BIOGAS

Safety first!

Guidelines for the safe use of biogas technology

BIOGAS Know-how_2

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Fachverband BIOGAS
German Biogas Association
www.biogas.org

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'Biogas is a key component of decentralised renewable energy supply, but it will only achieve long-term acceptance if biogas plants are operated in a professional manner. It is just as important to observe the state of the art in this field as in other forms of power generation. This means that everyone involved, manufacturers, distributors and operators, must comply with relevant regulations and requirements (in particular European directives such as the Machinery Directive 2006/42/EC and the ATEX Directive 2014/34/EU). They must properly assess any hazards that may exist in relation both to occupational health and safety and to protection of the environment, and then formulate and implement the necessary protection measures. This implies a certain technical challenge in order to understand the process engineering underlying the plant acquired from the manufacturer, but also an organisational challenge in the need to prepare the supporting documents.

In Germany, for example, the German Biogas Association (Fachverband Biogas e.V.) constantly collaborates with authorities and specialised bodies to deal with complex issues and find practical solutions. A huge range of working aids, fact sheets etc. have been produced, the principal content of which we are pleased to be able to present to you in this publication.

After all, as I said: only safe plants will ensure the acceptance
of biogas over the long term.'

– Josef Ziegler,
Spokesperson of the Safety Working Group
of the German Biogas Association

'In the area of renewable energy and energy efficiency, GIZ is currently implementing more than 170 projects in over 50 countries, of which more than 20 focus on biogas or have a biogas component. Thus, from a development policy perspective it is well known that biogas has a lot of advantages, like the reduction of greenhouse gas emissions, provision of reliable green energy and the creation of jobs.

In comparison to Germany, most of our partner countries do not have specific requirements concerning safety in biogas plants. Moreover, it is obvious that possible accidents in biogas plants are very harmful for sustainable biogas market development. The issue of safety is therefore an important part of our work and crucial to our partners in order to make sure that biogas projects become sustainable, efficient and safe.'

– Bernhard Zymla
Head of Energy and Transport
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Foreword

For the operation of biogas plants to be sustainable, efficient and reliable, safety is a matter of crucial importance.

Biogas is classified as a highly flammable mixture of gases that can be harmful to health when inhaled because of its toxic constituents. The process engineering systems used in biogas plants can be highly complex. Given such many and varied hazards, it is extremely important to have fundamental protective measures in place in order to keep the risks from biogas plants for people and the environment to an absolute minimum.

These Safety Guidelines for biogas plants provide a comprehensive description of the issue of safety in biogas plants and point to various forms of practical assistance, based to a large extent on the recommendations of the Technical Information 4 of the Social Insurance for Agriculture, Forestry and Horticulture (SVLFG). The Safety Guidelines therefore constitute an essential source of information for everyone involved in the planning, construction, operation, maintenance and testing of biogas plants. In addition, this publication – which came into being in cooperation with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH – is meant to provide a basis for policy-makers to develop possible national frameworks and safety standards.

The Guidelines focus on biogas plants in the medium and large size segments. Micro plants and domestic biogas plants are not discussed in detail in this publication. Apart from raising awareness of the issue of safety, the aim of this brochure is also to present proposals for internationally applicable safety requirements for biogas plants. Attention is primarily directed at occupational health and safety, in other words the protection of operators, employees and other individuals (third parties).

The Guidelines are basically divided into two main sections: general requirements, covering important topics such as the various dangers and hazards presented by a biogas plant, and specific requirements, such as those applying to parts and components of a biogas plant. Furthermore, requirements for biomethane production are also mentioned. In the final section, the German Biogas Association gives advice on the development of standards for biogas safety.

Biogas has many advantages – it is decentralised, climate-friendly and reliable – and is a safe form of energy, provided that certain rules are observed. Through this publication, the German Biogas Association and GIZ hope to play a part in helping the wide-ranging experience gained with this topic in Germany be put to use in advancing the issue of safety in biogas plants on international markets.

Biogas
can do it!

General requirements

1. Introduction

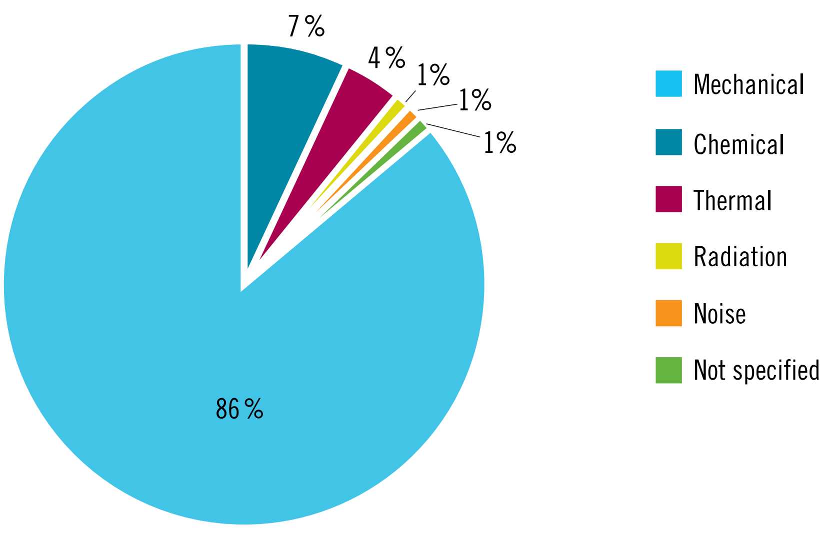
It is immensely important that biogas plants are operated safely, given the highly complex process engineering involved and the fact that highly flammable gases are produced and stored. However, if the appropriate protective measures are taken, hazards in and around biogas plants can be limited and reduced to the extent that the potential threats are manageable and the plant is operated in the intended manner. To ensure that a plant can be operated safely, it must be borne in mind that biogas safety starts right from the planning phase and continues through the whole operation of the plant, requiring close collaboration between manufacturers, planning consultants and operators.

But even if various technical, organisational and personal protective measures are in place, threats to people and nature may still occasionally arise from biogas plants. The Social Insurance for Agriculture, Forestry and Horticulture (SVLFG) is the organisation responsible for work insurance for farmers in Germany, among other services. In 2012 it analysed the personal injuries suffered by workers at biogas plants between 2009 and 2012. As shown in Figure 1, the most common accidents at biogas plants during this period were of a mechanical nature (being struck by something, falling, getting cut, crushed, etc.). Of the accidents analysed, almost 50 % happened during maintenance activities and less than 1 % resulted in persons being fatally injured.

The application of toxic, harmful and/or sensitising chemicals to the process – the processing aids, biological agents or compounds used to desulphurise the biogas – was also a cause of various accidents in biogas plants in Germany.

This illustration presents the situation in Germany at the time when the survey was conducted. Thanks to the high safety standards, accidents resulting in personal injury, for example those caused by explosion or fire, are relatively rare. In other countries these statistics may look completely different. It is clear, therefore, that compliance with specific provisions (legislation, sets of regulations, standards) can indeed have a substantial influence on safety in biogas plants and significantly improve it.

Figure 1: Types of hazard relating to accidents resulting in personal injury (SVLFG, 2012).



2. Terms and definitions

Ammonia (NH_3)	Nitrogenous gas arising from the degradation of nitrogen-containing compounds such as protein, urea and uric acid.
Anaerobic treatment	Biotechnological process taking place in the absence of air (atmospheric oxygen) with the aim of degrading organic matter to recover biogas.
Biogas	Gaseous product of anaerobic digestion, comprising primarily methane and carbon dioxide, but which, depending on substrate, may also contain ammonia, hydrogen sulphide, water vapour and other gaseous or vaporisable constituents.
Biogas plant	Plant designed for the production, storage and use of biogas, including all equipment and structures serving the operation of the plant; gas is produced from the anaerobic digestion of organic matter.
Biogas upgrading to biomethane	Process for separating methane and carbon dioxide and for reducing other undesirable gaseous constituents (H_2S, NH_3 and other trace gases). The product gas has a high methane content (similar to natural gas) and is referred to as biomethane.
Biomethane	Biomethane is a gaseous, biologically produced fuel, the main constituent of which is methane and which conforms to the national standards for natural gas.
Carbon dioxide (CO_2)	Colourless, non-combustible, slightly sour smelling, in itself non-toxic gas formed along with water as the end product of all combustion processes; concentrations of 4–5 % in air have a numbing effect, and concentrations above 8 % can cause death from asphyxiation.
Condensate	Biogas produced in the digester is saturated with water vapour and must be dehydrated before it is used in the CHP unit. Condensation takes place either via an appropriately situated underground pipe in a condensate separator or by drying of the biogas.
Combined heat and power (CHP) unit	Unit for the conversion of chemically bound energy into electrical energy and thermal energy on the basis of an engine linked to a generator. Simultaneous conversion of released energy into electrical (or mechanical) energy and heat intended for use (useful heat).
Desulphurisation	A physio-chemical, biological or combined method of reducing the hydrogen sulphide content in biogas.
Digestate	Liquid or solid residue from biogas recovery, containing organic and inorganic constituents.
Digestate storage tank (liquid-manure pond)	Container or pond in which liquid manure, slurry or digested substrate is stored before subsequent use.
Digester (reactor, digestion tank)	Container in which microbiological degradation of the substrate takes place and biogas is generated.
Explosive range	Concentration at which combustible gases, mists or vapours in a mixture with air or another gas supporting combustion can be ignited.

General requirements

Explosive limits	If the concentration of biogas in air exceeds a minimum value (lower explosive limit, LEL), an explosion may occur. An explosion is no longer possible if the concentration exceeds a maximum value (upper explosive limit, UEL).
Gas storage tank	Gas-tight tank or membrane gas holder in which biogas is held in temporary storage.
Gas purification	Facilities for purifying biogas (e.g. desulphurisation).
Hazardous area/Ex zone:	Area in which a dangerous explosive atmosphere may occur due to local and operational conditions.
Hydrogen sulphide (H_2S)	Highly toxic, colourless gas that smells of rotten eggs; can be life-threatening even in low concentrations.
Installation room	Room where gas purification, gas pumping, gas analysis or gas utilisation equipment is installed, including the associated instrumentation and control equipment.
Methane (CH_4)	Colourless, odourless and non-toxic gas; its combustion products are carbon dioxide and water. Methane is one of the most significant greenhouse gases and is the principal constituent of biogas, sewage treatment gas, landfill gas and natural gas.
Normal cubic metre Nm^3 or m_N^3	One normal cubic metre is the amount corresponding to one cubic metre of gas at a pressure of 1.01325 bar, humidity of 0 % (dry gas) and a temperature of 0˚C.
Nitrogen oxide	The gases nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are referred to collectively as NOx (nitrogen oxides). Nitrogen monoxide is a toxic but colourless and odourless gas. Nitrogen dioxide is a reddish-brown, toxic gas that has a pungent smell similar to chlorine. They are formed in all combustion processes as a compound of atmospheric nitrogen and oxygen, but also as a result of oxidation of nitrogenous compounds contained in fuel.
Safety distance	Area around gas storage tanks for the protection of the tank and its equipment.
Solids feeding system	Part of a biogas plant used for loading non-pumpable substrates or substrate mixtures directly into the digester.
Substrate	Raw material for anaerobic digestion or fermentation.
Sulphur dioxide (SO_2)	Colourless, pungent-smelling and toxic gas that irritates the mucous membranes. In the atmosphere, sulphur dioxide is subjected to a range of conversion processes which result in the formation of various substances including sulphurous acid, sulphuric acid, sulphites and sulphates.

3. Properties of biogas

Biogas essentially consists of methane (50 to 75 % by volume), carbon dioxide (20 to 50 % v/v), hydrogen sulphide (0.01 to 0.4 % v/v) and traces of ammonia, hydrogen, nitrogen and carbon monoxide. In addition, it may contain volatile substances. An example of the composition of biogas from an average biogas plant using manure: methane 60 % v/v, carbon dioxide 38 % v/v, residual gases 2 % v/v (see Table 1).

According to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) (United, 2015), biogas is described as an extremely flammable gas (H220) and it should be kept away from heat, hot surfaces, sparks, open flames and other ignition sources, such as smoking (P210); it should be stored in a tightly closed container (P233) and in a well-ventilated place (P403 + P235). Hazard and precautionary statements (H and P statements or phrases) are brief safety instructions concerning the use of chemicals. H statements describe physical hazards, health hazards and environmental hazards. P statements are safety instructions that describe general precautions, preventive measures, responses (measures to be taken following an accident), storage instructions and disposal instructions.

Further information is available on the website of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS).

1.3.1. Density

The density of biogas may vary, depending on its composition, moisture content and temperature. Biogas may be heavier or lighter than air, and does not separate under the influence of gravity. This property must be borne in mind when determining protective measures (e.g. the positioning of fixed gas warning systems).

Table 1: Properties of various gases (SVLFG, 2016).

	Biogas (60 % CH_4)	Natural gas	Propane	Methane	Hydrogen
Heating value (kWh / m^3)	6	10	26	10	3
Density (kg / m^3)	1.2	0.7	2.01	0.72	0.09
Density relative to air	0.9	0.54	1.51	0.55	0.07
Ignition temperature (°C)	700	650	470	595	585
Max. flame propagation speed in air (m / s)	0.25	0.39	0.42	0.47	0.43
Explosive range (% v / v)	6 – 22	4.4 – 15	1.7– 10.9	4.4 – 16.5	4 – 77
Theoretical air consumption (m^3 / m^3)	5.7	9.5	23.9	9.5	2.4

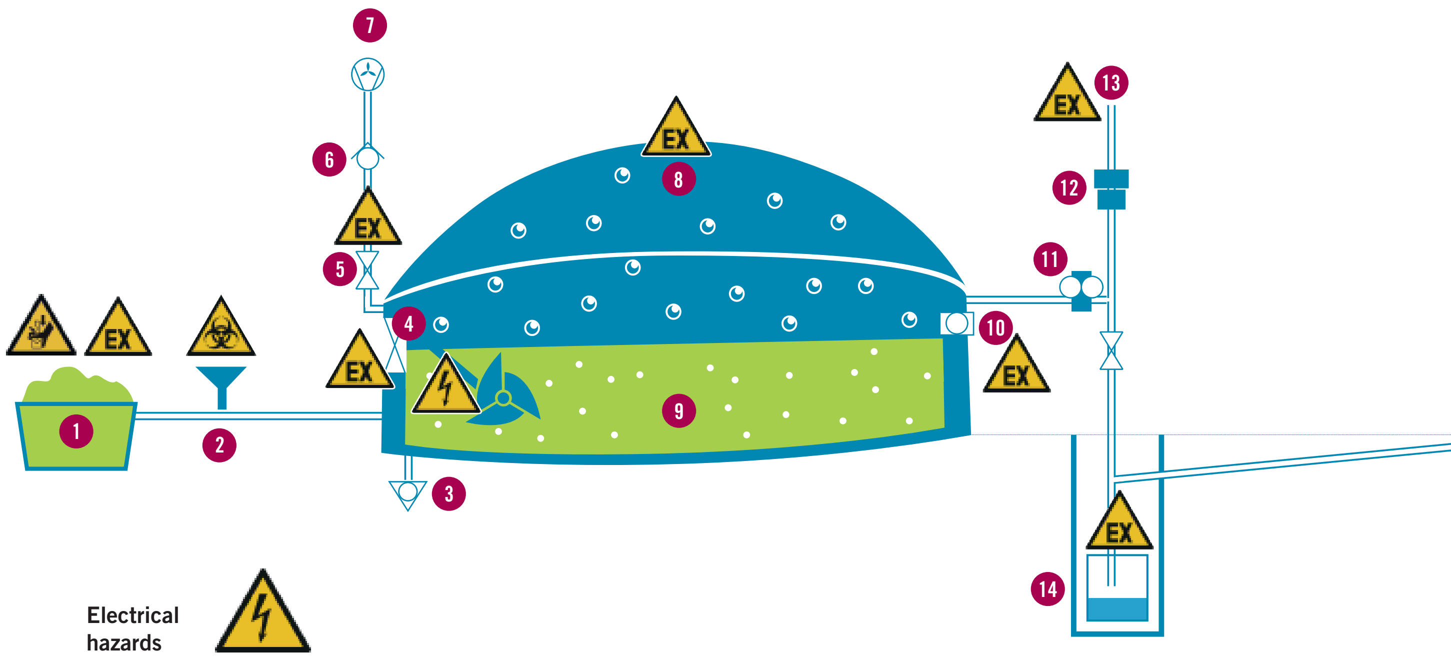
4. Hazards

Biogas plants are complex process engineering systems in which a range of different hazards can occur. Essentially, the hazards can be divided into health hazards and environmental hazards.

