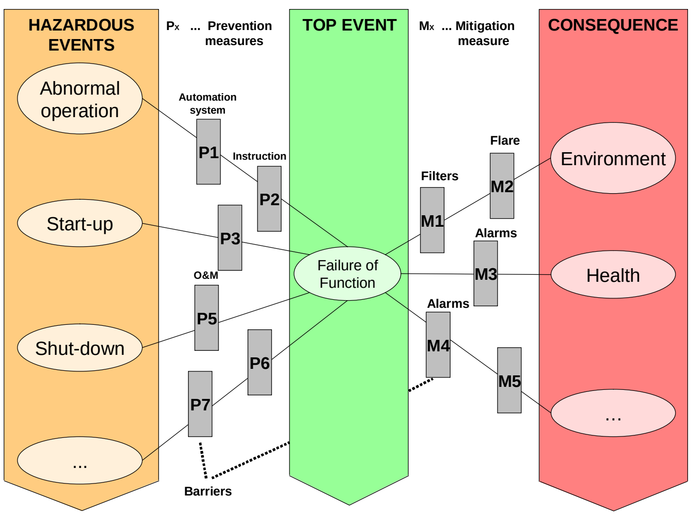

Figure 4-5 Bow-tie diagram for risk assessment

4.6 Documenting the outputs of the risk assessment

The documentation of the risk assessment and risk reduction is 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 may be carried out with the assistance of computer software, which helps considerably with structuring the documentation and with placing cross-references to recurring events and consequences.

4.7 Software Tool for Risk Assessment

A software tool (called RISK ANALYSER) was developed to facilitate the implementation of the risk assessment proposed in this Guideline. HSE issues of small-scale biomass gasification plants can be treated in a very structured way when the assessment is supported by the software tool.

The target groups of the software tool are, in the first place, manufacturers, project developers, operators, researchers, and implementers of biomass gasification plants. The software can also be used for types of processes other than biomass gasification.

In the software, a recommended risk assessment procedure is implemented, which is practicable and sufficient for the application in small-scale biomass gasification plants. The chosen method, which was presented before, is based on a HAZOP study and is enlarged by additional features specific to biomass gasification plants.

The risk assessment procedure with the software follows the following steps:

1. *Definition of plant basic data*

   The basic information of the investigated plant is given (project name, plant manufacturer, operator, power output of the plant, etc)

2. *Definition of process units*

   The plant is subdivided into process units corresponding generally to the process steps - e.g. gasifier, gas cooling, gas cleaning, gas conditioning and gas utilisation.

3. *Definition of functions*

   The unit functions have to be defined (e.g. fuel supply for section gasifier). They represent the basic data for the risk assessment.

4. *Definition of the operation modes*

   In this step, a short description of the foreseen operation modes for start-up, shut-down, normal operation and emergency shut-down is requested. This will help identify the hazards in different operation modes.

5. *Definition of parts*

   The functions are fulfilled by dedicated parts, which have to be defined. This requires input on:

   - Design parameters (pressure, temperature, flow rates, etc. in all operation conditions, as well as minimum and maximum values);
   - Information on plant media as well as plant utilities (safety characteristics, operation temperature and pressure of the treated media, etc);
   - Information textbox, if necessary (optional).

   This comprehensive documentation of the information should give all the necessary basics for the rest of the risk assessment.

6. *Risk assessment*

   The programme supports the risk assessment with a preset of possible events and consequences. The software tool rates the risk potential according to the proposed risk matrix.

Important note: within this first risk assessment, the original plant and operation concept is investigated. Countermeasures for risk reduction are added in the next step.

7. *Countermeasures*

Setting of countermeasures is supported by the tool, giving the possibility of a re-assessment of revised process configurations. The description of countermeasures allows categorising in technical, process control and organisational countermeasures. An editing of the operation procedure is feasible. Automated system control measures can be documented for each operation mode.

8. *Summary*

The summary is the final step. It gives an overview of the original plant concept (before applying countermeasures), its functions and parts. The outcomes of the risk assessment are documented for each investigated process function, including the improvement resulting from the countermeasures.

At the end of the risk assessment of the whole process, a report can be generated. This can be used as a documentation of the risk analysis.

5 Potential hazards and good design principles

5.1 Introduction

This chapter briefly describes the potential dangers associated with the design, operation and maintenance of biomass gasification plants (BGPs). It is an essential prerequisite for the complete risk assessment process to first analyse the hazards and then go on to assess the risks that they present and determine what, if any, ameliorating measures should be taken.

It is good practice to apply a number of good engineering principles that apply to design as a hierarchy, by aiming to eliminate a hazard in preference to controlling the hazard, and controlling the hazard in preference to providing personal protective equipment.

A holistic approach is important in order to ensure that risk-reduction measures that are adopted to address one hazard do not disproportionately increase risks due to other hazards, or compromise the associated risk control measures. Where appropriate, consideration should also be given to the balance of risk between workers and the public, and to the increased risk due to action taken during normal operation which is intended to reduce risks during an emergency condition.

In the “Guidance on ‘as low as reasonably practicable’ (ALARP) decisions in control of major accident hazards (COMAH)”, the following three important principles are defined *[ref. 27]*:

Principle 1

"HSE starts with the expectation that suitable controls must be in place to address all significant hazards and that those controls, as a minimum, must implement authoritative good practice irrespective of situation based risk estimates".

Principle 2

"The zone between the unacceptable and broadly acceptable regions is the tolerable region. Risks in that region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits in the expectation that:

- the nature and level of the risks are properly assessed and the results used properly to determine control measures;
- the residual risks are not unduly high and kept as low as reasonably practicable (the ALARP principle); and
- the risks are periodically reviewed to ensure that they still meet the ALARP criteria, for example, by ascertaining whether further or new controls need to be introduced to take into account changes over time, such as new knowledge about the risk or the availability of new techniques for reducing or eliminating risks."

Principle 3

"both the level of individual risks and the societal concerns engendered by the activity or process must be taken into account when deciding whether a risk is acceptable, tolerable or broadly acceptable’ and ‘hazards that give rise to …. individual risks also give rise to societal concerns and the latter often play a far greater role in deciding whether risk is unacceptable or not".

5.2 Primary safety considerations

Occupational hazards relate to hazards or risks inherent in certain employment or workplaces. Occupational health and safety issues should be considered to be part of a comprehensive hazard or risk assessment, including, for example, a hazard identification study [HAZID], hazard and operability study [HAZOP], or other risk assessment studies. BGP's presents several occupational hazards of different nature: physical, chemical, biological, environmental, mechanical, psychosocial, etc. Most of them are not specific to BGPs, for instance: slips and trips, collisions, falls from height, struck by objects, workplace transport, electricity, noise, vibration, lighting, compressed air/high pressure fluids, confined space, cold stress, heat stress, crushing, cutting, friction and abrasion, vehicle movements, impact, moving parts, work related stress, etc.

The operator must be aware of these different aspects of occupational hazards, and also of the national regulations related to them, and take appropriates measures.

The Health and Safety Executive (UK) provide on its website (www.hse.gov.uk/) a list of possible hazards to be considered in a workplace. Some guidance on how to prevent and manage these hazards is also given.

The French institute competent in the area of occupational risk prevention (INRS) also gives some guidance on the different areas of occupational hazards on the following website (document in French):

www.inrs.fr/htm/frame_constr.html?frame=/INRS-PUB/inrs01.nsf/IntranetObject-accesParReference/ED%20840/$File/Visu.html.