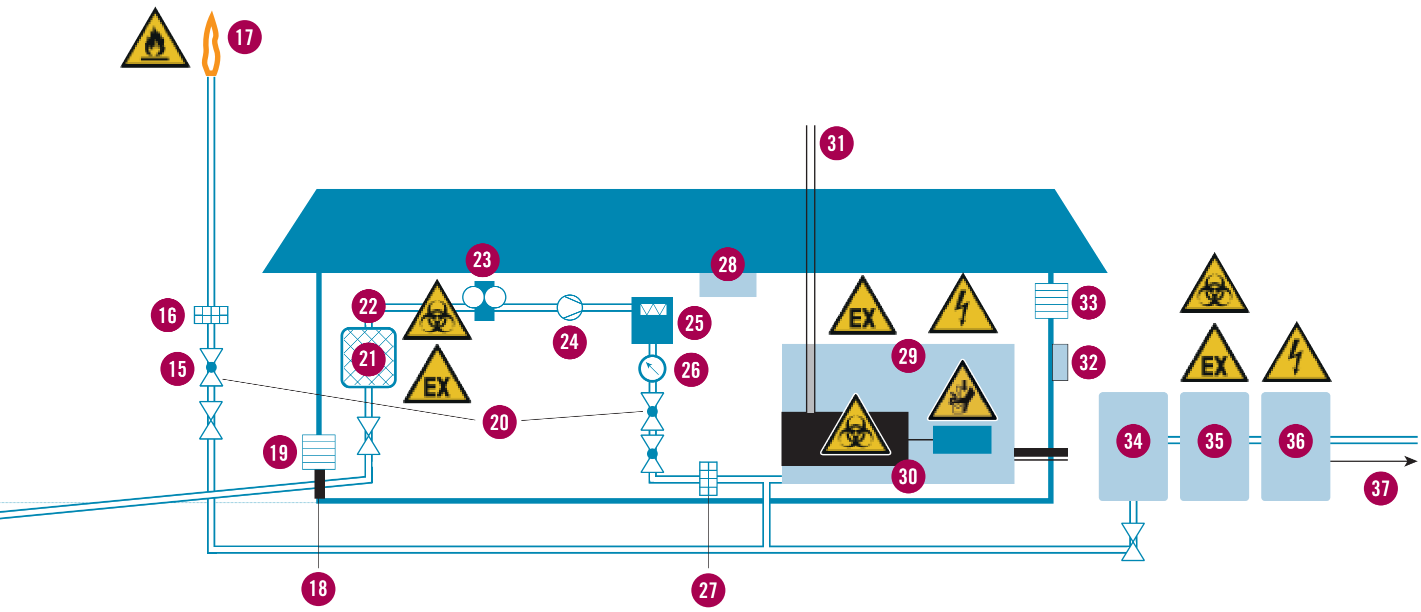
Possible hazards at biogas plants include fires and explosions, for example, but also dangerous substances (e.g. processing aids), electric current and not least biogas itself also presents risks. Attention also needs to be paid to mechanical hazards in certain parts of the plants.

Figure 2 shows the principal hazards in relation to the respective parts and components of a biogas plant. In this diagram the focus is on health hazards.

Figure 2: Overview of hazards in biogas plants



1 Feeder
2 Dosing station for processing aids
3 Potential equalisation
4 Access opening
5 Shut off valve
6 Return valve
7 Air injection for the biological desulphurization
8 Gas storage
9 Digester
10 Observation window
11 Low pressure monitor
12 Over- and underpressure protection
13 Blow off pipe
14 Condensate trap



15 Shut off valve
16 Flame arrester
17 Gas flare
18 Fire protection for the wall entry of the gas pipe
19 Fresh air inlet
20 Autmoatic shut-off device
21/22 Gas fine filter/Activated carbon filter
23 Low pressure monitor

24 Compressor
25 Gas-counter
26 Manometer
27 Flame arrester
28 Gas warning device
29 CHP (Combined Heat and Power Unit)
30 Oil tray
31 Exhaust pipe CHP

32 Emergency switch
33 Air outlet
34 Upgrading unit
35 Conditioning unit
36 Injection unit
37 Utilization of biomethane

General requirements

4.1. Environmental hazards

Essentially the environment is only exposed to danger if biogas escapes into the atmosphere or working materials in the plant (e.g. digestion substrate, silage effluent, oils or fuels) enter nearby bodies of water. An accident of this type may be caused by structural faults or operating errors.

Environmental hazards from biogas plants can be divided into emissions into air and emissions into soil and water.

Effects of an accident at a biogas plant

PHOTO: JOSEF BARTH

In an accident at a biogas plant in Germany in June 2015, around 350,000 litres of slurry poured into nearby waters. Six tonnes of dead fish were recovered from the waters.

Gaseous emissions

One of the main environmental advantages of biogas technology is the avoidance of uncontrolled greenhouse gas emissions from the storage of organic materials. Furthermore, biogas substitutes fossil fuels and synthetic mineral fertilisers, thus reducing carbon dioxide and methane emissions. However, methane – a particularly potent greenhouse gas – is also produced through the anaerobic digestion process at biogas plants. In order to preserve the climate change benefits of biogas, unwanted methane emissions must be kept to a minimum.

Analyses of biogas plants show that the digestate storage tank is one of the main sources of methane emissions, especially if it does not have a gas-tight cover. The CHP unit also presents some hazard, however in a lower degree. Other plant components are normally relatively gas-tight, but gas leakages at connection parts between the gas storage and the digester and pre-digester pits could happen.

Recommendations for minimising methane emissions include:

- All construction work must be as gas-tight as possible.
- An automatic flare system should be installed. This is particularly relevant regarding the CHP unit, as it is typically shut down for 5 to 10 % of the time for essential maintenance and repair work; in this time biogas is produced continuously, and must not be allowed to escape unburned.
- It should be ensured that the plant's overpressure relief device is not released too often, the flare system should kick in before the overpressure relief device does.
- Digestate storage tanks should have a gas-tight cover.
- Methane emissions should be checked with appropriate measuring instruments, e.g. a gas camera or foam-forming agents.
- The CHP unit should be optimised for the combustion of biogas. The methane emissions of CHP units can range from below 1% to over 2 % of methane production.

Emissions of ammonia from biogas plants should also be minimised. Ammonia causes acidification in soils, promotes eutrophication, can damage vegetation and can have detrimental impacts on health (in higher concentrations it is toxic; in groundwater, converted to nitrite, it adversely affects metabolism). Measures to reduce ammonia are similar to those for methane. This means that gas emissions to the atmosphere should be avoided (especially from the digestate storage tank). The techniques used for field spreading of digestion products have a crucial influence on ammonia emissions. Where possible, digestion products should be worked into the soil quickly, and if at all feasible application should not take place when ambient temperatures are high (i.e. preferably on cool days and not around the middle of the day).

Various combustion products such as nitrogen oxides, sulphur dioxide, carbon monoxide and particulates, among others, are produced during the combustion of biogas. Emissions of these products should be regulated in the respective national regulations.

Emissions to soil and water

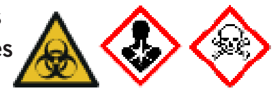
The quantities of liquids processed and stored in biogas plants range from around a hundred to several thousand cubic metres, individual tanks often hold several thousand cubic metres. The contents of the tanks should not escape into the environment, whether in normal operation or in the event of an accident. Environmental impacts are most likely to arise from the organic load and nutrients. If a tank leaks, for example, large quantities of organically polluted liquids enter the environment. The high organic load (high chemical oxygen load) is broken down by microorganisms, thereby consuming oxygen. The greatly reduced oxygen content can lead to death of fish populations. If large quantities of substrate enter the environment there is a considerable risk of eutrophication of water bodies.

The use of processing aids (refer to section on hazardous substances) also brings with it the risk of environmental hazards. Mixtures of trace elements, for example, if spilled into bodies of water, can be highly toxic for water organisms and have a long-term impact.

4.2. Health hazards

In light of the potential sources of danger outlined above it is impossible to completely rule out health hazards for operators, employees and third parties. These health hazards can be divided into four categories: hazardous substances, electrical hazards, mechanical hazards, and explosion and fire hazards.

4.3. Hazardous substances



Hazardous substances are substances, materials or mixtures that exhibit certain hazardous properties. Such hazardous properties include ‘harmful to health’, ‘toxic’, ‘very toxic’, ‘corrosive’, ‘sensitising’ and ‘carcinogenic’. Hazardous substances can take the form of solids, liquids, aerosols or gases.

Hazardous substances that are particularly likely to be present at biogas plants are biogas, processing aids, oils, activated carbon, silage effluent, slurry, wastes and biological agents.

Typical hazards include:

- Risk of asphyxiation and/or poisoning by fermentation gases/biogas in feedstock receiving areas. Release of highly toxic gases such as hydrogen sulphide in the receiving area, especially during mixing, as a result of reactions between feedstock materials.
- Hazards associated with the use of additives and auxiliary materials with hazardous properties (e.g. carcinogenic and reprotoxic mixtures of trace elements).

4.4. Biological agents

According to the International Labour Organisation (Hurst & Kirby, 2004), biological agents are any microorganism, cell culture or human endoparasite which may cause an infection, allergy, toxicity or otherwise create a hazard to human health. In biogas plants, these biological agents can occur in feedstock, digestates and biogas condensates.

The intake of biological agents through the respiratory tract, hand-to-mouth contact, skin/mucous membrane contact, cuts and stab injuries is relevant to the assessment of potential hazards.

The following are examples of hazards that may arise from biological agents during the production of biogas:

- Inhalation of dusts or aerosols containing moulds, bacteria or endotoxins, for instance from silage or dry poultry excrement that has become damp (SVLFG, 2016).
- If activities are conducted with visibly mouldy wastes, it is impossible to rule out acute toxic effects from the inhalation of mycotoxins or other microbiological metabolic products (TRBA 214, 2013).

Additional hazards that may arise in plants where other substrates are used beside energy crops, liquid manure and solid manure: biological agents in co-substrates (e.g. pathogens); manual contact during sorting.

PHOTO: MARTINA BRÄSEL

General requirements

Various risky agents and materials are also liable to arise in the course of waste treatment. These may include impurities (interfering substances), animal carcasses, or wastes from hospitals, doctor's practices or households with people who are sick or in need of care (e.g. used syringes and cannulas). Biological agents can also be introduced by rodents, birds or other animals and their excrement.

4.5. Hazards from electrical equipment

A variety of electrical equipment is used in biogas plants (control equipment, CHP unit, pumps, agitators, measuring instrumentation, etc.). Under certain circumstances this equipment may have adverse effects on health as a result of electrical hazards from the presence of electrical energy.

- Danger of electric shock or arc caused by an electric shock through an individual's body or by an arc flash.
  Example: damaged power cables on agitators

- Danger from electric or magnetic fields from irritant effects in the human body created by the circulation of induction currents caused by electric fields, induced currents or magnetic fields. These effects occur in a frequency range up to 30 kHz (low-frequency range).
  Example: electromagnetic, electrical and magnetic radiation from the generator of the CHP unit (danger for people with pacemakers).

- Danger from static electricity caused by an electric shock from the discharge of static electricity.

4.6. Mechanical hazards

Mechanical hazards are usually not specific to biogas technology. However, the most common types of accident at biogas plants are attributable to mechanical hazards: falling, impact, crushing, cutting.

Accident blackspots in this connection include work on the silo or other workplaces at a height, work in the vicinity of rotating parts (e.g. feeding systems) or work in the vicinity of moving vehicles (risk of being run over). Accidents are particularly likely to occur during maintenance and repair work if inadequate protective measures have been taken.

4.7. Gas hazards

Biogas is a mixture of different gases, the concentration of which may vary depending on the plant in question. Key constituents of biogas are listed below, along with their properties regarding risks to health (see Table 2).

The workplace exposure limit (TRGS 900, 2016) or occupational exposure limit (OEL) is the time-weighted average concentration of a substance in air at the workplace over a specified reference period at which no acute or chronic harm to the health of employees is expected to be caused. As a rule, the limit is set on the assumption that the exposure is for eight hours a day, five days a week over a working lifetime.

The workplace exposure limit is specified in units of mg / m³ and ml / m³ (ppm).

Table 2: Properties of the gaseous constituents of biogas. Sources: (TRGS 900, 2016) and (SVLFG, 2016)

	Properties	Hazardous atmosphere	Workplace exposure limit
CO_2	Colourless and odourless gas. Heavier than air.	8 % v / v, danger of asphyxiation.	5500 ppm
NH_3	Colourless and pungent-smelling gas. Lighter than air.	Above 30 – 40 ppm mucous membranes, respiratory tract and eyes become irritated. Above 1000 ppm breathing difficulties, potentially inducing loss of consciousness.	20 ppm
CH_4	Colourless, odourless gas. Lighter than air.	4.4 – 16.5 %	-
H_2S	Highly toxic, colourless gas. Heavier than air. Smells of rotten eggs	Above a concentration of 200 ppm the sense of smell becomes deadened and the gas is no longer perceived. Above 700 ppm, inhaling hydrogen sulphide can lead to respiratory arrest.	5 ppm

PHOTOS: UWE MÜHLING

4.8. Explosion and fire hazards

An explosion is defined as the sudden chemical reaction of a flammable substance with oxygen, releasing large amounts of energy. There is a sudden expansion in the volume of gases as the energy is released. This can be brought about by an explosive atmosphere, for example.

Flammable substances may be present in the form of gases, vapours, mists or dusts. An explosion can only occur if three factors apply simultaneously:

- flammable substance (in distribution and concentration conducive to explosion)
- oxygen (from air)
- source of ignition

Depending on the circumstances, two types of explosion can take place in biogas plants: detonation and deflagration.

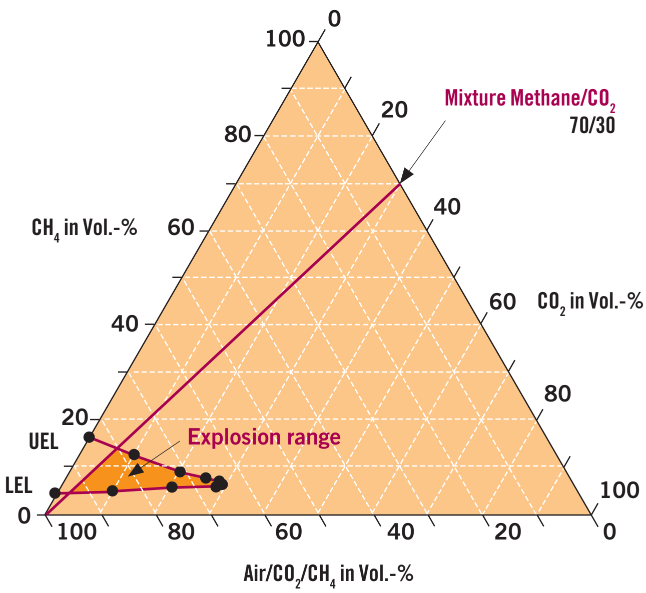
A detonation is rapid combustion occurring at the explosive limit. The pressure generated is lower than in the case of a deflagration, but is sufficient to destroy window panes, for example. Personal injuries are usually limited to bruising, burns and cuts.

A deflagration is a form of explosion in which the propagation velocity of the reaction front is below the speed of sound in the respective medium and the combustion gas plumes flow in the opposite direction of propagation. The resultant pressure is enough to damage or entirely destroy buildings. People may suffer serious injuries, which may even be fatal.

If the concentration of biogas in the atmosphere is between 6 and 22 % v/v, there is a risk of explosion in the presence of an ignition source (explosive range, explosive atmosphere). In the case of pure methane gas, the explosive range is between 4.4 and 16.5 % v/v. The ignition temperature of biogas is 700°C (methane 595°C). The composition of biogas may vary with regard to the proportions of methane and carbon dioxide, with the result that the explosive range of the gas mixture in the presence of air also varies.

Figure 3 therefore shows by way of example the explosive limits of a methane/carbon dioxide mixture (70 % CH_4 – 30 % CO_2) and their trend (upper and lower limit). Gas-air mixtures above or below the explosive range are not ignitable.

Figure 3: Explosion triangle for biogas



Example of a ripped gas storage

PHOTOS: VGH VERSICHERUNGEN

There are various potential sources of ignition in biogas plants (see Table 3).

Table 3: Potential sources of ignition in biogas plants (TRBS 2153, 2009)

Source of ignition	Examples
Hot surfaces	>500 °C (turbochargers)
Naked flames	Fire, flames, embers
Mechanically generated sparks	Friction, beating, grinding
Electrically generated sparks	Switching operations, loose connection, equalising currents
Exothermic reaction	Spontaneous combustion of dusts
Lightning strike	missing lightning protection
Electrostatic discharge	Caused by missing potential equalization

4.9. Sources of danger from the surrounding environment

In addition to the specific hazards outlined above, weather-related or other environmental sources of danger may also arise, for example from flooding, earthquakes, storms, ice and/or snow, power outage, heavy rainfall or frost. Site-related sources of danger such as the effect of neighbouring businesses or the traffic situation must also be taken into account.

Environmental sources of danger such as these may result in interactions with other specific hazards.

4.10. Hazards arising from inappropriate behaviour

Potential hazards arising from inappropriate behaviour must also be taken into account in the operation of a biogas plant. These include, for example:

- action by unauthorised persons
- dangers from personnel (operating errors, on-call service not working, deliberate failure to carry out fault rectification measures, sabotage, etc.)

5. Hazard assessment

In order to prevent accidents, hazards in biogas plants must be systematically identified, assessed and minimised. This is the purpose of a risk analysis.

A tool to conduct this analysis is the risk matrix (see Table 4), which shows the likelihood of an undesirable event occurring (the risk) in relation to the consequences of that event, in the form of a table. The categories for the likelihood of an event occurring or taking effect are: rare, unlikely, possible, likely and almost certain.

The categories are 'reasonably estimated' or statistically verified in the course of the risk assessment. The categories for the severity of the consequences are as follows:

- minor injuries or illnesses, e.g. bruising
- moderately severe injuries or illnesses, e.g. simple bone fractures
- severe injuries or illnesses, e.g. paraplegia
- possible death, disaster, e.g. severe injuries to numerous people

Appropriate protective measures must be defined and implemented on the basis of this assessment. The findings obtained must be taken into account in the design and selection of equipment and materials and in the design of workplaces, working and production processes and operating sequences, and the way in which these interact with each other.

This can also be laid down in national regulations. As a rule, the operator is responsible for producing the hazard assessment, or a person appointed by the operator for this purpose. The hazard assessment must be updated prior to initial start-up of the plant, following resumption of operation and after any changes are made that are relevant to safety.

In order to assist operators in fulfilling their duties in this regard, in Germany it has proven worthwhile for a qualified expert to check both the hazard assessment and the effectiveness of the protective measures (see Figure 4). A hazard assessment must also be carried out before maintenance and repair work is performed and before faults and malfunctions are rectified.

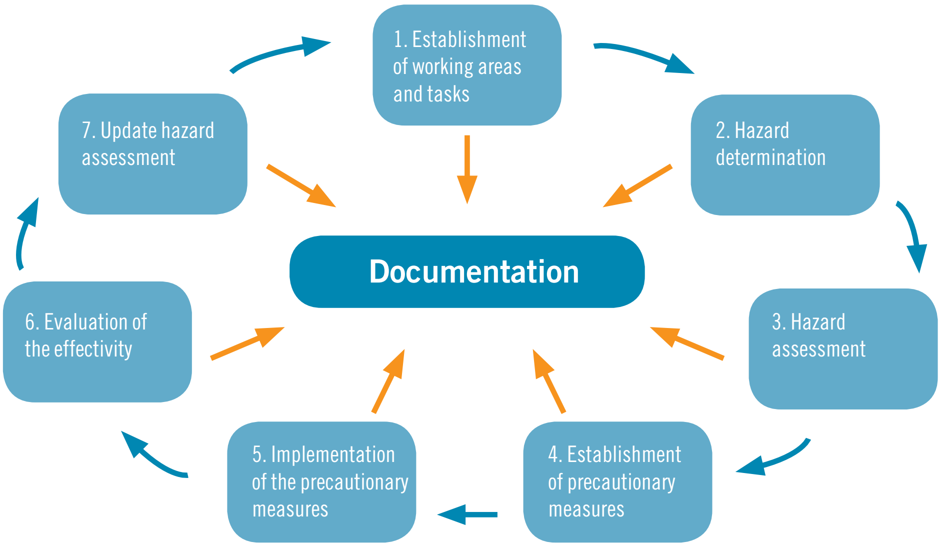
The findings of the hazard assessment and the recurring updates must be documented, along with a record of implementation of the protective measures.

Table 4: Risk analysis

			Potential Consequences				
			Minor injuries or discomfort. No medical treatment or measurable physical effects	Injuries or illness requiring medical treatment. Temporary impairment.	Injuries or illness requiring hospital admission.	Injury or illness resulting in permanent impairment.	Fatality
			Not Significant	Minor	Moderate	Major	Severe
Likelihood	Expected to occur regularly under normal circumstances	Almost Certain	Medium	High	Very High	Very High	Very High
	Expected to occur at some point	Likely	Medium	High	High	Very High	Very High
	May occur at some point	Possible	Low	Medium	High	High	Very High
	Not likely to occur in normal circumstances	Unlikely	Low	Low	Medium	Medium	High
	Could happen, but probably never will	Rare	Low	Low	Low	Low	Medium

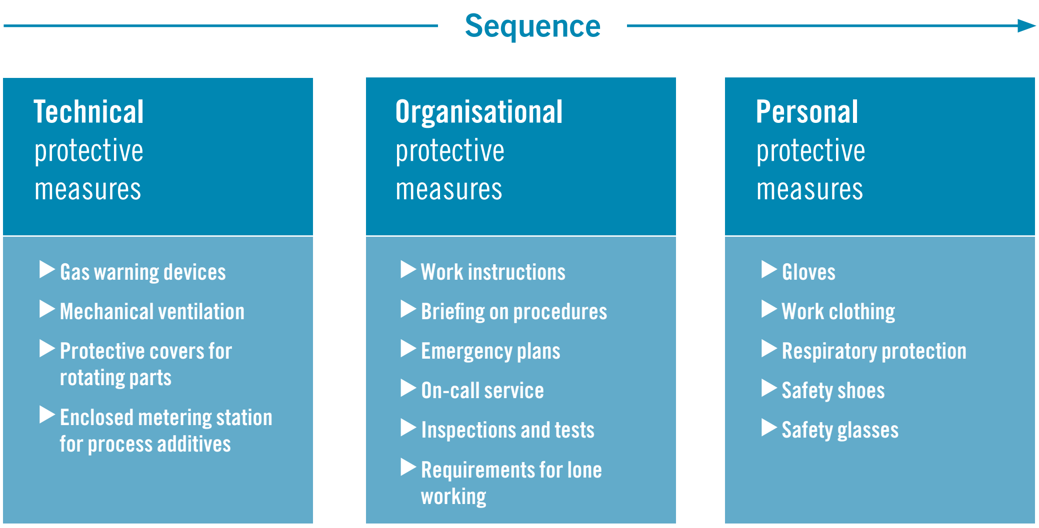
General requirements

Figure 4: Action at the various stages of hazard assessment



As a general rule, the hierarchy determined by the so-called TOP principle (see Figure 5) should be applied when instituting protective measures. This means that first of all it is necessary to take technical measures, such as enclosing rotating parts or ensuring that filling takes place in closed systems. Once all possible technical protective measures have been exhausted, organisational measures must be implemented, such as producing operating instructions and holding instruction and briefing sessions so that devices and equipment can be operated safely, but also for example making certain that filling does not take place when any individual is within the danger area. In some cases, hazards are unavoidable, despite technical and organisational protective measures. In such instances, personal protective measures need to be put into practice to protect persons in the event of a hazard. This includes actions such as wearing a respirator (breathing mask) if a release of biogas is unavoidable.

Figure 5: Protective measures according to the TOP principle



5.1. Hazard assessment for specific operating states

Normal operation for a plant is the state in which the plant is operated within its design parameters. It is not appropriate to consider start-up/shut-down or maintenance work on a continuously running biogas plant as normal operation. Statistical evaluations of personal injuries at biogas plants reveal a significantly high accident rate in connection with maintenance work and start-up or shut-down procedures. These operating states should therefore be considered separately, with their own specific operating instructions.

5.2. Start-up / commissioning

It is always advisable to draw up a start-up plan before starting commissioning, and to follow it closely during the start-up phase.

Before the digester is filled for the first time, all work on it including the associated pipework must be completed in order to prevent potential damage or injury. Precise knowledge of the plant load requires the feedstock materials to be properly weighed. This is highly important both for start-up operation and for ongoing process control. In addition, regular chemical analysis of the feedstock materials and in particular of the digestion mixture is a sensible control measure for speedy start-up. However, if the organic loading rate rises too fast during the phase of establishing the digestion biology, the process can quickly become overloaded; ultimately this can extend the duration of start-up operation. Incompletely filled tanks can lead to an uncontrolled escape of biogas. During filling it is therefore important to take care that the filling level is sufficient to ensure that the substrate feeding equipment is fully immersed in the liquid phase.

It should also be noted that during start-up of the plant an explosive gas mixture is temporarily present because of the increase in the proportion of methane in the biogas (with a volume fraction of 6–22 % biogas in air).

5.3. Maintenance and repair work

Only persons who have the necessary specialist knowledge and experience for the relevant work and of whom it can be expected that they will perform their task reliably should be allowed to maintain and repair biogas plants. The protective measures required for the maintenance and repair of biogas plants must be defined by the client on the basis of the hazard assessment (see section headed Hazard assessment and see Figure 6) and must be applied when the work is carried out (TRGS 529, 2016).

The necessary protective measures must be determined and documented as part of the hazard assessment before the work is carried out. The documentation must also include written work instructions, and in addition, in the case of work with ignition hazards, must contain a permit-to-work system (see Annex 2 'Instruction record for subcontractors and employees for maintenance, installation and repair work').

During maintenance work on biogas plants, in addition to the areas subject to explosion hazard designated in the explosion protection document under normal operation (see section headed Explosion protection document) there may be further areas with a hazardous explosive atmosphere (and depending on the H_2S content of the biogas, areas posing a health hazard) for the duration of the work (for example when membrane roofs are opened in order to replace the agitator).

Appropriate protective measures include:

- Establishing and marking or cordoning off areas where a risk of fire/explosion or a health hazard is to be expected.
- Shutting down electrical and other non-explosion protected systems.
- Removal of biogas from parts of the plant.
- Selection of appropriate explosion-proof equipment and tools.
- Clearance measurement, i.e. the determination of the concentration of hazardous materials or oxygen content using appropriate measuring techniques in a certain area. The purpose of this is to classify the surrounding atmosphere as safe for employees or to initiate further protective measures.
- Use of appropriate personal protective equipment.
- Ensuring adequate ventilation.
- Appointment of a supervisor.

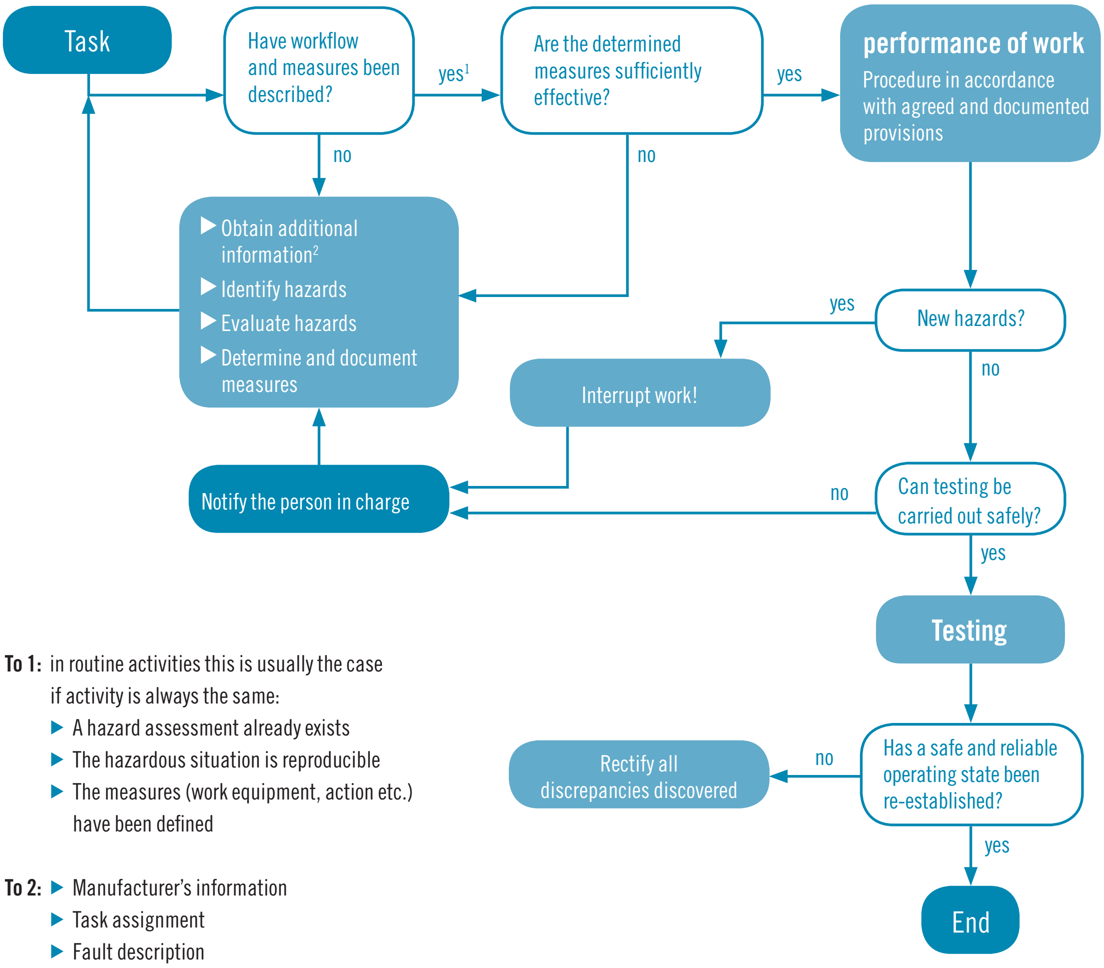
Employees engaged in activities in the vicinity of maintenance and repair work must be notified of the timing, location and nature of the planned work and of the restrictions and hazards that could arise as a result and therefore the precautions and care that they need to take. Maintenance and repair work must always be performed by employees who are capable for the work and have been assigned to it by the plant operator or owner. They must have the necessary specialist knowledge to carry out the maintenance or repair order by virtue of their vocational education or professional training.