Similar guidance in German language is available ("Ratgeber zur Ermittlung gefährdungsbezogener Arbeitsschutzmaßnahmen im Betrieb") on the website of the German Federal Institute for Occupational Safety and Health (BAuA):

http://www.baua.de/nn_12456/de/Publikationen/Sonderschriften/2000-/S42.html?__nnn=true

Each activity can have some inherent and specific occupational hazards. This chapter highlights the hazards specific to the gasification process, such as: fire, explosion/deflagration, toxic substances, etc.

The focus in this chapter will be to identify precautionary measures to be taken for health and safety. These measures are based on available expertise within the consortium, external advisors, using generally available information and information gained from case studies. As mentioned in Chapter 1 (Introduction), some target groups may have conflicting interest such as end-user versus the permitting authority, or manufacturer versus plant owner. Therefore, it is necessary to have as complete as possible insight into all HSE concerns and best practices accepted by the international community.

5.3 Good engineering and operation practice

Good design engineering and construction based on a decent risk assessment and/or HAZID/HAZOP study are compulsory to put a biomass gasifier plant on the market. Most risk assessments provide a general overview and are not intended to be comprehensive in every aspect. They can create liability issues and give a false sense of security. The following paragraphs provide a general overview of good engineering practices, and are not compulsory to each gasifier design, e.g. the safety issues are different whether the gasifier operates at overpressure or underpressure, etc.

5.3.1 Good design practice related to plant building construction

When designing the gasification plant buildings, a number of health, safety and environmental measures should be considered:

- The fuel storage facility must be separated from the gasification building or divided using a high performance fire curtain.
- For safety reasons, the control and staff rooms must be separated from the remainder of the plant due to fire, explosion and toxic gas release hazards.
- The control rooms should have positive pressure ventilation (special attention must obviously be paid on where the inlet air is taken from).
- The gasification building must be well ventilated and the flows monitored or verified across critical operational areas.
- There should be two escape routes from each point within the gasifier building to the outside.
- The ATEX directive requires that all areas classified as hazardous shall be identified with a warning sign. The sign must be triangular, black on yellow with the text EX to be displayed at points of entry into explosive atmospheres. It is recommended that a study to identify the areas appropriate to be controlled to this standard be undertaken.
- Equipment exceeding a certain noise level, like compressor or engine, should be placed in acoustically insulated cabins.

5.3.2 Good engineering practice related to process equipment

Good engineering practice related to process equipment is the responsibility of the manufacturer. If the plant is designed properly according to the Machinery Directive, the basic hazards should be eliminated.

Choice of material

- Reactor vessels, valves and piping materials should be constructed from good quality materials;
- Heat resistant stainless steel or other appropriate material shall be chosen for the gasifier and gas cooling device;
- Chemical resistant stainless steel is recommended for gas scrubbing and washing media circulation.

Gas tightness

Gas tightness is important to avoid gas escape and air intake, which may lead to the formation of explosive mixtures and/or the release of toxic gas. The following engineering practices are suitable to ensure gas tightness:

- The use of welded connections is preferred above flanges, in particular for hot pipes above 500°C. In all cases, proper flange sealing like chemical and thermal resistant material need to be used;
- All pipes, aggregates, measurements devices have to be of proper materials;
- Proper material should be used with regard to chemical resistance, temperature and pressures, corrosion, particle size.

Valves

- All air inlets and gas outlets to/from gasifier, including fuel feeding section, flare and engine should be equipped with block devices or anti-backfiring valves in series (after the other in the same line);
- When valves are in contact with pyrolysis or gasification gas they may get stuck;
- Valves used to ensure a safe mode in case of failure and emergency stop must be of the fail safe type;
- Valves at air pipes, filters and cyclones should have position micro switches;
- Faulty settings of manual valves should not be possible. Malfunction of critical valves should be detected.

Electrical devices

- It is recommended to electrically ground all gas conducting parts.
- PLC should be properly grounded in order to avoid malfunction and accidents.
- Galvanic separation of electrical supply of measurement devices is strongly recommended.
- It is recommended to supply PLCs with uninterrupted power supply units (UPS).
- Duplicate plant key operation measurement points (critical temperatures, pressures, etc.) are recommended for monitoring using a secondary measurement system during emergency case or in case of failure of the main PLC system.
- Gas/air inlet into engines should be earth grounded, and shielded cables should be used to avoid electrical breakdowns that could cause backfiring in the inlet system.
- In equipment where there may be a gas-air mixture, instrumentation and electrical equipment should be for Zone 1, otherwise the equipment should be secured; in the gasifier itself equipment should be for Zone 2. A study to determine the relevant zone rating for each area is highly recommended as many plant have been designed for open areas and the Zone classification is highly dependent upon building ventilation.
- There should be safety switches and local circuit breakers on:
    - rotating parts and switches;
    - access panels;
    - pressure relieve equipment;
    - critical valves with access to gas containing equipment such as feeders, cyclones and ash outlet.
- The use of area E-Stops should be considered.

Control and safety devices

- CO detectors, giving indication and alarm at about 25/50 ppm CO, must be installed in rooms with equipment containing pyrolysis or gasification gas.
- Pressure and temperature sensors included in the safety concept should be duplicated or tripled. The failure probability regarding the influence of operation/installation must have been estimated.
- Heat exchangers between gas and air form a possible hazard source in case of leaks between the media due to e.g. thermal cracks or corrosion. Similarly for expansion joints in long welded pipes. Hazards from this possible malfunctioning should be avoided by well designed equipment and by temperature and oxygen sensors downstream to be able to detect leakages.
- It should not be possible to tamper safety related devices.
- All alarm values should be specified in the manual before start-up of the plant.

- Temperature sensors should be installed before and after the main plant reactor system components. Preferred and allowable operating temperatures shall be available for the operators in plant manuals and secured with proper alarm levels.

The movable or rotating parts
- The plant movable parts, such as conveyor belts, motors, engines could generate a risk of gas explosions. They should be shielded and equipped with 'visible' signs and emergency stop.
- At standby, gas blowers and other rotating equipment in the product gas line should be maintained, otherwise it may corrode or seize through the condensation of tar, which will lead to break down.

Hot surfaces
- The plant can have several hot surfaces. These could generate a risk of gas or dust explosion and also present a risk of accidental contact with operators. The plant equipments that can pose an occupational risk due to high temperatures should be adequately identified and protected (shielded) to reduce risks.
- Training should be provided to educate operators regarding the hazards related to hot surfaces and the use of personal protective equipment (e.g. gloves, insulated clothing, etc).

Gas flaring system
- The flare or a similar device for burning the gas is used when the gas quality is poor and can not be used in the gas engine, or in case of engine failure.
- In case where valves in contact with pyrolysis or gasification gas get stuck, the gas should automatically be flared.
- Gasifiers will have to vent gases as they purge pipe-work from the gasifiers to the engine. At start-up, the gas will always pass through and LEL and UEL.
- The flare should be equipped with:
    - an automatic ignition system;
    - flame monitoring with alarm;
    - water seal.

A HAZOP study is recommended to understand the issues relative to the gas flaring system and then identify the suitable counter-measures, for instance inert gas purging.

Safety equipment
The following safety equipment or tools should be present in each separate part and/or building of the gasifier plant:
- Fire detection and suppression equipment that meets internationally recognized technical specifications for the type and amount of flammable and combustible materials stored at the facility;
- CO detection system;
- Fire fighting equipment;
- Personal protective equipment: ear protectors, eye glasses, gloves, respiratory equipment, personal CO detectors;
- Emergency equipment: shower, first aid kit.

5.3.3 Recommendations regarding operating and monitoring procedures

Important operating and monitoring procedures to be considered include the start-up procedure (cold and hot start-up), normal operation, normal shutdown procedure and emergency shutdown. These should be considered within the HAZOP study and described in the O&M manual.
It is recommended to develop and implement start-up, normal operation and shutdown routines for the entire gasification plant (preheating, gasifier ignition, normal operation, etc.) to avoid human error in manual operation. Fail-Safe routines have to be part of the plant operation concept.