In all maintenance and repair work it is essential to use tools and other work equipment that is suited to the intended purpose and the conditions at the workplace when used appropriately.

To summarise, in specific exceptional operating states the operator must

- define the responsibilities for implementing the requisite protective measures;
- ensure adequate communication between operating staff and maintenance and repair personnel;
- secure the working area during the maintenance and repair work;
- prevent unauthorised parties from entering the working area, if this is deemed necessary according to the hazard assessment;
- provide safe access points for maintenance and repair personnel;
- avoid hazards from moving or elevated work equipment or parts of the equipment and from hazardous energy or materials;
- ensure that devices are disconnected from energy sources. Remaining mechanical and electrical energy (e.g. current leak) should be removed safely. These devices must be marked or labelled appropriately;

Figure 6: Flow diagram for maintenance and testing (TRBS 1112-1, 2010)



To 1: in routine activities this is usually the case if activity is always the same:

- A hazard assessment already exists
- The hazardous situation is reproducible
- The measures (work equipment, action etc.) have been defined

To 2:

- Manufacturer's information
- Task assignment
- Fault description

- stipulate safe working practices for working conditions that deviate from the normal state;
- provide all necessary warning symbols and hazard warning signs regarding maintenance and repair work on the work equipment;
- ensure that only suitable devices and tools are used, and appropriate personal protective equipment;
- comply with relevant protective measures if a hazardous explosive atmosphere occurs or is formed;
- use systems for approving certain works.

If the technical protective measures applied during normal operation are partly or entirely taken out of service during maintenance or repair work on work equipment, or if such work must be performed in the presence of an energy hazard, the safety of the employees for the duration of this work must be ensured by taking other suitable measures. The workflow for maintenance measures is shown in Figure 6.

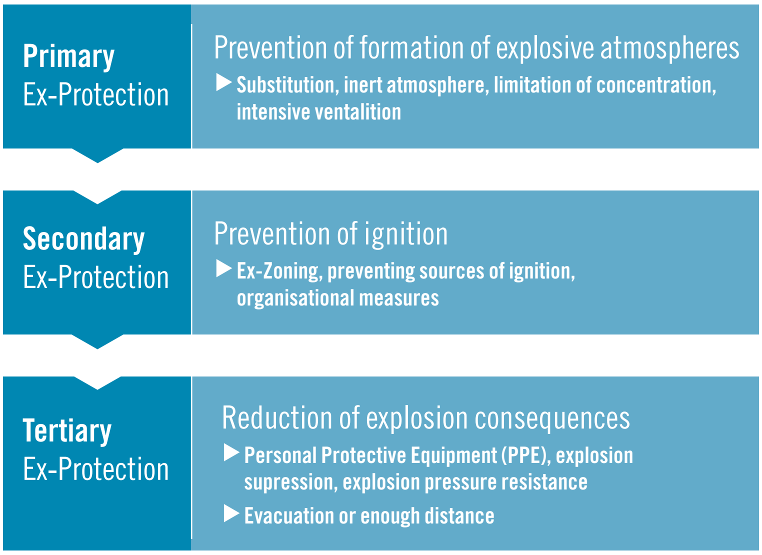
5.4. Shut-down/decommissioning

The removal of a biogas plant from service is a special operating state that requires particular measures. The Ex zones classified in the explosion protection document (see section headed Explosion protection document) take account of this operating state to only a limited extent.

These specific hazards are therefore considered separately in a set of work instructions.

- The loading of substrate in the digesters is stopped, while removal continues. The quantity of substrate removed must not exceed the volume of gas generated in order to prevent the formation of a hazardous explosive atmosphere.
- If the quantity of substrate removed is liable to exceed the volume of gas generated, the digestion tank is shut off from the gas collection system and a connection to the atmosphere is established, for example by emptying the liquid seal of the over and under pressure unit. A hazardous explosive atmosphere may now be formed in the digester as a result of the entry of air. Ignition sources (see section headed Explosion and fire hazards) must be avoided.
- The digester must be shut off from the gas collection system in order to prevent gas backflow.

Figure 7: Sequence of explosion protection measures



- A hazardous explosive atmosphere may be formed around outlet nozzles. Ignition sources must be avoided (see section headed Explosion and fire hazards).
- Before entering the digester and throughout the time spent in the tank it must be ensured that any risk of asphyxiation, poisoning, fire or explosion is safely prevented through adequate ventilation and that sufficient air is available to breathe. Any operational equipment such as pumps or agitators must be safely secured to prevent them from being switched on.

5.5. Explosion protection document

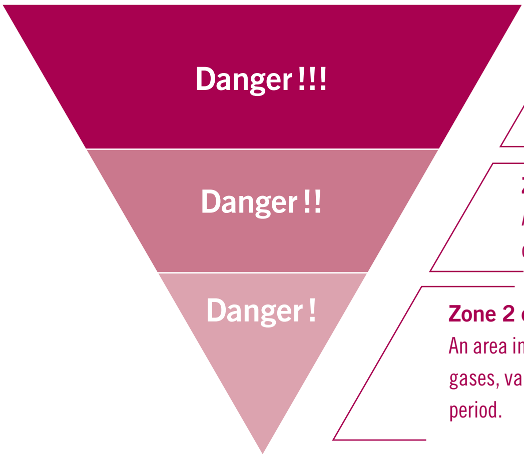
The explosion protection document is part of the hazard assessment, involving the identification and evaluation of explosion hazards. In particular it is necessary to determine where a hazardous explosive atmosphere (or potentially explosive atmosphere – PEA) can be expected and what potential ignition sources could cause ignition (see section headed Explosion and fire hazards). As a general principle the first step is to implement primary structural measures that prevent hazardous explosive atmospheres from arising. Secondary, technical measures must then be implemented if a hazardous explosive atmosphere is unavoidable; they are aimed at avoiding the creation of ignition sources. The final choice of measure should be tertiary or organisational measures, which are aimed at reducing the potential consequences of an explosion (see figure 7).

General requirements

Hazardous areas can be divided into zones according to the frequency and duration of the occurrence of hazardous explosive atmospheres (see Figure 8).

The national guidelines on the classification of areas as Ex zones must be observed. Examples of zoning and the associated protective measures are given in the second part of this document.

Figure 8: Classification of Ex zones

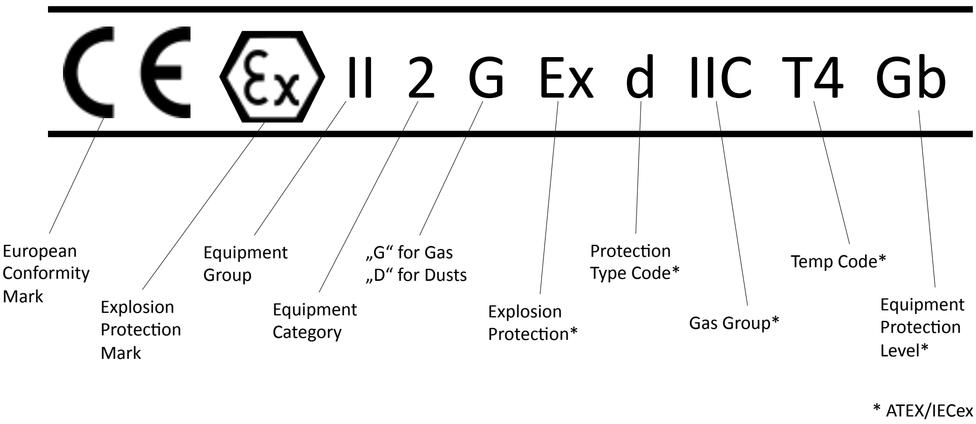


Zone 0 or zone 20
An area in which a hazardous explosive atmosphere consisting of a mixture of air and combustible gases, vapours or mists is present continuously or for long periods or frequently.

Zone 1 or zone 21
An area in which a hazardous explosive atmosphere consisting of a mixture of air and combustible gases, vapours or mists is likely to occur occasionally in normal operation.

Zone 2 or zone 22
An area in which a hazardous explosive atmosphere consisting of a mixture of air and combustible gases, vapours or mists does not normally occur but, if it does, does so only rarely and for a short period.

Figure 9: Description of an ATEX label



Further information
The ATEX Guidelines can be consulted on the European Union Law website and are available in English, Spanish, French and Portuguese.

5.6. Requirements for work equipment in hazardous areas

To enable work equipment to be used in hazardous areas (potentially explosive atmospheres, PEA), it must be approved for use in the respective Ex zone. European Directive 2014/34/EU (ATEX, 2014) (ATEX Product Directive, referred to in the following simply as ATEX), has become established as the basis for the use of equipment and protective systems in Ex zones (see Figure 9).

According to this directive, only equipment that is approved for zone 0 and is correspondingly marked may be used in zone 0. Only equipment and protective systems of equipment group II category 1 G according to Annex 1 of ATEX may be used.

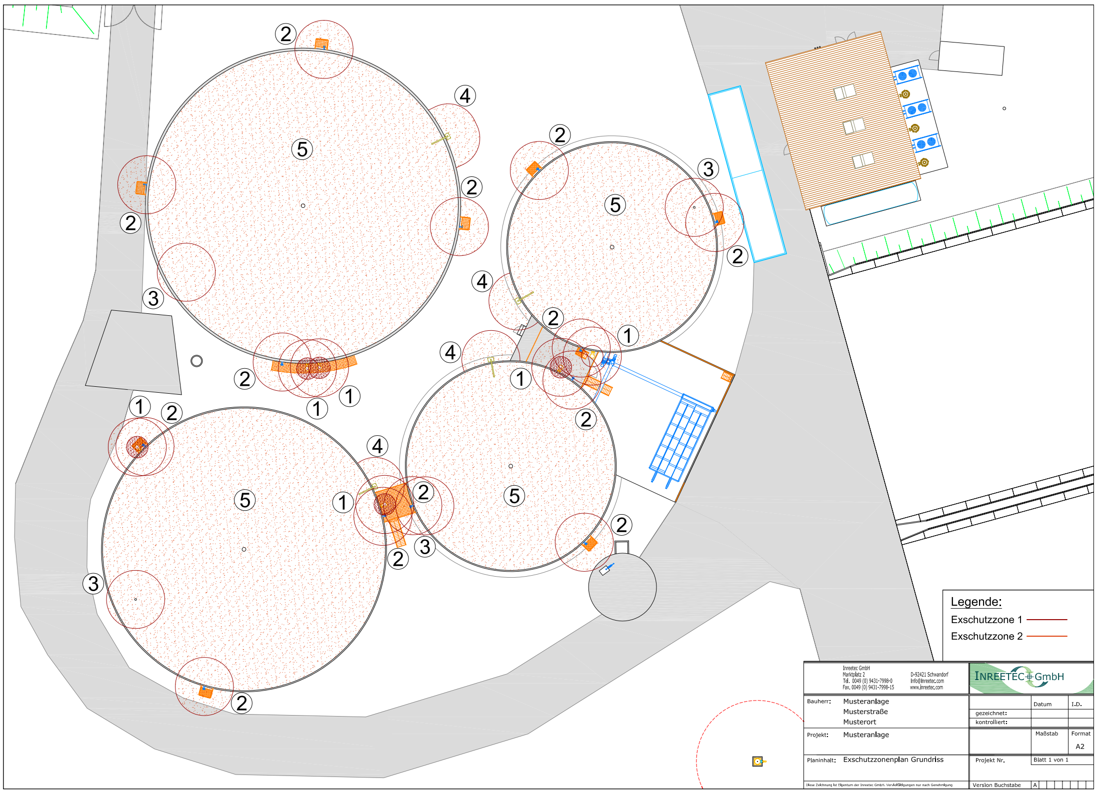
In zone 1 only equipment that is approved for zone 0 or 1 and is correspondingly marked may be used. Only equipment and protective systems of equipment group II category 1 G or 2 G according to Annex 1 of ATEX may be used.

In zone 2 only equipment that is approved for zone 0, 1 or 2 and is correspondingly marked may be used. Only equipment and protective systems of equipment group II category 1 G, 2 G or 3 G according to Annex 1 of ATEX may be used.

Details of the zoning must be recorded in an Ex zone plan (see Figure 10). This must be regularly checked to ensure that it is up-to-date, and adapted as necessary.

Figure 10: Example of a Ex-zone plan for a biogas plant (red = zone 1, orange = zone 2)

① Overpressure and underpressure protection
② Wall duct for submersible mixer
③ Outlet of the membrane gas storage tank
④ Blower of the membrane gas storage tank
⑤ Space in between the membranes of the gas storage



SOURCE: INREETEC GMBH

6. Fire protection concept

Biogas plants have various fire loads depending on the plant concept, plant size, substrate input, the operating and work equipment used and the materials used. Structural, technical and organisational fire protection measures must be included from the design and planning of the plant. In particular, national guidelines must be taken into account regarding fire protection.

6.1. Structural fire protection

The following structural fire protection measures have proved their worth in practice:

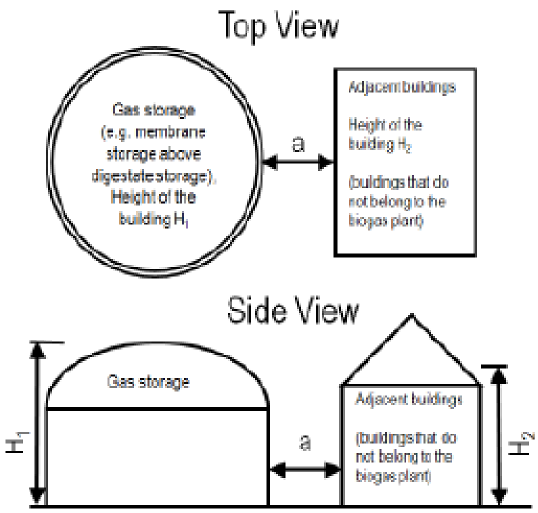
- **Digester:** If thermal insulation is necessary for digesters, it should be at least normally inflammable. Within an area of 1 m around openings where gas is released during normal operation, it must be made of at least low-flammable material.