Normal start-up and shutdown procedures
- At start-up it is recommended to remove the oxygen inside the plant by inertizing the system with for instance nitrogen.
- Experience shows that most accidents take place at start-up and shutdown. Therefore, operators should be instructed not to stay unnecessarily close to system components (gasifier, cyclone bins, filters, etc.) containing flammable materials during start-up and shutdown.
- At start-up and emergency shutdown or in the case where valves get stuck, the gas must be flared.
- If the gas engine were to be shutdown for whatever reason, any residual gas should be immediately flared by switching valves by the automation and control system. If the engine can not be re-started (after two attempts), the emergency stop procedure should be initiated.

Normal operation procedure
- Procedures for manual intervention during operation of the plant should be documented properly in the O&M manual.

Emergency shut down procedure
- The development of the plant operational manual and appropriate scada control must consider the implications identified within the Hazid and Hazop. Each emergency shutdown procedure is therefore highly specific and customized to the individual application.
- Typical emergency shutdown measures include:
    - stop feeding to the gasifier;
    - stop air supply to the gasifier;
    - direct the gas to the flare;
    - note: inerting the gasifier with nitrogen is not effective as the gasifier normally contains a lot of fuel and charcoal.
- Evacuation procedures must be in place.
- Proper training in evacuation and emergency procedures for operators and visitors at induction must be in place.

Maintenance procedure
- Schedules should be developed for start-up checks and regular inspection of sensor devices for accuracy. For instance, when pressure transmitters pipes are blocked by tar or dust, sensors may show wrong readings, etc. Procedures should be available for inspection even if the sensors are functioning properly.

- During plant maintenance, the operators should avoid contact and inhalation of either toxic or suffocating gases or toxic liquids. All plant maintenance procedures should be well documented while operators should routinely follow procedures.

5.3.4 Supplementary precautions

The adoption of the following supplementary precautions is recommended:
- Operators must be aware that condensation of tarry compounds and steam inside producer gas piping, reactor vessels and valves is likely to be a frequent occurrence. The plant design and maintenance procedure should deal with this issue. It is recommended that operators have a clear understanding of the effect of temperature and pressure on condensation of gaseous components.
- At the fuel gas-air mixer before the gas engine, there is a possibility of condensation when for instance the outside temperature is low, or the air is very humid. Condensate may cause hammering (= knocking) with damage to the gas engine. It is good practice to monitor the air temperature – and preheat the air, if necessary – and monitor the humidity of the gas entering the gas-air mixer. For modern engines with full electronic control, this is less relevant.
- Besides overpressure, plant components should also be able to withstand under-pressure for example the full design pressure of the main gas fans. Vacuum conditions may form during cooling after plant shutdown.

5.4 Safety related issues in practice

Several hazardous events may occur, having different consequences. A checklist is provided in Annex A. The most critical safety issues during the operation and/or maintenance of gasifier plants are related to:

- Asphyxiation/toxic issues like unplanned release of potentially hazardous gas and liquids;
- Explosion / deflagration hazards;
- Fire hazards;
- Operator failures.

For each safety issue, a description is given in the following paragraphs on:
- When and where to address these issues
- Potential impact of these issues, and
- Possible corrective measures to implement best practices.

5.4.1 Explosion / deflagration

When:
- Gas explosion at biomass gasification facilities can occur when a mixture of combustible gases (mostly CO, H_2 and higher hydrocarbons) and oxygen within the flammability limits meets an ignition source.
- A gasifier plant routinely pass through the Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL). The limiting oxygen concentration depends on the producer gas composition, the moisture, the temperature and the pressure. For hydrogen and carbon monoxide at room temperature and ambient pressure, the

limiting oxygen concentration is about 4%. In particular, a dangerous situation may occur during plant start-up, at shutdown and in an emergency case of uncontrolled air intake, for instance due to leakages.

- A combustible vapour cloud can be formed after the spillage of flammable liquids. This depends on the volatility of the liquid, the flash point, the vapour density. Attention should be given to the auxiliary media stored on site.
- Dust explosion from small biomass and char particles can occur at BGPs when a mixture of dust and air in a proper concentration meets an ignition source. The severity of the explosion depends on several parameters such as the size of the dust particles, the degree of confinement of the building, etc.
- Specific attention should be paid to hybrid mixtures, where there is a combination of a flammable gas and dust.
- Ignition sources can be sparks resulting from the build-up of static electricity, glowing particles (char, partially converted biomass), lightning electrical or mechanical sparks (from an electromotor of the blower for instance), hot work (welding, cutting, grinding and sawing), hot surfaces, self-ignition in dust layers and open flames.
- Product gas from gasification can auto-ignite at temperatures above ca. 600-650°C. If a small amount of air is added to gas at high temperature - or vice versa – a quiet combustion will take place at the air/gas interface. If gas and air can be mixed without immediate reaction and subsequently set on fire by an external source such as e.g. a spark or a glowing particle, gas explosion may take place, the reaction velocity and the peak pressure depending on the degrees of turbulence and confinement of the gas mixture.

Where:

- In plant sections where pressure build up exists (i.e. after a blower), there is a risk of gas escape to the atmosphere, which may lead to a toxic atmosphere, a fire or an explosion on the outside of the particular plant section. Similarly, at under-pressure there is a risk of air ingress and the explosion may occur inside a particular plant section.
- Backwards flowing producer gas is a potential hazard in case for instance valves are not properly functioning.
- Although the gasifier reactor is operated at under-stoïchiometric conditions, locally higher oxygen levels may occur, which can result in rapid temperature increase and explosive mixtures. However, at high temperatures the maximum explosion pressure decreases and classical low-speed deflagration or “Verpuffung” may occur.
- In the gas cleaning section, explosion can be more severe with large volume gas. In most cases, the ignition source would be burning pieces of charcoal/ashes, entrained with the raw gas.
- In the gas flare, back-firing can cause the flame to travel backwards into the gas cleaning section.
- In the gas feeding to the engine, in case of back-firing of the engine takes place.
- In the ash removal section, in case carbon rich ash is generated.
- During repairs (in particularly during welding, cutting, grinding and sawing) explosion can occur if there is still gas inside the system.
- In the fuel storage, feeding section and at places where excessive dust is present, explosions may occur when clouds of dust are formed, depending on the processed biomass and on fuel particle size.

- Attention should be given to auxiliary media such natural gas/propane gas storage and piping. As they are stored under pressure, a risk of leakage exists.

What happens:

- In most cases, there is a minor explosion called low-speed deflagration or in German “Verpuffung”, caused by “unstable” operation, where a local explosive mixture may be present for a short time.
- From theory and practice it is known that pressure in the system due to explosion depends on the producer gas composition and the developed temperature, where explosions/deflagration occur.
- The explosion pressure of (wood) dust/air mixtures is similar to that of flammable gas/air mixtures. Dust explosions could be severe mainly due to the large volume of explosive mixture that can be formed when extensive dust gets dispersed in air. The severity of explosions will depend on the degree of confinement, which – in case of BGPs – is the highest inside equipment, where gases are present (and not dust).
- A gas or dust explosion can cause significant damage to the building, the equipments and the personnel.
- A gas or dust explosion can initiate a fire.

Possible reduction measures:

The following measures are specific to gasification facilities:

- Gasification facilities should be designed, constructed, and operated according to international standards for the prevention and control of fire and explosion hazards, including provisions for safe distances between tanks in the facility and between the facility and adjacent buildings.
- Safety procedures must be implemented for operation and maintenance, including use of fail safe control valves and emergency shutdown and detection equipment.

According to ATEX, there are three principle ways to reduce the explosion risk:

- primary measures which consist in avoiding the occurrence of an explosive atmosphere,
- secondary measures which consist in avoiding the ignition source, and,
- tertiary measures which consist in mitigating the effects of explosions.

Furthermore, some general measures are to be considered.

- Primary measures: avoidance of explosive atmospheres.
    - At plant sections where over-pressure exists, gas leaks will lead to CO and H_2 escaping to the atmosphere. On the contrary at under-pressure, O_2 will enter into the plant section. Therefore, an oxygen sensor must be installed to monitor the O_2 level in the plant system, and CO monitors must be installed to measure the CO level around the plant. The maximum value of

O_2 at the sampling point must be defined with consideration of determined flammability limits and dispersion effects due to the geometry of the equipment. Reference is made to the normative standard BGR 104[7], where design practices are given in terms of flanges to be used, type of sealing, etc.
- o At start-up, explosive atmosphere can be avoided by operation in combustion mode or purging with nitrogen.
- o After shutdown and cooling, the whole system should be inertized with nitrogen. Purging with air is used as well, but this is not recommended because in that case the ignition source have to be eliminated which is a secondary protection measure.
- o The control of dust is an important consideration to avoid the formation of an explosive atmosphere:
  - ▪ Good housekeeping is the key to avoid dust explosions. This includes removing dust deposits and maintaining a clean working floor.
  - ▪ The facility should be well ventilated.
  - ▪ Flooding with inert gas can also be considered when relevant.

- ➢ Secondary measures: avoidance of ignition sources:
  - o Proper grounding will prevent static electricity build-up and lightning hazards (including formal procedures for the use and maintenance of grounding connections).
  - o The use of intrinsically safe electrical installations and non-sparking tools is recommended.
  - o The implementation of permit-to-work system and formal procedures for conducting any hot work (welding, cutting, grinding and sawing) during maintenance activities, including proper tank cleaning and venting, is highly recommended. Flammable material and explosive mixtures or atmospheres must be removed or prevented when performing such work.
  - o Backfiring from a flare can be prevented by using a water seal acting as a flame arrestor (Reference to EN 12874).
  - o Application of hazardous area zoning for electrical equipment in design is required. Ex-zoning will determine which type or category of equipment is allowed. When ex-zones have been defined, it will be necessary (in a second step) to assess all potential sources of ignition in these areas. Zoning of places where hazardous explosive atmospheres may occur has to be applied according to ATEX directive 1999/92/EC – the following plant

[7] BG-Regel 104 „Berufsgenossenschaftliche Regeln für die Sicherheit und Gesundheit bei der Arbeit - Explosionsschutz-Regeln“, Ausgabe Juli 2008, SMBG

sections are recommended to be considered for the occurrence of an Ex-Zone[8].

- Fuel storage and feeding with respect to dust explosions;
- Fuel intake;
- Ash and dust removal system;
- Waste water removal system;
- Flare and auxiliary firing systems (e.g. misfiring);
- Engine and exhaust gas system;
- Man/hand holes and sampling ports;
- Measurement and instrumentation points;
- Liquefied petroleum gas tanks or cylinders.

Ex-Zoning requires a risk based approach. A study to determine the relevant zone rating for each area is highly recommended as many plant have been designed for open areas and the Zone classification is highly dependent upon building ventilation.

- There are tertiary measures which may be appropriate for gasification plants:
  - to construct the whole system to withstand explosion pressure. For a single vessel (not interconnected) the explosion pressure has been assessed to be around 8 bars. When calculating the maximum explosion pressure, one must take into account any possible pressure pilling effects in interconnected vessels. The maximum explosion pressure in inter-connected vessels would indeed be higher than the value calculated for a single closed vessel;
  - to use of flame arresting devices preferably in the form of water seals;
  - to use explosion venting devices to relieve the explosion pressure[9]

- Other general measures:
  - Smoking in the facilities should be banned, and clear ‘no smoking’ signs in the facilities must be installed with staff instructions/training.
  - The whole system should be purged before ignition at start-up by either using excess air or inert gas at 6 times the system volume.

[8] Explosive mixtures at non-atmospheric conditions, e.g. at increased temperature, are outside the scope of Directive 1999/92/EC, and Ex-zoning may not be appropriate in this case. Conditions for the formation of such mixtures and appropriate safeguards need to be addressed separately.

[9] Devices like bursting discs are not preferred due to the small surfaces and they can be expensive. With such devices, ATEX requires decoupling of the particular plant section from the other parts by flame arrestors before and after the particular plant section. This makes the whole system quite complicated. In practice also spring-loaded doors are applied at the gasifier reactor, but they are not preferred since they may get blocked after a while due to sticking of tar and dust. Reference is made to the standards EN 14994 (Gas explosion venting protective systems - 2006) and EN 14797 (Explosion venting devices – 2005).

5.4.2 Fire

When and where:

- An explosion can initiate a fire.
- Self-ignition of moist and high piles biomass feedstock can lead to a fire. Spontaneous ignition of piles of biomass feedstock can result from the heat accumulation in a relatively large mass where combustion starts deep inside the pile. A small amount of biomass feedstock is not likely to lead to self-heating, but this can occur in huge piles and lead to a fire.
- In cases where the maximum allowable temperatures are exceeded.
- Sparks from hot work (welding, cutting, grinding and sawing) can initiate a fire.
- At the removal of hot ashes, a fire can be initiated.
- In the case where, the decelerating of the engine occur with the wrong ignition timing, a very rich mixture can form in the exhaust manifold. This mixture is hot enough to self-ignite, if the amount of air is enough to support the ignition. If the timing is too late a backfire through the carburetter may happen. If the timing is too early backfiring through the intake valve may occur, which could burn the intake valve. It is to be noted that with the use of modern engines using integrated control systems, this is less likely to happen.
- Failure of the anti-backfiring system (valve-, rotary valve system, double sluice) due to unexpected foreign material, failure in the fuel dosing routines and apparatus, etc may lead to a fire.
- The spillage of flammable liquid could lead to a fire, if an ignition source is present.

What happens:

- Physical injury to human being.
- Damage or destruction of the BGP and other buildings.
- May act as an ignition source for an explosion.
- Release of toxic fumes.

Possible reduction measures:

- Fuel should be stored in a closed container, fire isolated, or in a separate room or building.
- A fire-resistant separation (with a specified fire resistance time) between the fuel storage and the gasifier may be required according to local fire-protection regulations.
- The installation of anti back-firing system at reactor, flare and the air inlet to the engine may be required according to national regulations. A humidification system at the ash removal in order to prevent fire hazard from glowing particles or nitrogen inerting on ash removal screws.
- It is recommended to monitor the temperature in the fuel storage pile.
- Ample ventilations is recommended, preferably natural ventilation.
- Fire detection and suppression equipment that meet internationally recognized technical specifications for the type and amount of flammable and combustible materials stored at the facility should be used.
- Accommodation areas should be protected by distance or by fire walls.
- The ventilation air intakes should prevent smoke or gas from entering accommodation areas.

- A formal fire-response plan supported by the necessary resources and training, including training in the use fire suppression equipment and evacuation, must be prepared. Procedures may include coordination activities with local authorities or neighbouring facilities.
- Fire-extinguishing system like fire extinguishers and/or Sprinkler system should be used (Note: Regulations on the construction of the fire protection system must be coordinated with the pertinent fire-protection expert of the licensing public authority). Fixed systems may also include foam extinguishers and automatic or manually operated fire-protection systems.
- All fire systems should be located in a safe area of the facility, protected from the fire by distance or by fire walls. The detection equipment specified needs to be suitable for use in a dusty environment to prevent false alarms or accidental discharge.