> *Further information on the thermal insulation requirements for construction products and building elements can be found in the standard DIN EN 13501-1.*

- **CHP unit installation rooms and installation in buildings not belonging to the plant:** Walls, supports and ceilings above and below installation rooms must be at least fire resistant (e.g. F 90 in Germany) and be made of non-flammable building materials. No cladding or insulation made of flammable materials may be used for walls, ceilings or supports. Doors in fire-resistant walls must be at least fire-retardant and self-closing; this does not apply to doors leading to the open air. Ventilation ducts and other pipework or cables should only be run through walls and ceilings if the ducts, pipes or cables themselves are incapable of spreading fire or precautions have been taken to prevent fire spreading (e.g. cable penetration seal with general approval from the construction supervision authority, or fire dampers suited for the intended purpose). Exhaust gas lines (stacks) and the associated penetrations must comply with the respective country-specific requirements. Sufficient clearance from flammable materials should be ensured. Spaces in the penetrations must be filled with non-flammable, dimensionally stable materials. This condition is met if suitable materials are used which have the same fire-resistance rating as the components being sealed.
- **Electrical installations:** Electrical installations must comply with recognised rules (applicable in each specific country) and must be regularly checked by an authorised electrician. The operator should regularly carry out visual checks for rodent damage and signs of scorching in order to minimise the risk of fires starting.
- **Safety distances:** The purpose of safety distances is to reduce mutual influence in the event of damage occurring and to prevent fire from spreading and protect the gas storage tank. To this end it is necessary to provide for safety distances of at least 6 m in a horizontal direction between gas storage tanks and adjacent non-biogas-related installations, facilities and buildings (with a height below 7.5 m) or to transport routes.
  - If one building is higher than 7.5 m, gas storage or building not belonging to the plant, the formula for the distance a is: $a = 0.4 \times H_1 + 3$ m.
  - If there are two buildings higher than 7.5 m, gas storage or building not belonging to the plant, the formula for the distance a is: $a = 0.4 \times H_1 + 0.4 \times H_2$.

Safety distances of at least 6 m must be provided within a biogas plant between the gas storage tank and installation rooms for internal combustion engines. In above-ground installations the safety distance is measured from the vertical projection of the edge of the storage tank (see Figure 11).

Figure 11: Safety distances between gas storages and adjacent builidings



Danger to persons and the risk of fire inside or outside the biogas plant through thermal radiation or convection must be precluded by appropriate positioning of the emergency flare. In this regard consideration must be given to buildings, plant components, transport routes and public areas.

- **Protective wall:** The safety distance can be reduced through sufficient covering with earth or an adequately dimensioned protective wall or fire insulation (i.e. firewall). Doors in protective walls must be fireresistant and self-closing. A protective wall can also be an appropriately designed building wall without openings. The height and width of the protective wall must comply with the requirements of the respective national guidelines.

6.2. Organisational fire protection

Within the safety distances there should not be combustible materials stored in quantities of over 200 kg without additional protective measures, and there should neither be buildings that do not belong to the biogas plant nor public roads or paths. Additional protective measures may include fire prevention measures, fire protection measures and fire-fighting measures (see section on protective walls, for example). Besides this, the following conditions apply:

- transport routes essential for operation of the plant are permissible;
- no vehicles may be parked within the safety distance area;
- machinery and activities that can cause danger to the gas storage tank (e.g. welding or cutting) are not permitted without additional protective measures;
- no gas flares may be operated;
- fires, naked flames and smoking are prohibited.

Employees and external companies must be instructed periodically, as and when appropriate, on measures to be taken in the event of operational faults, accidents and emergencies and how to prevent these.

It has proven worthwhile to discuss and coordinate fire protection considerations at the plant with the responsible fire brigade prior to commissioning and at regular intervals. Close coordination with the leaders of the local fire brigade units is essential in advance of tactical deployment of the fire brigade in the event of fire or for other forms of technical assistance. It is recommended to hold an exercise in order to ensure that correct action is taken in the event of a deployment. In case of deployment, the fire brigade should use appropriate personal protective equipment, a gas detector (CH_4, CO_2, H_2S, etc.) must be kept ready for use, attention must be paid to the wind direction when approaching the site, a safe distance must be maintained, the formation of ignition sparks must be avoided (e.g. electrical switches!), and the operator on site must be consulted.

As far as possible, all necessary safety and health protection signage should be considered during the planning of workplaces (for example when drawing up escape and rescue plans). It is also important to appoint first aiders. Extinguishing agents (fire extinguishers, supply of fire-fighting water) must be made available according to the fire loads, in consultation with the fire brigade.

> **TIP**
> *The latest rescue and fire safety symbols are specified in ISO 7010.*

PHOTO: FOTOLIA_OKTAY ORTAKCIOGLU

7. Protective measures

With regard to occupational health and safety, the general rule is to establish protective measures according to the TOP principle (see section Hazard assessment).

The plant operator must ensure the safe handling of work equipment and the safe operation of plants and plant components with the aid of technical protective measures. The technical protective measures for specific plant components are explained in the second part of this brochure.

7.1. Organisational protective measures

Organisational structure
The operator should design and document the plant's organisational structure in such a way that all activities and tasks can be safely performed and monitored at all times.
The following arrangements should be made, at the very minimum:

- responsibilities (e.g. for checking the operating log, carrying out instruction/briefing and performing the hazard assessment; the employer can delegate tasks to an employee)
- deputisation arrangements
- on-call service: if the plant is operated by several people in shifts, handover at the change of shifts must be ensured and any particular occurrences must be documented in writing (e.g. in the operation diary)
- if necessary, assignment of the right to issue instructions

Operating instructions
A thorough briefing (presentation of the operating instructions) by the plant manufacturer is essential prior to commissioning and if any modifications are made. Evidence of the content covered should be given in writing. In addition, the operating personnel of the biogas plant should take part in further training and continuing professional development, and the certificates should be kept. If personnel from external companies work at the biogas plant, their professional suitability must be established and verified as necessary. A suitable briefing form should be used to ensure that external personnel are briefed on operational hazards.

Instruction and briefing
Instruction and briefing by the plant operator on the safe handling of work equipment should be carried out and repeated in accordance with the findings of the hazard assessment.
Examples of instruction and briefing:

- Safety and health at work
- Work in areas where there is an explosion hazard
- Internal company instructions
- Hazardous substances present or arising at the workplace
  - in particular hygiene regulations
  - information about measures to be taken to prevent exposure
  - information about wearing and using personal protective equipment and protective clothing

Before commencing work/activities, employees must receive initial instruction and then at regular intervals, at least once a year. A written record of the instruction should be kept.

Dangerous tasks must be performed in accordance with the written instructions of the employer or the person responsible; a permit-to-work system must be used when dangerous activities are to be carried out or activities that can become dangerous in combination with other work. Examples: work inside tanks and in tight spaces, work entailing an ignition hazard (welding, flame cutting, drilling etc.), work on roofs, work in hazardous areas.

Appropriate supervision must be ensured during the presence of employees in hazardous areas. The German Biogas Association provides an example of a permit-to-work system with the Instruction record for subcontractors and employees for maintenance, installation and repair work (see Annex 2).

Employees must receive instruction prior to commencing work on or with new work equipment, new procedures/changed procedures, new hazardous substances or new responsibilities.

The following should be documented:
- *Content of the briefing*
- *Briefing of external personnel*
- *Briefings and instruction held*

Requirements for lone working
As part of the hazard assessment it is necessary to examine which activities can be performed by work-

ing alone and to document these. If it is established in the course of the hazard assessment that a particular activity cannot be performed alone, this activity should always be performed by at least two employees. As a rule, the following activities cannot be performed alone:

1. work inside tanks and in tight spaces (a person must be assigned to stand guard for safety reasons when work is carried out inside tanks or in tight spaces, if there are no doors through which the worker can leave);
2. work in areas where additional explosion hazards may arise in the course of maintenance or repair work because of the local conditions, the equipment installed in those areas or the substances, preparations or impurities contained in them or introduced into them (TRBS 1112-1, 2010).

Where lone working is permissible, appropriate technical and organisational protective measures must be determined by means of which effective first aid can be ensured if the need arises. Examples of suitable protective measures include the following:

- permanently staffed camera surveillance,
- use of a personal emergency signalling device with automatic alarm functions,
- reporting intervals with visual or voice contact,
- working within visual range,
- supervision through inspection tours,
- provision of a landline phone/mobile phone to make emergency calls.

If these protective measures might themselves be or include sources of ignition, their suitability must be examined before they are used in hazardous areas (TRGS 529, 2016).

Organisational protective measures also include regular maintenance of the plant, systems and components. In order to be able to guarantee safe operation, it is essential to draw up a maintenance plan with specific details of the plant components to be maintained and to specify maintenance intervals. Maintenance also includes functional testing of the individual components and completion of the relevant documentary evidence.

Maintenance work with protective measures in a digester

PHOTO: POLYGONVATRO GMBH

7.2. Personal protective measures

In addition to technical and organisational protective measures, personal protective measures must also be planned for specific aspects of plant operation. The choice of measures to be used depends on the hazard assessment (see Table 5).

Table 5: Hazards and possible protective measures

Hazards	Examples	Personal protective equipment
Hazardous substances (airborne)	Microorganisms Aerosols Biogas (constituents) Additives and auxiliary materials	Protection for the eyes and face if spraying or squirting of infectious materials or liquids can be expected and technical measures do not provide adequate protection. Tasks for which respiratory protection is used must be expressly considered in the hazard assessment. Suitable respiratory protection must meet the following requirements as a minimum: ▸ Half mask with class P2 particle filter to DIN EN 143 or FFP2 particle-filtering half mask to DIN EN 149. ▸ Filtering half masks with exhalation valve are the preferred choice. If biogas is released, closed-circuit self-contained breathing apparatus must always be used because of the possibility of high concentrations of H_2S and of oxygen displacement.
Hazardous substances (skin contact)	Moulds Bacteria Viruses Endotoxins Additives and auxiliary materials	Heavy-duty, liquid-impermeable and low-allergen gloves, also with extended cuffs in order to prevent liquid contamination with pathogens from entering the gloves. The gloves must be resistant to the disinfectants being used. Protection for the eyes and face if spraying or squirting of infectious materials or liquids can be expected and technical measures do not provide adequate protection. Waterproof aprons, if it can be expected that clothing will become soaked. Waterproof footwear, if it can be expected that footwear will become soaked.
Electrical hazards	Static discharge Defective cables	Safety shoes that conform at least to the requirements of protection class S2 and safety boots that conform at least to the requirements of protection class S4 according to DIN EN ISO 20345 should be provided.
Mechanical hazards	Falling, stumbling, crushing, cutting	Safety shoes that conform at least to the requirements of protection class S2 and safety boots that conform at least to the requirements of protection class S4 according to DIN EN ISO 20345 should be provided, as well as weatherproof clothing as required. (TRGS 727, 2016)
Fire and explosion hazard	Personnel can become statically charged, for example when walking, when standing up from a chair, when changing clothes, when handling plastics, when carrying out work involving pouring or filling, or through induction when standing in proximity to charged objects. A statically charged person touching a conductive object, e.g. a door handle, causes spark discharges.	In hazardous areas classified as zone 0, 1 or 20, conductive footwear with a leakage resistance to earth of less than $10^8\ \Omega$ should be worn. The same requirement applies in zone 21 in the case of dusts with a minimum ignition energy (MIE) ≤ 10 mJ. Work clothing or protective clothing must not be changed, removed or put on in hazardous areas classified as zone 0 or 1. Personal protective equipment must not become dangerously charged in hazardous areas or in the presence of explosive gas mixtures, for example during maintenance work or on emergency call-outs. (TRGS 727, 2016)

Basic hygiene measures must be ensured. These include washing hands before going for breaks and upon completion of work, as well as regular and need-based cleaning of the workplace and cleaning/changing of work clothing and personal protective equipment. The measures could be laid down in a cleaning and hygiene plan. Employees must refrain from eating or drinking at workplaces where there is a risk of contamination by biological agents. If the hazard assessment calls for disinfection measures, these must be carried out with tested disinfectants.

- No one wearing microbiologically contaminated work clothing is permitted to enter break rooms or staff rooms.
- Wastes containing biological agents should be collected in suitable containers.
- Work clothing and personal protective equipment should be kept separate from private clothing.
- Microbiologically contaminated clothing must not be cleaned at home.
- If pests such as rodents, pigeons, insects or other animals gain access to the working area, regular pest control is essential.
- Storage conditions that encourage biological agents to multiply must be avoided, in as far as operation of the plant allows.
- Adequate ventilation of the working area must be provided in accordance with the hazard assessment.

Figure 12 provides an overview of the various elements of personal protective equipment. It should be noted that not all elements need to be used in each instance. The need to wear a helmet or a fall arrest system, for example, depends on the situation.

Figure 12: Personal protective equipment (PPE)

Further information on the technical requirements for personal protective equipment can be found in the following standards:
DIN EN 143: Respiratory protective devices - Particle filters - Requirements, testing, marking
DIN EN 149: Respiratory protective devices - Filtering half masks to protect against particles
DIN EN ISO 20345: Safety footwear

8. Documentation

The following items must be documented, in accordance with national requirements:

- Responsibilities/rights to issue instructions: list of phone numbers of persons to contact (both internal and external, e.g. authorities, agencies).
- Emergency plan (operating instructions for procedures in the event of accident, fire, explosion, the release of substrate, power outage, prevention of unauthorised persons from gaining entry etc.)
- Hazard assessment/explosion protection document
- Operating instructions for the employees
- Instruction manuals from the manufacturer
- Hazardous substances register
- Safety data sheets
- Release/briefing forms
- Maintenance and repair plan (including schedule according to manufacturer's instructions)
- Regular tours of inspection and operation diary
- Evidence of recurring tests (electrical tests, tests of work equipment)
- Evidence of initial and recurring training courses
- Plans of present inventory of facilities and equipment (floor plan for firefighting, piping and instrumentation diagram, piping layout plan, etc.)
- Process management matrix
- Fire protection certificate

TIP
Maintenance contracts with specialist companies are particularly advisable for parts of the plant that are of relevance to safety and need to be regularly calibrated (e.g. gas warning system, gas analyser, gas detector, personal protection monitor, fire detector).

As a rule, the plant operator is responsible for proper documentation, i.e. ensuring that the documentation is complete, up-to-date, of the appropriate quality and in conformance with the respective legal provisions in the country concerned. In individual cases it should be clarified what consequences there would be under liability law in the event of an infringement of the applicable law.

The documentation should be readily available at all times; it should be kept at the biogas plant. A backup copy of the documents should be kept at alternative locations. This is particularly important in emergencies or in the event of faults. In such instances the operator must make arrangements for deviations from normal operation in order to ensure that the plant reverts to normal operation as quickly as possible or to minimise the extent of the disruption.