5.4.3 Toxic liquid escape

When:

- In case of leakage in the gas cooling section.
- In case of leakage in storage or holding tanks containing toxic liquids.
- During the maintenance of gas cooling section.

Where:

- Condensed water and tar vapours can be toxic. This could be particularly relevant at wet scrubbing systems.
- Scrubbing liquor and other media used for dissolution or lubrication of tar covered moving parts (including some industrial degreasers) can be toxic and caustic.

What happens:

- Contact with the toxic/caustic liquid can lead to physical injury, suffocation, irritation to eyes or irritation after inhalation.
- The liquid may evaporate with subsequent risk of inhalation of the associated toxic vapours like PAH, (some PAH are carcinogenic).
- Toxic liquid escapes can lead to environmental hazards and pollution.
- If the liquid is also flammable, a risk of formation of a combustible vapour cloud can exist.

Possible reduction measure:

- Wear safety (chemical resistant) hand gloves, glasses and safety shoes.
- Wear suitable respiratory equipment to prevent the inhalation of the toxic vapours.
- Ample ventilation of the surrounding work area.
- Storage in bin/tank to be collected and treated by certified company, as prescribed in the permit document.
- Reduce inventory of toxic/caustic liquid onsite.
- Spill cleanup kits available.
- Use of non-sparking tools in the facilities.
- Regular inspections of the stock of toxic/caustic liquids.

5.4.4 Toxic gas escape (in particularly CO)

When:
- Toxic gas escapes can occur in case of leakages and an over-pressure in the system. In particular, when a plant is shut-down, the whole system is filled with toxic gas. It is important to understand that after a planned or emergency shut-down, the gasification reactions still continue for quite some time, which may result in an over-pressure in the system if the gas is not safely vented. This is in particular valid to fixed-bed gasifiers containing large volumes of fuel
- During plant maintenance.
- In case volatile toxic liquids escape.

Where:
- Water seals in case of over-pressure.
- Leakages where over-pressure can occur.
- Exhaust gas emission.

What happens:
- CO poisoning.
- There is also an explosion hazard with CO (see 5.4.1).
- Suffocation (CO, PAH,…).
- Toxicity, both short term and long term as some components of the syngas e.g. PAH are carcinogenic.
- Irritation to eyes, inhalation.

Possible reduction measures:
- Gas-tight construction, see also par. 5.5.
- Wear portable CO monitors during operation and maintenance and install fixed online CO detectors in fuel storage buildings, gasifier building and gas engine room, giving an indication and alarm at about 25/50 ppm.
- The control rooms should have positive pressure ventilation.
- Ample ventilation of gasification building.
- In case volatile toxic liquids escape, the reduction measures cited in 5.4.3 also apply.

5.4.5 Operators failures

Only skilled and qualified personnel are allowed to operate and maintain the plant. They should be trained by the technology supplier or on-the-job using the original O&M manual. However, there are several potential risks due to failures of operators, like:
- (Un)authorised re-programming of the alarm settings. These set-points must be reset again after the problem is solved.
- Safety-related changes to the process control system must be performed by trained personnel and properly documented. The operation manual must clearly indicate and address this type of actions (e.g. changing alarm setpoints, re-programming, etc.).
- Operational procedures should be in place, which indicates whether the plant should be operated by only one or two operators.

5.5 Norms and Standards

As for construction and operation of BGP's, different regulations and norms exist. Applicable directives are listed in Chapter 3. An up-to-date list of harmonized standards relating to European Directives can be found at:
http://ec.europa.eu/enterprise/newapproach/standardization/harmstds/reflist.html.
Regulations for operation can typically be found in national legislation, technical rules etc. These are not defined in norms or standards (like EN or ISO standards).

Gasification plants must be approved for the design, construction and safe operation by the local fire department and permitting authority, and sometimes supplemented by third-party inspectors, expert opinions and/or environmental authorities. The exact types of approval vary between EU countries (Chapter 3), and will depend on plant parameters like thermal capacity, gasifier feedstock, plant location and the like.

5.5.1 A norm for gas tightness

A couple of standards is used in the chemical industry for a safe handling of hazardous substances (toxic and flammable) in pipes and vessels. Norms for gas tightness relate to "good practices" regarding the methods for avoiding leakages, methods of detection, etc.
Technical measures regarding the use of piping standards and the design and maintenance of piping systems can be found on the Health and Safety Executive website. These are good practices for COMAH (Seveso II) sites:
http://www.hse.gov.uk/comah/sragtech/techmeaspipework.htm

Even if the Seveso II regulation is not relevant to BGPs, these recommendations in terms of gas tightness could be considered as applicable to BGPs (such as the values of frequencies and severity for the risk assessment part). The standards showed in Table 5.1 might be relevant.

In German regulations, a few definitions and remarks on "technically leakproof" units are available:

- in the non-binding Guide on directive 1999/92/EC, cf. the glossary of that Guide and chapter 3.2.1/remarks on zone 2
- in the
  - German Technical Rules on Industrial Safety: TRBS 2152 part 2, chapter 2.4.3,
  - German Technical Rules on Hazardous Substances: TRGS 722, and in
  - technical rules of the German "Berufsgenossenschaften" (employers' liability insurance associations / professional organisations): BGR 104 "Explosion Protection" (very similar definitions and descriptions appear in these documents).

German Technical Rules make a difference between units that are "technically leakproof" ("= technisch dicht") and "permanently technically leakproof" (= "auf Dauer technisch dicht"). In the latter case, no hazardous release of flammable material is anticipated, and there is no need to classify a hazardous area around such equipment. TRBS 2152-2 etc. give some examples of the types of connections which

are deemed "permanently technically leakproof", e.g. certain types of flanges used in pipe connections.
In some cases, technical measures combined with regular inspection and maintenance may also result in equipment being regarded as "permanently technically leakproof".

With equipment regarded only as "technically leakproof", releases are anticipated on rare occasions, and this will typically lead to a zone 2 classification around such equipment / such connections.

With a view to environmental protection, there are some requirements on permissible leak rates of flange connections and gaskets in TA-Luft (chapter 5.2.6.3). These refer to gaseous emissions of certain (volatile or hazardous) organic liquids, however, and do not formally apply to producer gas.
Concerning technical requirements, TA-Luft refers to regulation VDI 2440 (for technically leakproof flange connections) and to EN 1591-2 for selection and design of flange connections.
These standards could also be useful for flange connections in pipes with hazardous gases.

5.5.2 Literature regarding zoning and explosion protection measures

The Health and Safety Executive website gives general information about:

- Fire and explosion:
www.hse.gov.uk/fireandexplosion/index.htm

- ATEX regulation (called DSEAR in United Kingdom)
www.hse.gov.uk/fireandexplosion/atex.htm

- Short guide to the ATEX regulation:
www.hse.gov.uk/pubns/indg370.pdf

- Zone classification:
www.hse.gov.uk/fireandexplosion/zoning.pdf

Some guidance is also given by different sources compiled in Table 5.2. These different sources contain information on explosion protection measures (for instance: EN 1127-1:2007).

Table 5.1: Standard for gas tightness that might be applicable

Source	Name	Description
American Society of Mechanical Engineers (ASME) http://www.asme.org/	B31.3-2002 Process Piping	Petroleum refineries; chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants; and related processing plants and terminals. Content and Coverage (a) This Code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping. (b) This Code applies to piping for all fluids, including: (1) raw, intermediate, and finished chemicals; (2) petroleum products; (3) gas, steam, air, and water; (4) fluidized solids; (5) refrigerants; and (6) cryogenic fluids. (c) See Fig. 300.1.1 for a diagram illustrating the application of B31.3 piping at equipment. The joint connecting piping to equipment is within the scope of B31.3. Packaged Equipment Piping. Also included within the scope of this Code is piping which interconnects pieces or stages within a packaged equipment assembly. Exclusions. This Code excludes the following: (a) piping systems designed for internal gage pressures at or above zero but less than 105 kPa (15 psi), provided the fluid handled is nonflammable, nontoxic, and not damaging to human tissue as defined in 300.2, and its design temperature is from -29°C (-20°F) through 186°C (366°F); (b) power boilers in accordance with BPV Code2 Section I and boiler external piping which is required to conform to B31.1; (c) tubes, tube headers, crossovers, and manifolds of fired heaters, which are internal to the heater enclosure; and (d) pressure vessels, heat exchangers, pumps, compressors, and other fluid handling or processing equipment, including internal piping and connections for external piping.
IGEM www.igem.org.uk	IGE/UP/1/New Edition 2 2003 Guide to non-domestic gas tightness testing and purging standards.	IGE/UP/1 (Edition 2) gives practical guidance to gas operatives when engaged in strength testing, tightness testing and purging gas pipework used in the non-domestic sector.
IGEM Energy Institute Publications http://www.igem.org.uk/Technical/energyinstitute.asp	IP Model Code of Safe Practice Part 13: Pressure piping systems examination	The purpose of this Code is to provide a guide to safe practices in the in-service examination and test of piping systems used in the petroleum and chemical industries. The Code gives general requirements regarding the provision and maintenance of adequate documentation, in-service examination, the control of modifications and repairs, examination frequency, protective devices and testing of piping systems. In many countries statutory requirements exist, both local and national, pertaining to the in-service examination of pressure vessels and, where this is so, this Code should be regarded as being complementary to such requirements.

British standards	BS 3636:1963 Methods for proving the gas tightness of vacuum or pressurized plant	Ten methods for application to evacuated plant, seven to pressurized plant. Five involve direct measurement of quantities but are insensitive or lengthy. Others use search gas and detectors sensitive to such gas. Four use vacuum gauges which may be able to serve another purpose on plant. Each method describes apparatus, special precautions, procedure, interpretation of results, working principles, sensitivity. Design of plant; contracts; blockage of capillary leaks; leak rates of different fluids; worked examples; safety precautions; bibliography; methods of leak location.
British standards	BS 4504-3.3:1989 Circular flanges for pipes, valves and fittings (PN designated). Specification for copper alloy and composite flanges	Types of flanges from PN 6 to PN 40 and in sizes up to DN 1800. Facings, dimensions tolerances, bolt sizes, marking and materials for bolting and flange materials with associated pressure/temperature ratings.
API	API 570 2nd Edition 1998 Piping Inspection Code	Covers inspection, repair, alteration, and rerating procedures for in-service metallic piping systems. Establishes requirements and guidelines that allow owner/users of piping systems to maintain the safety and mechanical integrity of systems after they have been placed into service. Intended for use by organizations that maintain or have access to an authorized inspection agency, repair organization, and technically qualified personnel. May be used, where practical, for any piping system. Piping inspectors are to be certified as stated in this inspection code.
API	API 510 - "Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration"	Addresses the maintenance inspection, repair, alteration and re-rating procedures for pressure vessels used in the petroleum and chemical process industries.
API	API RP 572 - "Inspection of Pressure Vessels"	Addresses the inspection of pressure vessels. It includes a description of the various types of pressure vessels and the standards that can be used for their construction and maintenance.
API	API RP 574 - "Inspection Practices for Piping System Components, June 1998"	Addresses the inspection practices for piping, tubing, valves (other than control valves), and fitting used in petroleum refineries and chemical plants.
API	API RP 575 - "Inspection of Atmospheric and Low-Pressure Storage Tanks"	- Addresses the inspection of atmospheric storage tanks that have been designed to operate at pressures from atmospheric through 0.5 psig and inspection of low-pressure storage tanks that have been designed to operate at pressure above 0.5 psig but less than 15 psig.
Health and Safety Executive	Web site	http://www.hse.gov.uk/chemicals/spctechgen33.htm#App2

Table 5.2: Guidance for ATEX

Source	Name	Description
Energy Institute (leading professional body for the energy industries) http://www.energyinst.org.uk/index.cfm?PageID=1005#whatis	Model Code of Safe Practice Part 15: Area Classification Code for Installations Handling Flammable Fluids	*Model code of safe practice Part 15: The Area classification code for installations handling flammable fluids* (EI 15, formerly referred to as IP 15) is a well-established, internationally accepted publication that provides methodologies for hazardous area classification around equipment storing or handling flammable fluids in the production, processing, distribution and retail sectors. It constitutes a sector-specific approach to achieving the hazardous area classification requirements for flammable fluids required in the UK by the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002 and in doing so, provides much more detail than BS EN 60079-10 *Electrical apparatus for explosive gas atmospheres: Classification of hazardous areas*. Note that the scope of EI 15 excludes hazardous area classification arising from dusts.
SHAPA (SHAPA has been the UK's leading specialist association for the solids handling and processing industry since its formation in 1981)	Practical Guidance for Suppliers and Operators of Solids Handling Equipment for Potentially Explosive Dusts Compliance with legislation implementing the ATEX Directives. http://www.shapa.co.uk/atex.php	The purpose is to provide practical guidance to manufacturers, suppliers and operators, when manufacturing, installing and operating equipment or systems that may require compliance with standards under the ATEX Directives, particularly in dusty atmospheres. A brief description of the two relevant ATEX Directives is included, together with their purpose and scope. Pdf document**:** http://www.shapa.co.uk/pdf/atex.pdf
Bundesministerium für Arbeit und Soziales (German Federal Ministry of Labour and Social Affairs)	TRBS 2152 "Gefährliche explosionsfähige Atmosphäre" (Technical Rules on hazardous explosive atmosphere)	TRBS 2152 (TRBS = Technische Regeln für Betriebssicherheit, Technical Rules on Workplace Safety) describe rules for protection against hazards from explosive atmospheres in the workplace. If these rules are followed, compliance with the German Regulations on Workplace Safety and Regulations on Hazardous Substances is assumed. TRBS 2152 is referred to in BGR 104, which gives a comprehensive description of the formation and prevention of hazardous explosive atmospheres, on potential sources of ignition and their prevention, and on constructive measures to mitigate the effects of explosions. BGR 104 contains a detailed list of practical examples of ex-zones and safeguards, taking various factors (e.g. ventilation, source strength) into account.
DGUV (Deutsche Gesetzliche Unfallversicherung), (former HVBG)	BGR 104: Explosionsschutz-Regeln (EX-RL) – Regeln für das Vermeiden der Gefahren durch explosionsfähige Atmosphäre mit Beispielsammlung (explosion protection rules with practical examples)	
European commission	Guidance on ATEX Directive 94/9/EC	http://ec.europa.eu/enterprise/atex/guide/index.htm Harmonized guideline: http://ec.europa.eu/enterprise/atex/guide/atexguidelines_august2008.pdf

		Considerations PAPERS by the ATEX Standing Committee on How to apply the Directive: http://ec.europa.eu/enterprise/atex/standcomm.htm
European commission	Guidance on ATEX Directive 1999/92/EC	COMMUNICATION FROM THE COMMISSION concerning the non-binding guide of good practice for implementing Directive 1999/92/EC of the European Parliament and of the Council on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres: **http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2003:0515:FIN:EN:PDF** [available in other languages, too; search http://eur-lex.europa.eu for COM(2003) 0515 document]
European standard	EN 1127-1 Explosive atmospheres - Explosion prevention and protection - Basic concepts and methodology	Explosive atmospheres, Fire risks, Explosions, Hazards, Classification systems, Ignition, Surfaces, Flames, Electric sparks, Gases, Particulate materials, Electrostatics, Electric current, Lightning, Electromagnetic radiation, High frequencies, Ignitability, Ionizing radiation, Ultrasonics, Chemical hazards, Design, Ventilation, Protected electrical equipment, Hazardous areas classification (for electrical equipment), Dust, Fire safety, Flame traps, Safety measures, Instructions for use, Marking, Hand tools, Control equipment, Electrical safety, Risk assessment
European standard	EN 60079-10 Electrical apparatus for explosive gas atmospheres Part 10: Classification of hazardous areas	The standards EN 60079-10 and EN 61241-10 explain the basic principles of area classification for gases and vapours and for dusts, respectively. These standards form a suitable basis for assessing the extent and type of zones, and can be used as a guide to complying with the national requirements towards explosion protection. However, they cannot give the extent and type of zone in any particular case, as site-specific factors should always be taken into account
European standard	EN 61241-10 Electrical apparatus for use in the presence of combustible dust - Classification of areas where combustible dusts are or may be present	

For the purpose of the Gasification Guide, the names of the European (EN) standards have been quoted, but the various national translations have been omitted, as the list would have become lengthy otherwise.