Specific requirements

Biogas plants are complex process engineering systems. A variety of pumps, compressors, agitators, screw conveyors and pipes are needed to transport substrate and produce gas. It must be possible to ensure safe operation of all of these plant parts and components at all times. Furthermore, the operator must provide the requisite quantities of work equipment, devices and materials, all in working order. Accordingly, the various parts and equipment have to satisfy numerous requirements regarding the protective measures that need to be taken. There are certain general requirements in terms of stability, vibration damping, operability, sabotage and vandalism that apply to all parts of the plants:

- **Stability:** Parts of the biogas plant installed above-ground outdoors must be mounted on a sound foundation and protected against damage. They must be installed in such a way as to be easily accessible. Sufficient structural stability must be ensured.
- **Vibration damping:** Moving parts and parts subject to vibration within the biogas plant (CHP unit components, blowers, pumps, compressors, etc.) must be decoupled with compensators and vibration dampers, for example.
- **Operability of vital plant components in different weather conditions:** The parts, components and equipment of the biogas plant relevant to safe operation must be designed to remain operable at all times at the anticipated ambient temperatures and in the expected weather conditions.
- **Sabotage/vandalism:** System-relevant and safety-relevant fittings and controls must be protected against sabotage and vandalism. Lockable equipment can be used to ensure that this is the case, or fencing can be erected around the biogas plant as appropriate.

The specific requirements for safe operation of the individual parts of the plant are described in the following section. Each description is divided into three parts:

Technical protective measures

Organisational protective measures

Zoning according to the potential explosion hazard

1. Requirements for feeding systems

Technical protective measures

When choosing and designing the feeding systems it is essential to pay attention to whether the materials used are subject to particular stress or exposure (e.g. acids, sand etc.). It is strongly recommended that stainless steel or coatings should be used in particularly sensitive areas. Depending on the local climatic conditions, plant components at risk of freezing must be designed to be frost-proof. Mechanical drives must be fitted with protective covers. Separators to remove interfering substances must be provided where necessary. Openings through which filling takes place, e.g. solids feeding equipment, must be secured to prevent people falling in. Measures to prevent falling in include:

- covered loading hoppers with a height of > 1.30 m in combination with a cover
- loading hoppers with no cover with a height of ≥ 1.80 m
- fixed grids with a rod spacing ≤ 20 cm
- self-closing flaps on vertical openings
- wash-in channels in which vertical openings are covered

If the digester is filled by means of a compacting screw, in consideration of all operating states it must be sufficiently immersed to prevent the possible escape of gas. The immersion must correspond to at least five times the response pressure of the overpressure protection device. If it is impossible to rule out the formation of hazardous gases outside the feeding system (CH_4, CO_2, H_2S, NH_3, H_2 etc.) it is necessary to prevent or reduce their release, for example through the use of appropriate filling equipment in a closed system or through spatial separation from other areas of the plant. Note the prevailing wind direction when positioning filling openings so that gases will be blown away from the operating area. If feeding systems are installed inside buildings, they must be equipped with ambient air monitoring and ventilation. Liquid substrates must be fed in through hoses/pipes in such a way that no gases can escape into the building. Ventilation systems to/from the holding tank must end in a safe area via a closed line.

Organisational protective measures

The general principle is that the formation of hazardous gases outside the feeding system must be prevented if at all possible, or at least minimised, for example by preventing certain chemical reactions from taking place (filling at different times). Mixing of substrates outside closed tanks from which hazardous gases such as hydrogen sulphide, carbon dioxide or ammonia can be formed as a result of chemical reactions (for instance acid-base reactions) should be avoided. If reactions are to be expected as a result of feedstock materials being mixed before they are fed into the digester, reaction tests should be carried out with harmless quantities of the substances before mixing.

Different feeding systems

PHOTOS: MT ENERGIE

In order to be able to assess such reactions, operators of biogas plants must obtain the following details from the producers of their feedstocks and document these in the operating diary:

Documentation of details of feedstock materials

- *main constituents, chemical composition, pH value and admixtures, e.g. stabilisers, preserving agents, etc.*
- *details of origin (e.g. from a slaughterhouse, from the production of heparin in the pharmaceutical industry, etc.)*
- *transport and delivery conditions (e.g., duration of transport, temperature, ...)*
- *potential hazards (e.g. ‘can release hydrogen sulphide upon addition of acids’). If it is impossible to rule out the formation of hazardous gases, especially H_2S, it is necessary to prevent or reduce their release, for example by means of closed filling, spatial separation or forced removal of the gases.*
- *other remarks*

Materials with a high sulphur content include wastes from slaughterhouses, waste biomass (mycelium) from biotechnological processes, rapeseed cake, remnants of animal feed (e.g. soy protein), methionine from animal feed (feed additive), residues from yeast production, sodium sulphate as a preserving agent, adjuvants such as iron sulphate or catering waste.

Feeders may need to be fitted with a control platform to ensure that the filling or flushing hose is safely controlled. Attention must be drawn to the gas hazards in the immediate proximity of the feeder. If the occurrence of gases in hazardous concentrations in feeding areas cannot be ruled out, suitable gas warning equipment must be installed to ensure that warning is given of gas hazards, in particular from H_2S.

In the course of their work on feeders, employees may be exposed to biological agents through contact with substrate, fermentation products or condensate or with impurities in pipes and gas-carrying plant parts. The number of employees who are or may be exposed to biological agents must be limited to those actually needed to perform the task in hand. Before carrying out work in the danger area of feeding systems, check whether the work is permitted to be performed alone. In particular it is important to be certain of preventing the feeding systems from starting up automatically during maintenance work.

During the filling process, trace elements (e.g. nickel, selenium) are often added to the feedstock. As a general rule the use of trace elements should be restricted to the necessary minimum. If the use of additives and auxiliary materials is unavoidable, zero-emission or low-emission types must be chosen (e.g. pelleted or coated products rather than powdered products), and this must be documented. Appropriate measures must be taken to avoid the open handling of additives and auxiliary materials. Employees' exposure to additives and auxiliary materials must be avoided or at least reduced to the minimum achievable through technical and organisational measures.

The following types of work with additives and auxiliary materials are most likely to present hazards:

1. visual inspection of packaging for damage, acceptance check
2. unloading from delivery vehicle, transport within the plant, placing in storage
3. removal from storage, making ready for use, putting to use
4. removal of impurities
5. performance of maintenance work, e.g. on the metering system
6. disposal or return of packaging

Classification of Ex zones

If a tubular screw conveyor system to feed input materials is installed below the surface of the liquid in the digester, the following requirements must be met:

- limitation of the removal flow rate and daily checking of the fill level, or
- if the fill level falls below a minimum limit, an alarm is automatically triggered and removal is shut down so that the system remains safely below the level of the liquid.
  No zoning necessary, unless the manufacturer's instructions specify different classification of zones.

In the case of liquid feeding systems (silage diluted with liquid feedstock to make it pumpable) the possibility of a hazardous potentially explosive atmosphere being formed cannot be ruled out. Additional explosion protection measures (ventilation, monitoring of CH_4 concentration, etc.) are required in the vicinity of the feeder.

2. Requirements for substrate treatment systems

The following substrate treatment methods may be used, depending on the process engineering needs:

- mechanical systems
- chemical systems
- biotechnological systems

Technical protective measures

If rotating parts are used, they must be designed in such way that technical measures (e.g. a protective cover) prevent people from reaching in, being pulled in or falling in.

Organisational protective measures

Wherever mechanical systems are used, hazards caused by moving or flying parts and by the risk of falling in, especially during maintenance work, must be taken into account. Where chemical systems are used, for example additives and auxiliary materials, the relevant safety data sheets from the manufacturers and distributors must be heeded. When using substances that pose a risk to health (e.g. trace elements), ensure that they are stored and metered in closed systems to minimise emissions.

Classification of Ex zones

→ See Ex zone classification for holding tanks/digester preliminary pits (see section 3)

Preliminary pit

3. Requirements for holding tanks/preliminary pits

Technical protective measures

Holding tanks/preliminary pits for substrates inside buildings must be equipped with a suitable (e.g. explosion-protected) extraction unit with at least five air changes per hour and flow monitoring with an alarm in the event of failure.

Organisational protective measures

The equipment for extracting the gases must be automatically switched on during the filling process. Openings in the receiver tanks must remain closed except during the filling process.

Satisfactory functioning of the extraction unit must be checked prior to commissioning and the results must be documented.

Classification of Ex zones

- **Holding tanks/preliminary pits:**
  Pit or tank, open or closed, for the receipt, buffer storage and feeding of feedstock, in some cases involving the mixing or recirculation of substrate or digestate, with or without heating.
  No zoning necessary, unless the manufacturer's instructions specify different classification of zones.
- **Open holding tanks/preliminary pits outdoors:**
  Pit or tank for slurry, open across its entire cross-section, with or without floating cover (no heating, no substrate recirculation and no digestate recirculation), gas accumulation not possible.
  No zoning necessary, unless the manufacturer's instructions specify different classification of zones.
- **Closed holding tanks/preliminary pits outdoors:**
  Pit or tank with a technically leak-tight cover; even slight leaks are detected at an early stage by regular checks; suitable gas displacement with respect to the gas system in order to reliably prevent overpressure and underpressure; leak-tight feedstock input thanks to loading below the surface of the substrate. Closed receptacles of this type also include receptacles with substrate recirculation, substrate mixing and heating.
  No zoning necessary, unless the manufacturer's instructions specify different classification of zones.
- **Interior of closed holding tanks/preliminary pits:**
  Zone: same as the zone with the highest requirements in the connected gas system.
- **Vicinity of closed holding tanks/preliminary pits:**
  No zoning necessary, unless the manufacturer's instructions specify different classification of zones.
- **Covered holding tanks/preliminary pits without substrate recirculation and without heating outdoors:**
  Non-technically leak-tight receptacle, not connected to the gas system. Has openings for filling.
  No zoning necessary, unless the manufacturer's instructions specify different classification of zones.
- **Holding tanks/preliminary pits for easily degradable substrates:**
  Easily degradable feedstock materials include liquid and paste-like biowastes. An adequate flow rate (e.g. at least five times air change of the pre-digester pit volume) is provided by monitored extraction.
  Zone 2: interior.
  No zone: exterior.
- **Holding tanks/preliminary pits for slurry with maximum fill level below ground level:**
  A sufficiently large opening area, e.g. through grating covers; very low gas production rate as a result of the low temperature.
  Zone 2: interior
  No zone: exterior
- **Insufficiently large opening area:**
  Air exchange takes place only during loading and emptying processes. Very low gas production because of the low temperature.
  Zone 1: interior
  Zone 2: in the immediate area surrounding the openings

4. Requirements for the digester

Technical protective measures

Structural analysis of concrete containers must take account of the thermal stresses that are expected to arise depending on the planned insulation and the temperature of the substrate.

In plants where leaks can arise above the level of the surrounding ground it has proved worthwhile to build a surrounding wall that retains the volume that could be released in the event of operational faults until appropriate safety precautions take effect, and at least traps the volume of the largest tank. This does not apply to storage facilities for solid digestion feedstock materials. The surrounding wall does not have to be completely closed; it can also take the form of a partial retaining wall if this sufficiently ensures the retention of escaping materials. The base within the surrounding wall may consist of cohesive soil or paved areas, for example concrete and asphalt.

Access openings must have an inside diameter of at least DN 800 (according to ISO 6708) or have minimum dimensions of 600 x 800 mm. If it is necessary to enter a tank for maintenance or repair work, it must be possible to provide adequate ventilation; the same safety measures are also required when accessing inspection chambers. These openings must be considered for the static concept of the digester.

Every tank (including pre-digestion holding tanks/ preliminary pits) that holds gas, substrate or digestion products must be capable of being shut off from the rest of the system individually and in all directions.

In the digestion tank and secondary digester a fill level monitoring system must ensure that the fill level is not exceeded, for example by the digested substrates being fed to the liquid-manure pond via a riser pipe (overflow) with frost protection or the maximum fill level of the tanks being limited with a suitable overfill protection device.

Particular attention must be paid to the operation of tanks that have greatly fluctuating fill levels, such as secondary digesters or gas-tight end storage tanks, for example with regard to explosion protection.

PHOTO: SCHMACK

Interior of a digester prior to commissioning

PHOTO: JÜRGEN WINDMEIER

An accident at a biogas plant

Organisational protective measures

The visible parts of the tank must be regularly checked for leaks, and likewise the tightness of the sight glasses. See section on inspections and tests for further details.
Submersible-motor agitators and submersible-motor pumps must always be submersed when in operation. Appropriate operating instructions must ensure that this is the case.

Classification of Ex zones

Interior of the digester
The tank is constantly filled with gas and is operated with positive pressure. If the pressure drops, there is a risk that atmospheric oxygen can enter the interior. Oxygen is prevented from entering the interior in the following ways:

Specific requirements

- Ensure gas production, e.g. by regular feedstock input
- Ensure that the enclosure is leak-tight and stable
- Monitor the fill level of the substrate and if necessary shut off withdrawal from the liquid phase (gas isolation point)
- Ensure operation with positive pressure even in the event of a sudden drop in temperature, e.g. by means of
  - **i.** suitable gas displacement with respect to the gas storage tank(s)
  - **ii.** constant monitoring of gas overpressure in the interior and gas withdrawal
  - **iii.** sufficiently variable volume of the gas storage tank
- In addition, where inflatable double layer roofs are used: ensure that the supporting air pressure is lower than the pressure in the gas storage tank, and ensure that the inner membrane is leak-tight and stable.
  No zoning necessary, unless the manufacturer's instructions specify different classification of zones.

In the event that the above-mentioned requirements are in place without all measures to monitor and safeguard positive gas pressure being implemented, the following conditions apply:

- The occurrence of potentially explosive atmospheres is identified, and measures are taken to ensure that such atmospheres occur only rarely and for short periods.
  Zone 2: above the surface of the substrate in the interior

Foreseeable disruptions or process-related operating states that occur occasionally can allow air to enter the interior of the digester, resulting in concentrations falling below the UEL.

- The occurrence of potentially explosive atmospheres is occasionally possible.
  Zone 1: above the surface of the substrate in the interior

Agitators and ducts for agitator shafts and adjusters for agitators, e.g. cable mechanisms
Submersible-motor agitators and submersible-motor pumps should comply with degree of protection IP 68 according to DIN EN 60529. Material requirements relating to corrosion, shear forces and thermal stability should be taken into account when selecting the agitators.

- Ducts, technically leak-tight, in combination with regular checks and maintenance, or the agitator penetration below the surface of the liquid/substrate.
  No zoning necessary.
- Ducts, technically leak-tight and above the surface of the liquid/substrate.
  Zone 2: 1 m around penetration.

Overflow aid

- Overflow aid with screw conveyor.
  Zone: as in downstream gas space.
- Pressure surge overflow aid with physical limitation of the injected air (volume limitation and flow rate limitation).
  Zone 0: in the pipe and in the vicinity of the overflow.
- Pressure surge overflow aid without physical limitation of the injected air.
  Zone 0: in the pipe and in the digester.

Surroundings of sight glasses in inside spaces

- Bull's eyes and observation windows must be fitted in a leak-tight mounting in the digester and permanently technically leak-tight according to manufacturer's declaration.
  No zone.
- Sight glass technically leak-tight, routine leak checks in accordance with manufacturer's instructions.
  No zone.
- Sight glass technically leak-tight, but no routine leak checks.
  Zone 1: immediate vicinity.
  Zone 2: remaining area.