5.6 Documentation

5.6.1 Operation and Maintenance manual

- Technical process description of the main plant sections (as in chapter 2), including the process flow diagram (PID)
- Description of the automation and control strategy and process
- Main technical specifications
- Contact details of manufacturer
- Procedures for operation and maintenance
  - Start-up
  - Normal operation, including display and set-point overview
  - Unmanned operation
  - Shutdown
  - Emergency procedures
  - Check lists (inspection and maintenance tables: what to do, where and when)
  - Troubleshooting
  - Maintenance
- HSE instructions
  - Skills of operators
  - Description of hazards
  - During normal operation
  - During inspection and maintenance
  - During repairs or modifications

Most of this documentation has to be supplied by the manufacturer. For some documents – like the permit – the manufacturer has to supply information upon request. The operator and plant owner are responsible for keeping the information updated in case of modifications to the plant or changes in O&M procedures like adjustments of set-points, etc.

5.6.2 Other documentation

- Emergency procedures
  - Check lists (what to do, where and when)
  - Description of escape routes
  - Contact addresses in case of accident
- Accident register
- Spare parts lists
- Log book (if electronic it must have a safe back-up system)
- Training manual
- Detailed plant description (Design book)
  - Process description
  - PID of each main process step (unit operation)
  - List of components (I/O listing)
  - HAZOP analyses
  - Risk assessment analyses report

    - Arrangement drawings
- ➢ Component documentation and drawings
- ➢ Permits (building, environment, CE marking, etc.)

Table 5-3 shows which parts of the documentation have to be provided by the manufacturer and which parts are to be drafted by the operator/owner.

Table 5-3: Target group responsible for documentation

Document	***Manufacturer***	***Operator***
Operation and Maintenance Manual	*X*	
Training Manual	*X*	
Updating the O&M Manual		*X*
Description and map of escape routes		*X*
Detailed plant description (Design Book)	*X*	
Accident register		*X*
Logbook		*X*

6 Emission abatement in biomass gasification plants

As described in chapter 3.6, the questions

- which emission abatement techniques from standard combustion applications can be successfully transferred to small biomass gasification plants and
- which emission values may thus be achieved,

still need to be answered, taking both environmental and economic considerations into account.

6.1 Emission abatement techniques

The description of emissions and emission abatement techniques in this chapter refers to the basic units of a biomass gasification plant which have been described in chapter 2.

Basic potential release routes for gasification plants can be identified as follows:

SOURCE RELEASES To: Air Water Land A W L	Substances									
	Particulate Matter	Oxides of Sulphur	Oxides of Nitrogen	Oxides of carbon	Organic compounds	Acids/alkalis/salts etc	Volatile organic	Hydrogen Sulphide	Ammonia	Metals and their salts
Fuel storage and handling	A				A W L		A			
Water treatment	W				W	W				W
Slag/Ash Handling	A									
Gas Handling & Treatment	A	A	A	A	A		A	A	A	
Salt Recovery	A				L W					
Wastewater Treatment	W			A	W	W			W	
Site drainage (incl Rainwater)	W				W					
Boiler Blowdown	W					W				W

Fig. 6.1: Potential release routes for gasification [30]

6.1.1 Fuel storage, pre-treatment, transport and feeding

A description of potential emissions and emission abatements techniques for the storage and handling of solid biofuels has recently been compiled by the Nordic Innovation Centre [31].

Solid biofuels dust may contain large amounts of microspores from actinomycetes (bacteria with a growth pattern similar to fungi) and moulds (fast-growing fungi), which find a favourable environment for growth in wet biomass, e.g. in chipped wood. These microspores are easily inhalable and can cause allergic reactions and alveolitis. The spores become airborne when the biomass is handled.

A way to avoid microbial growth and to reduce microspore emissions is to store only dry biomass (<20% moisture content), preventing the stored material from getting wet. In case of outdoor storage, it is important to utilize fuel or raw material piles according to age; the oldest first (FIFO-principle: First-in – First-out) [31]. Storage time of moist biomass should be reduced as much as possible.

If very large amounts of comminuted biomass are stored in enclosed spaces (like silos), the formation of appreciable levels of CO in the storage space is possible [31].

When dried biomass is mechanically treated or conveyed, dust will be released. Enclosed conveying systems can help to mitigate the release of dust. As described in chapter 5.4.1, good housekeeping (which includes the removal of dust deposits) will be a key to avoid self-ignition of dust layers on hot surfaces and to prevent dust explosions.

6.1.2 Gasification reactor

Operation of a gasification reactor at ambient pressure or at a slight underpressure will in general help to prevent gas emissions from the reactor. A reactor design that avoids both gas leaks and uncontrolled gas flow from or to the reactor is usually required for stable reactor operation and good producer gas quality.

Rotary gate valves, double sluice lock hoppers or similar systems are often used to prevent backfire and producer gas flow from the gasification reactor into the biomass feeding line, thus also avoiding producer gas emissions in case of disturbances in the gas cleaning and/or utilising system.

During reactor start-up and shutdown, the quality of the producer gas may not be adequate for gas engine utilisation. For these situations as well as for periods when the gas engine is temporarily unavailable, a flare or a similar device can be used to incinerate the producer gas (cf. chapter 5.3.2) in order to avoid atmospheric venting.

Ash removal from the reactor can be a source of dust emissions. If carbon-rich ash is produced, additional measures will be required to prevent self-ignition of the ash upon contact with air. Wet ash removal systems may be useful for both targets.

6.1.3 Gas cooling and gas cleaning

Unless the gasification reactor produces a very clean gas, tar and dust removal from raw producer gas will normally be required to permit reliable and disturbance-free operation of the gas engine. As described in chapters 2.5 and 2.6, raw gas cleaning can be accomplished with a combination of cyclones and (dry) filters or (wet) scrubbers, occasionally supplemented with electrostatic precipitators. This will minimise large-molecule tar components (e.g. polycyclic aromatic hydrocarbons, PAHs) in the fuel gas to the gas engine, but may not be effective for organic components with a high vapour pressure (e.g. benzene).

If significant amounts of ammonia are present in the raw producer gas, removal e.g. by water scrubbing will be required to prevent formation of high concentrations of fuel-NOx in the gas engine.

If liquid residues are produced in the gas cleaning section which contain appreciable amounts of hydrocarbons, these may be fed to the gasification reactor or to other thermal units of the plant for thermal conversion. If the liquids are mostly water, they may be treated in activated carbon filters before being discharged to the sewer system. Otherwise, it may be necessary to dispose of such liquids as waste for off-site controlled treatment.