Digestate storage with connection to gas system prevent air entering the gas system in the following ways:

- Ensure operation with positive pressure even during removal of digestion products, e.g. by constant monitoring of gas overpressure in the interior and shutting off gas extraction pipes and extraction points from the liquid phase;
- Planned, monitored removal of digestion products, especially by
  - ensuring gas supply,
  - visual inspection for ethylene propylene diene monomer (EPDM) rubber membranes or gas fill level monitoring for double membrane systems or rigid gas storage tanks,

- ▷ throttling the CHP unit,
- ▷ stopping removal of digestion products at minimum gas fill level;
- Ensure technical tightness with the aid of initial and periodic checks, e.g. through location with a gas camera and checking with foaming agents or a suitable gas detector;
- In the case of floating roofs, additional measures; see section on gas storage tanks.
  In the interior, ***same zone*** as gas system.

As operation with positive pressure during removal of digestion products is not guaranteed in this case, the following applies:

Zone 1: in the interior of the digestate storage tank and the interior of the connected gas system.

5. Requirements for the gas storage tank

Technical protective measures

Gas storages must be gas-tight, pressure-tight and resistant to the medium, to ultraviolet light, temperature and weathering (storm, snow etc.) in accordance with needs. With regard to wind and snow loads, in particular, it is essential that the manufacturer produces a design that is site-specific.

Gas storages must be connected via the gas-carrying system with overpressure and underpressure protection device.

Gas storage and their equipment must be protected against mechanical damage. To prevent damage from vehicles in vulnerable areas, the gas storage and its equipment must be protected by (for example) collision impact protection guards, non-traversable areas, barriers or observance of a safety distance. One means of meeting this requirement is to erect a safety fence around the gas storage. If the fence is less than 850 mm away from the gas storage, the fence must prevent reaching through. The safety fence must take the form of a non-passable barrier, for example made of wire mesh, at least 1.50 m high.

Especially in the case of gas storages made of plastic membranes, the following requirements must be met when selecting the materials:

- Tear strength min. $\frac{500\ \text{N}}{5\ \text{cm}}$ or tensile strength $\frac{250\ \text{N}}{5\ \text{cm}}$
- Permeability with regard to methane < $\frac{1000\ \text{m}^3}{(\text{m}^2 \times \text{d} \times \text{bar})}$
- Thermal stability for the specific application (mesophilic, thermophilic digestion process)
- Gas storages must be tested for leakage prior to commissioning

PHOTO: ADSOLUTIONS

Lagoon digester in Costa Rica

Especially in biogas plants operating according to the lagoon system, the large digester and gas storage surface areas pose additional demands on safety.

- Both to protect the environment and for safety reasons, the link between the gas storage and the lagoon digester should be technically leak-tight. Merely sealing the membranes by covering them with earth in the ground can be considered inadequate. The basic technically leak-tight attachment must be supplemented with regular organisational protective measures (checking for digester/gas storage leaks by foaming, gas detectors and infrared cameras).
- Gas storage facilities connected to lagoon digesters have a very large surface area and thus a potentially higher risk of leaks (edge formation, friction, tears etc.). All surfaces must be therefore checked for leaks at regular intervals (at least annually). Infrared cameras are useful for this purpose because then direct inspection of the membranes is not necessarily.

- Because of the very large surface area there are additional dangers from wind exposure and the membranes being torn off. The gas storage should therefore be fitted with additional safeguards to prevent this from happening.

Organisational protective measures

The gas storage must be checked for technical tightness prior to commissioning, after being repaired and at appropriate intervals.

The proper operation of gas storage systems requires complete documentation and regular checks and maintenance work.

If maintenance and repair measures have to be performed on single-layer or double-layer biogas storage membranes, they must not be stepped on. Any such loading (weight of an individual person) is only permissible if proof of walk-on stability has been furnished and a hazard assessment has been provided for the activities to be performed in the course of the maintenance or repair. Within the framework of the hazard assessment, a particular focus must be placed on fall protection measures.

Classification of Ex zones

Support air system

The support air system includes the interspace, the support air inlet, support air outlet and the support air blower.

- The support air outlet is monitored for a sudden escape of gas by a suitable gas warning system with an alarm and for a gradual escape of gas by a suitable gas detector.
  Zone 2: inside the support air system and 3 m around air inlets and outlets.
- The support air outlet is monitored for a gradual escape of gas by a suitable gas detector.
  Zone 1: inside the support air system.
  Zone 2: 3 m around air inlets and outlets.
- Blower (no cross-flow through the interspace, therefore occasional build-up of a concentration of diffusing biogas and sudden release when the gas membrane is lifted or the blower stops) is possible. The build-up of concentrations at certain times is prevented by breathing as a result of pressure fluctuations.
  Zone 0: in the interspace.
  Zone 1: 3 m around openings.

Outer surroundings of the attachments of gas storage membranes outdoors

- The attachment is technically leak-tight combined with adequate organisational measures, and the attachment is regularly checked for technical tightness. The clamp connection is released only rarely. Technical tightness over the long term is ensured in particular by seals appropriate to the pressure rating, the prevention of pressure loss in the clamp hose connections, design resistance to precipitation and wind loads and organisational protective measures. Maximum pressure level p max = 5 mbar (5 hPa) (depending on attachment system). Biogas-resistant seals have to be implemented. Technical tightness is tested initially and periodically, e.g. by locating with a gas camera and subsequent checking with foaming agents or a suitable gas detector.
  No zone: exterior.
- As above, but the attachment is not only rarely released.
  Zone 2: 2 m around the attachment

Surroundings of single film systems

- Technical tightness combined with adequate organisational measures. Initial and periodic monitoring, e.g. locating with a gas camera and checking with foaming agents or a suitable gas detector.
  No zone.
- As above, but no adequate organisational measures and without periodic checking.
  Zone 2: 3 m around gas storage and 2 m downwards at 45°

6. Requirements for wooden roof structures in gas storage systems

Wooden roof structures are often used as a substructure for gas storage systems. As wooden roof structures in biogas storages are exposed to particular conditions, and visually indiscernible damage to wood reduces the load-bearing capacity of the beams to such an extent that they are liable to fail without notice, a special approach to checking structural stability must be used for the sake of the safety of all persons charged with inspection/maintenance work.

Technical protective measures

Whenever wooden roof structures are used it is important to make sure that the structural analysis calculations take account of the unusual environment, water saturation and sulphur deposits. In order to guarantee the stability of the wooden structure, reinforcements must be installed between the beams. It is also necessary to choose suitable quality timber that is precision-cut to size.

The supporting construction of the timber beams must be designed such that the beams are prevented from slipping out if they become deformed.

Organisational protective measures

In order to ensure the stability of wooden roof structures, regular visual inspections and checks must be carried out during operation to identify any abnormalities. If the tank is opened for operational reasons, a load test must be performed prior to walk-on access.

Regular checks of timber roof structures

- Regular visual inspection through sight glasses by the persons responsible (operator, person appointed by the operator or specialised firm) for:
  - conspicuous deformation, irregularities, breaks or splintering, for the purpose of ruling out acute apparent danger during subsequent investigative steps.
- Regular checks regarding abnormalities in operation by the persons responsible (operator, person appointed by the operator or specialised firm) for:
  - damage to or malfunctions in agitators, screw conveyors, etc.
  - pieces of wood in pumps, coarse material screens or separators.

The aim is to detect damage at an early stage and prevent economic consequences.

- Ad hoc check
  Checking carried out in the course of opening of the tank for operational reasons by the persons responsible (operator, person appointed by the operator or specialised firm):
  - A load test must be performed before anyone steps on the wooden roof structure.
  - The load test must be carried out with a load calculated according to the formula below at at least three representative points in midspan (centre of a beam in the longitudinal direction). If the entire area is affected, testing of the roof structure must be carried out on at least every third beam and on particularly conspicuous or sagging beams. The test load must be applied for a period of at least three minutes in midspan. This can be done with a crane, for example.


PHOTO: ÖKOBIT GMBH

Wooden roof structure of a digester

The method to be used for calculating the load needed to test the load-bearing capacity of the timber beams is as follows:

- **With cladding on the beams:**
  Area for loading a timber beam:
  $A = e x \frac{R}{2}$ (m^2)
  e = spacing between beams
  R = radius in meters
  Test load (concentrated load in midspan) for the load test: $P = A x \frac{75}{2}$ (kg)
  Minimum test load: 200 kg concentrated load per person, on each beam on which a person or persons will walk.
- **Without cladding on the beams:**
  In this case the load can be produced for example by a pallet with a water tank, placed on supporting beams (12/12 cm).
  Area for loading a timber beam: $A = e x \frac{R}{2}$ (m^2)
  Test load (concentrated load in midspan) for the load test: $P = A x \frac{75}{2}$ (kg)
  Minimum test load: 200 kg concentrated load per person, on each beam on which a person or persons will walk.

7. Requirements for installation rooms for gas storages

Technical protective measures

Installation rooms for gas storages must have non-closable air inlets and outlets that allow cross-ventilation. Where natural ventilation is used, the air inlet must be positioned near the floor and the air outlet in the opposite wall near the ceiling.

Gas storage facility

If a technical ventilation system is installed it must be ensured that the exhaust air is extracted from the ceiling area. The exhaust air must be expelled directly into the atmosphere. The forced ventilation system must be dimensioned such that a maximum possible gas volume is diluted to a maximum gas concentration of 20 % LEL in the installation room.

The air inlets and outlets must each have the following minimum cross-sections:

Gas storage volume	Cross-section
up to 100 m³	700 cm²
up to 200 m³	1000 cm²
over 200 m³	2000 cm²

Doors must open outwards and must be lockable. The safety distances as defined in the section on the fire protection concept must be taken into account.

Organisational protective measures

Clearance measurement is essential prior to work in hazardous areas. Written permission is required for work involving the use of an open flame.

Classification of Ex zones

The gas bag lies on the ground and is protected from the weather by a fixed housing. The housing is accessible all-round even when the bag is full.

In inside spaces

- Constant ventilation of the space between the gas bag and the housing; flow monitoring and concentration monitoring; installation of a gas overpressure protection device and installation of a gas low pressure switch.
  Zone 2: Inside the housing and within 3 m of all openings to other rooms, and in the vicinity of openings to the open air with the exception of the gas overpressure protection devices. In the interior, the same zone as the connected gas system.
- Natural ventilation of the space between the gas bag and the housing; installation of a gas overpressure protection device and installation of a gas low pressure switch.
  Zone 1: inside the housing
  Zone 2: within 3 m of all openings. In the interior, the same zone as the connected gas system.

Outdoors

Zoning outdoors is essentially the same as in inside spaces. However, the effects of weather outdoors generally make it possible to define a zone with lower requirements than those for comparable situations indoors, or to reduce the extent of the zone.

8. Requirements for substrate-carrying parts of the biogas plant

Technical protective measures

Substrate-carrying pipes (including fittings, valves, flanges, sealants and conveyor equipment) in biogas plants must be leak-tight and adequately resistant to the mechanical, chemical and thermal influences expected to arise with reference to the intended service life. They must be longitudinally force-locked and frost-proof.

Pipes must be installed in such a way that their position cannot be inadvertently altered. They must not be used as carriers for other piping or loads and must not be attached to other piping. Detachable joints and fittings must be installed as fixed points. Suitable materials must always be used for pipes (including fittings, valves, flanges, sealants and conveyor equipment); their suitability and proper fabrication must be verified and documented by the manufacturer in accordance with the relevant technical rules.

The material for each pipe must be chosen according to the chemical properties of the substrates flowing through it (if applicable, take account of possible changes of input materials), the operating temperature and operating pressure. Depending on the area of application, metal (steel, stainless steel) and/or thermoplastic (PVC-U [not underground drainage pipe], PE, PP) materials come into consideration. Pipes must be protected against external corrosion or UV radiation, as applicable, depending on the material and installation location. Pipework must be planned, designed and installed such that it can be inspected and tested not only prior to commissioning but also periodically (take account of test pressure; make provision for all necessary shut-off devices for tests).

Substrate-carrying pipes must be calculated and designed in accordance with the relevant technical rules. All forces and influences acting on the pipework (e.g. live loads, loads on connecting pipes, vibration stress, pressure surges, wind/snow) must be taken into account in the calculation and design of substrate-carrying pipes, all pipe parts and support structures. Where possible, above-ground substrate-carrying pipes must be routed outside traffic areas and marshalling areas; if this is not possible, they must be protected against mechanical damage with collision impact protection guards.

The pipes must be laid and installed in accordance with recognised standards of professional workmanship. Jointing work must always be performed by specialists qualified for the respective material. Prefabricated parts are to be used for connections (to pipes and shafts/ducts).

Pipes must be connected to buildings in such a way that subsidence, for example, does not adversely affect the tightness of the joints. Wall bushings must use pipe ducting systems that are tightly integrated into the wall and secured to prevent being pushed out. The installation instructions provided by the manufacturers of the pipes and wall bushing systems must be observed. Where necessary, pipes must be secured to prevent being lifted out. If it is impossible to rule out maximum operating pressure being exceeded, measures to prevent excessive pressure in the pipework must be taken. In order to prevent unintended discharge from a tank in the event of the failure of a pipe connected to the tank below the level of the liquid, the pipe must be capable of being shut off directly at the tank by means of a gate valve.

TIP: PVC-U pipes

PVC is not UV-resistant and its impact strength is low. Proper storage and processing are essential whenever it is used, which means in particular following the relevant instructions (for example manufacturer's instructions) regarding installation and processing. Proof must be provided that the installer has the requisite expertise. Copper is not resistant to biogas; experience shows that brass and gunmetal are suitable (commercially available PVC underground drainage pipes are not permissible because their structural rigidity corresponds to a maximum of only 500 hPa (0.5 bar)). Pipes including all associated equipment and flexible connections must have a structural rigidity of at least 1,000 hPa (1 bar).

As a general rule, steel pipes are to be used. Plastic pipes can be used outside enclosed spaces if laid below ground level in all cases and above ground level as connecting pipes to a plastic-sheeting storage tank and as connecting pipes to the digester. Plastic pipes must be protected against mechanical and thermal damage and, if necessary, against UV radiation.

Organisational protective measures

A piping layout plan (including the position and type of valves, fittings, connecting pipes and supports) must be drawn up which shows the material and size of the pipework, the pipe run and the integration of the pipework in the biogas plant.

Gate valves, especially those on filling equipment, and other shut-off devices (inspection openings, but also pumps) must be secured to prevent unauthorised opening.

The operator must regularly check all visible pipes for leaks by visual inspection and must document the inspection.

9. Requirements for gas-carrying parts of the biogas plant

PHOTO: SCHMACK

Gas pipes (and labelling)

Technical protective measures

Gas-carrying parts of the biogas plant must be protected against chemical, weather-related and – in vulnerable areas – mechanical influences and damage (e.g. collision impact protection guards in areas where vehicles move).

Gas-carrying pipes must conform to national requirements, with proof of proper manufacture, suitability for biogas and leak-tightness, for example by manufacturer certification. Requirements arising from structural analysis (wind, snow load etc.) must be taken into consideration when selecting pipe materials and calculating spans. The installation instructions provided by the manufacturers of the pipes and wall bushings must be observed when routing pipes through buildings (e.g. gas and substrate pipes) and for hydraulic engineering installations such as digesters, condensate shafts or other structures.