6.1.4 Gas engine operation and exhaust gas cleaning

The most important emissions from the gas engine are noise and exhaust gas. Noise emissions from the engines are limited by installing the gas engines in separate rooms with sound-absorbing walls and by using silencers for combustion air supply and on the exhaust gas lines.

Exhaust gas emissions have been described in chapters 2.7 and 2.8. Treatment of the exhaust gas with various techniques involving catalytic converters and post-combustion is basically possible for the reduction of single components in the exhaust gas (e.g. CO, NO_x, benzene, uncombusted hydrocarbons).
Long-term experience regarding the effectiveness and service life of catalytic converters in BGP application is not yet available at present. Catalyst service life is influenced substantially by catalyst poisons, e.g. heavy metal compounds, alkali compounds, etc., which in part can reduce the activity of the catalytic coating.

Due to the gas slip in internal combustion engines (cf. chapter 2.7), a fraction (about 1%) of the producer gas will pass through the gas engine uncombusted. In addition, combustion of nitrogen compounds in the producer gas (e.g. ammonia) will yield fuel-NO_x, which can be reduced by lean-gas operation, which means a relatively high oxygen level in the gas/air mixture, which lowers the exhaust gas temperature. However, at these conditions the CO emissions tend to increase.
Certain components in the producer gas may therefore require a combination of producer gas and exhaust gas cleaning techniques in order to achieve acceptable emission levels.

6.2 Emission limit values

In most European countries, national regulations that contain emission limit values for gas engines do not account in particular for engines fuelled with gas from thermal biomass gasification. Environmental permits for biomass gasification plants in these countries often draw on emission limit values that have been established in emission regulations for other types of fuels (e.g. biogas).

It is open to discussion whether emission limit values established for other gases in these regulations reflect the best currently available techniques for emission reduction in gas engines using producer gas from biomass gasification: some key process parameters of these activities are different, e.g. the CO content in the fuel gas, so emission limit values based on available and proven techniques for standard combustion activities (e.g. for CO-free fuel gas) may not be applicable to small BGPs. In addition, long-term efficiency of emission abatement techniques for small BGPs is still a matter of investigation. Therefore, it will be necessary to determine appropriate emission limits for small BGPs from continued experience with plants in operation and from measurements performed in these plants.

6.2.1 Emission limits in Denmark

In Denmark, specific emission limit values for gas engines fuelled with gas from thermal gasification of biomass waste have been established in 2005[5]. These emission limit values for NO_x, unburnt hydrocarbons (UHC), CO, and smell are cited below (reference state: dry exhaust gas at standard conditions, 5% O_2, except for smell – actual O_2 content):

NO_x:	550 mg/m^3
UHC:	1500 mg C/m^3 (valid for 30% electrical efficiency)
CO:	3000 mg/m^3
Smell:	20000 smell units/m^3

In combustion applications, the CO concentration in the flue gas is often used as an easy-to-measure indicator for combustion efficiency, with a special view to limiting the emission of high-concern substances like polycyclic aromatic hydrocarbons (PAH). In Denmark, measurements on the exhaust gas of gas engines in commercially operated biomass gasification plants had revealed [32] that PAH emissions of these installations are very low, irrespective of the CO content of the exhaust gas which is mainly caused by gas slip in the engine. Therefore, a relatively high CO emission limit value has been fixed in the Danish regulations for gas engines running on producer gas. (For *combustion* of producer gas, Danish emission limits are considerably lower.)
An emission limit for smell emissions has been introduced in Denmark because smell (basically from aldehydes) had been found to be an issue with exhaust gas from gas engines operating on natural gas [32].

6.2.2 Emission limits in Germany

In Germany, emission abatement requirements towards biomass gasification plants (BGPs) established in the authorisation procedure depend on whether construction and operation of the plant are *subject to a permission according to immission control legislation (environmental permission)* (which is the case for BGPs that can produce gas with an energy equivalent of 1 MW or more) or whether the plant *requires* a *construction licence* only.
According to German law, the operation of plants subject to environmental permission must neither cause harmful effects on the environment nor cause immissions that exceed limit values (as stipulated e.g. in the Air Quality Directive

[5] BEK 621 of 23/06/2005 (Order about limitation of emission of nitrogen oxides, uncombusted hydrocarbons, carbon monoxide etc. from engines and turbines)

2008/50/EC and in German administrative guideline on assessment of odour in ambient air). BGPs in combination with other sources of emissions (e. g. road traffic, wood combustion) must not cause a benzene concentration in ambient air in excess of 5 µg/m³ (annual mean) within the sphere of influence of the BGP. Equally, plant-specific odor must not be perceivable in more than 10 % of the hours per year (or 15 %, depending on the type of land use). Additionally, emission abatement measures are required which are based on best available techniques (BAT).

For the purpose of limiting gas engine exhaust gas emissions, German licensing authorities will generally stipulate emission limit values as listed below, partly derived from TA-Luft[6] requirements for gas engines that are fuelled with biogas:

- Carbon monoxide (CO): 650 mg/m³
- Nitrous oxide (NO_x), stated as NO_2: 500 mg/m³
- Formaldehyde (HCOH): 60 mg/m³
- Benzene: 1 mg/m³
- Dust: 20 mg/m³

Experience has shown that even a benzene concentration of less than 3 mg/m^3 in the purified exhaust gas will already require the use of rather large oxidising catalysts. Therefore, the value of 1 mg/m^3 for benzene is currently regarded as a target value by many authorities.

As distinguished from the above requirements, the operator of a plant *not subject to environmental permission* in Germany has to make sure that any harmful effects on the environment which are avoidable using the best available techniques (BAT) will be avoided, and unavoidable harmful effects will be kept to a minimum using emission abatement measures based on BAT. Whether or not harmful effects on the environment can be caused (e.g. by benzene or odor emissions) will essentially depend [33] on

- exhaust gas flow rate and emission concentrations in that gas,
- the height of exhaust gas release to atmosphere and whether removal takes place in undisturbed free air flow,
- the distance to neighbours,
- how often producer gas that cannot be used in the gas engine (e. g. during plant start-up and shut-down) is vented to atmosphere without being incinerated, and

[6] "Technische Anleitung zur Reinhaltung der Luft (TA-Luft)"; Technical Instructions on Air Quality Control, July 2002

- the quality of enclosure of equipment bearing strong-smelling substances (like raw producer gas, scrubbing liquids, tarry residues).

According to a recommendation given by a German Environmental Agency[7] [33], the licensing authority can generally assume without any further examination that a BGP will not cause harmful effects on the environment related to benzene emissions if these emissions do not exceed the minor mass flow of 5 g/h stipulated in section 4.6.1.1 of TA-Luft for diffuse emissions. This will be the case with plants that do not exceed 100 kW electrical power output (corresponding to an exhaust gas flow rate of less than 500 m^3/h at STP) if the benzene concentration in the purified exhaust gas is less than 10 mg/m^3, ensured e.g. by using an oxidising catalyst.

In general, this will depend on the fulfilment of additional conditions, e.g.

- a certificate issued by the manufacturer stating that
    - a benzene concentration of less than 10 mg/m³ will be safely achieved with the plant design (verified by measurements performed by an agency which is qualified for such measurements relating to the foreseen width of fuel),
    - producer gas not used in the engine will be safely incinerated, with a CO concentration in the flue gas of less than 2 g/m³ (verified by measurements which may be done by a chimney sweep in Germany), except for start-up and shut-down operation of less than 5 minutes once per week, and
    - no further development work will be necessary on the BGP which would require additional start-ups and shut-downs
- annual testing of proper catalyst function (CO reduction > 70 %), verified by measurement of the CO concentration upstream and downstream of the catalyst (which may be done by a chimney sweep in Germany).

[7] Recommendation by the Bavarian Environmental Agency (LfU Bayern)

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