In gas pipes leading to consumption equipment such as heating boilers, gas flares and combined heat and power units, flame arresters must be fitted and operated as close as possible to the end-use equipment.

Spigot-and-socket joints that are not in themselves longitudinally force-locked must be secured against thrust according to the pressures arising. The pipe connections must be longitudinally force-locked.

Mechanical damage from settlement (for example in the case of wall bushings) must be prevented through the use of suitable bushings and appropriate connections. If the gas is wet, it is important to ensure the pipes are protected from frost. Condensate discharge pipes must be designed to be frost-proof and operational at all times. Pipes connecting to the gas storage tank inside the gas storage tank's installation room are considered part of the gas storage tank.

Two shut-off valves must be installed in the gas line upstream of each engine unit. The valves must close automatically when the engine stops. The interspace must be regularly checked for leaks. If the supply line to the engine has a constant upstream pressure (> 5 mbar) even when the engine is stopped, automatic interspace monitoring is required.

Organisational protective measures

Pipes must be labelled to indicate the medium carried and the direction of flow. When available, the relevant national guidelines should be followed in this regard.

The location of gas lines laid below ground must be identified by gas pipeline warning tape. The suitability of flexible gas-carrying connecting pieces belonging to the CHP unit and the component parts of the charge-air cooling system must be certified by the manufacturer of the CHP unit.

Connection points in gas lines for non-stationary facilities, such as mobile gas flares, must be fitted with isolation valves. The shut-off valve must be installed upstream of the non-stationary facility, viewed in the direction of gas flow. It must be possible to operate it safely.

Classification of Ex zones

Gas-carrying pipes

- Pipes carrying biogas (technically leak-tight); periodic inspection of plant parts for leaks.
  Same zone as connected plant parts.
- Pipes carrying biogas (technically leak-tight); periodic inspection of plant parts for leaks, but a potentially explosive atmosphere may occur in connected plant parts. The penetration of potentially explosive atmospheres into the pipes is prevented by automatic isolation from the connected gas system.
  Same zone as connected plant parts.

10. Requirements for condensate traps

Technical protective measures

It must be possible to inspect and maintain condensate traps easily and safely, without having to climb into shafts or pits. Permanently attached climbing irons are not permissible unless the shaft of the condensate trap has forced-air ventilation. Furthermore, access to these shafts is only permissible after clearance measurement.

The design of the trap and maintenance measures must ensure that the escape of gas is prevented in all operating states. Condensate discharge pipes must be designed to be frost-proof and operational at all times.

Pressurised seal systems must be designed such that the sealing liquid is unable to escape when the system is triggered but instead flows back automatically. The filling level of the liquid seal corresponds at least to a pressure of 15 hPa (150 mm water column or 15 mbar) above the maximum response pressure of safety devices and is monitored using measuring instrumentation.

Organisational protective measures

Requirements applicable to lone working must be taken into consideration (see section on protective measures).

Classification of Ex zones

In inside spaces

- Gas escape is prevented by the use of closed drainage systems, e.g. locks with interlocked double-shut-off valves; spaces with natural ventilation.
  No zone necessary.
- If drain cocks are present, or open water seals, it must be expected that a hazardous explosive atmosphere will be formed as a consequence of the water seals being punctured or drying out, or because of an operating error. Discharge to enclosed spaces; space with technical ventilation.
  Zone 2: entire space
- If drain cocks are present, or open water seals, it must be expected that a hazardous explosive atmosphere will be formed as a consequence of the water seals being punctured or drying out, or because of an operating error. Discharge to enclosed spaces; space with natural ventilation.
  Zone 1: entire space
  Zone 2: 1 m around openings in closed space

Outdoors

- Drain cocks outdoors, or pipes from condensate separators installed indoors ending outdoors.
  Zone 1: 1 m around the outlet nozzle
  Zone 2: a further 2 m around the outlet nozzle

11. Requirements for overpressure and underpressure protection devices

PHOTO: : MT ENERGIE

Overpressure and underpressure protection device on a digester

Technical protective measures

Every gas-tight tank must be equipped with at least one protection device to prevent the pressure rising above or falling below set limits. Any gas released as and when necessary must be safely discharged. A separate low pressure monitoring device in the gas system or an equivalent measure must be used to ensure that the gas-consuming facilities or substrate/digestion product removal are safely forced to shut down before the underpressure protection device is triggered, and that an alarm signal is issued. If overpressure is present in the gas system (gas storages, pipes etc.), as a rule an alternative gas-consuming facility (e.g. gas flare) should prevent the uncontrolled release of biogas (see section requirements for gas flares). There must be no means of shutting off supply in the supply line to the overpressure and underpressure protection device. Over and underpressure protection devices must be frost-proof.

It must be possible to inspect and maintain overpressure and underpressure protection devices easily and safely (stairs instead of a ladder).

Foaming of the substrate inside the digester or tank is an operational fault and can have a detrimental effect on the functionality of the overpressure and underpressure protection devices. This must be prevented by technical and organisational measures. Breakdowns/damage caused by foaming must be prevented by the provision of for example a burst protection device, a pressure relief device or sufficient storage space.

The suitability of the overpressure and underpressure protection device must be proven by a verifiable calculation and functional description. If designed to be immersed, the liquid tank must not be allowed to run empty, dry out or freeze. Liquid seals used as protection devices must be designed such that the sealing liquid flows back automatically in the event of overpressure or underpressure. The automatic closing of overpressure and underpressure protection devices must also be guaranteed for mechanical and hydraulic systems.

Any gas released as and when necessary in the event of overpressure must be safely discharged either upwards or to the side. The discharge pipes from the overpressure and underpressure protection devices must lead to an end point at least 3 m above the ground or the operating level and 1 m above the roof or the edge of the gas storage, or at least 5 m away from buildings and public rights of way.

Organisational protective measures

Overpressure and underpressure protection devices must be inspected in accordance with the maintenance plans (see section on inspections and tests).

Classification of Ex zones

An Ex zone must be designated around the opening of the discharge pipe depending on the frequency and duration of the occurrence of a potentially explosive atmosphere.
General requirements:

- The outlet of the overpressure and underpressure protection device is at least 3 m above the control platform (inspection level) and 1 m above the upper edge of the gas storage with a discharge capacity of up to 250 m³/h; unhindered, safe outflow upwards or to the side. The overpressure and underpressure protection device is checked regularly (daily) to ensure proper functioning.
  No zoning necessary.

- Restriction of overpressure and underpressure protection device response and limitation of emission by automatic gas fill level monitoring for operation with residual volume reserve or load-variable consumption, e.g. CHP unit with power reserve, and combustion by additional and constantly available gas-consuming facility before the overpressure and underpressure protection device responds.
  Zone 2: 3 m around discharge opening

- Restriction of overpressure and underpressure protection device response and limitation of emission by automatic gas fill level monitoring for operation with residual volume reserve or load-variable consumption, e.g. CHP unit with power reserve, and combustion by additional and constantly available gas-consuming facility before the overpressure and underpressure protection device responds, but *not all of these measures can be implemented:*
  Zone 1: 1 m
  Zone 2: a further 2 m around discharge opening of overpressure protection device.

12. Requirements for gas purification

Biogas is normally subjected to pre-cleaning prior to utilisation. In addition to fine filters, this almost always involves the use of desulphurisation systems.

12.1. Internal desulphurisation through the supply of air to gas spaces in the digester

Technical protective measures

If desulphurisation is carried out by supplying air to gas spaces in the digester, the added air must be spatially distributed and proportioned such that even if the flow control system malfunctions it is not possible to pump a total volumetric flow significantly more than 6 % of the biogas produced within the same time period.

A backflow preventer (check valve) is required in the supply line to the gas space, as close as possible to the gas space. There must be no other fittings apart from a shut-off device between the check valve and the gas space. The space between the check valve and the metering pump must be depressurised to a safe area outdoors in the event of the pump stopping if there is a danger of gas escaping into an indoor space.

Organisational protective measures

Regular checking of the oxygen content by measuring the volumetric flow of oxygen and plausibility checking of the gas yield or regular measurement of the oxygen content using a gas analyser.

Classification of Ex zones

Air supplied to the interior of the digester. Pipe bushings through the digester shell permanently technically leak-tight. Air infeed protected against backflow with spatially distributed input; volume of air max. < 6 % of volume of biogasnominal. Limitation of the volumetric flow of air is ensured by technical means, e.g. maximum compressor capacity. ***Zone 0:*** only in the vicinity of the air infeed openings and adjacent zone of the gas system.

12.2. Internal desulphurisation through the addition of iron compounds

If desulphurisation is carried out by adding iron compounds (e.g. ferrous chloride) to the digester, the manufacturer's instructions must be followed as per the data safety sheet. As iron compounds often have a corrosive effect, the materials coming into contact with them should be resistant to them.

12.3. Desulphurisation by means of ferrous materials or activated carbon in external facilities

Ferrous materials or activated carbon are often used for the external desulphurisation of biogas. These materials are capable of accumulating sulphur compounds. There is a risk of spontaneous heating when these filter media are removed and regenerated.

Technical protective measures

To be able to assess the functional capability of the activated carbon or other materials at all times, including in ongoing operation, it is strongly recommended that suitable monitoring systems (e.g. a gas analyser) should be installed.

Organisational protective measures

If the use of ferrous materials or activated carbon is unavoidable, zero-emission or low-emission types must be chosen (e.g. pelleted or coated products rather than powdered products).

Classification of Ex zones

Surroundings of external desulphurisation units (outside digesters)

Outdoors

- Desulphurisation system technically leak-tight. ***No zoning*** necessary, unless the manufacturer's instructions specify different classification of zones.

In inside spaces

- Desulphurisation system technically leak-tight. ***Zone 2:*** entire space

13. Requirements for gas analysis

A variety of gas analysis systems are used in practice, with a distinction being drawn between mobile and fixed systems and between manual and automated systems. The following gas constituents are regularly detected: CH_4, CO_2, H_2S and O_2.

Technical protective measures

The gas being measured must be discharged to the open air or returned to the gas stream. Alternatively, a forced ventilation system must be installed with a minimum air exchange rate that ensures adequate dilution of the maximum possible gas volumes or the gas facility must be relocated to the CHP unit installation room.

Organisational protective measures

Regular maintenance and calibration of the gas analysis systems is recommended in accordance with manufacturer's instructions.

Classification of Ex zones

- After gas analysis, the gas is discharged from the analyser to the open air. ***Zone 2:*** in the vicinity of the discharge opening.
- Technically leak-tight gas analyser in combination with adequate organisational measures in combination with regular leak checks and adequate ventilation in the room. ***No zoning*** necessary, unless the manufacturer's instructions specify different classification of zones.

14. Requirements for fittings and safety devices exposed to gas

Biogas plants have various fittings and safety devices that are exposed to gas, including:

- Overpressure and underpressure protection devices
- flame arrester
- gate valve
- sampling tap
- shut-off valve
- dirt separator
- etc.

Technical protective measures

Fittings, safety devices and plant parts exposed to gas must be installed to be frost-proof in accordance with national guidelines and must be checked for leaks. They must also be sufficiently resistant to media, corrosion and pressure.

Organisational protective measures

Valves and fittings must be easily worked by an operator adopting a safe stance. Fittings used for gas withdrawal must be secured against unauthorised and unintentional opening, for example by locking the handle.

The work instructions/operating instructions must state that safety devices are to be checked after an operational disruption and at regular intervals in normal operation, taking account of the manufacturer's instructions.

15. Requirements for gas flares

In order to prevent climate-damaging methane from being released, various national guidelines require biogas plants to have alternative gas-consuming facilities (thermal utilisation). Flare systems are often used for this purpose. There are different types of flare, which can essentially be divided into three categories: open flares; enclosed flame flares (>850°C) and high-temperature enclosed flame flares (>1,000°C).

Technical protective measures

Gas flare systems intended for use as alternative gas-consuming facilities must be continuously ready for operation and be capable of accepting the maximum volume of biogas production. The gas flare system is usually driven by the fill level of the gas storage, either pressure-controlled or via an external signal. The length of the ignition intervals must be ensured by approved control technology. Every gas flare system must have a safety valve (slow opening/rapid closing, normally closed) that reliably prevents the uncontrolled flow of air into the gas system of the biogas plant. The rapid closing function is executed in less than one second. The gas flare system must meet the general requirements for plant parts exposed to gas (in particular technically leak-tight, corrosion-resistant and frost-proof – including the condensate discharge pipe – in accordance with the explosion protection requirements). Gas flares must be equipped with a flame arrester (DIN EN ISO 16852). This should be fitted as close as possible to the end-use equipment.


Gas flare

The heat resistance of the materials used must be taken into account, for which for example manufacturer's notifications or a type examination certificate must be presented. The necessary minimum gas supply pressure (flow pressure) for the gas flare must be agreed between the manufacturer and the operator for each gas flare system. Insufficient gas supply pressure can lead to extinguishing of the flame, especially if it is windy or in


Gas flare

other special operating states (widely fluctuating gas storage fill levels). In automatic gas flare systems it is recommended that a minimum cut-in pressure of 10 hPa (0,01 bar) should be ensured. If it is not possible to achieve sufficient gas supply pressure upstream of the gas flare system, appropriate equipment to rectify this must be provided (e.g. gas pressure booster blower, pressure-maintaining valve).

For emergencies and maintenance work outdoors the gas supply to gas flare systems must be capable of being shut off manually as close as possible to the installation location of the consumption equipment. The open and closed positions must be identifiable or labelled.

It must be possible to operate gas flare systems sufficiently reliably, for example independently of power supply from the electricity grid (off-grid e.g. by battery, emergency power supply or by other organisational measures on the part of the operator), that the release of unburned biogas is safely avoided. Gas flare systems must be set up and positioned such that no persons are endangered by gases, flames or hot parts. The gas flare system should be erected in such a way that the flame is blown away from the gas storage tank, pressure relief devices, buildings and public rights of way when the wind is from the prevailing direction.

The exhaust gases from the gas flare must be discharged above roof level with free outflow or via a discharge pipe that must be at least 5 meters away from buildings and public rights of way and must end at least 3 meters above the ground.

Organisational protective measures

The gas flare should be checked for technical tightness and for proper functioning of its safety and monitoring equipment at regular intervals. The manufacturer's instructions for commissioning, operation and maintenance should be followed.

Classification of Ex zones

- The escape of gas to the surrounding area if the flame is not burning is prevented by an automatic shut-off device coupled with an automatically actuated ignition device and flame monitoring (auto ignitor). A suitable flame arrester is fitted in the gas line upstream of the flare.
  No zone necessary.

16. Requirements for process control system/instrumentation and control (I&C) system

Technical protective measures

Control systems with safety functions must be designed to be fail-safe, unless they are backed up by a redundant system, for example a mechanical overpressure protection device to protect against overpressure or an overflow to protect against overfilling.

In the event of failure of the auxiliary power (electricity, hydraulic or pneumatic supply to the biogas plant), a safety shut-down or actuation of the emergency stop switch, the plant or the relevant parts of the plant must switch to a safe state. The safe state can be achieved by means of control engineering measures, hydraulic measures or mechanical measures.

Examples:

- Closing of automatic gas valves outside the CHP unit installation room
- Switching off relevant gas compressors
- Disconnecting all non-explosion-protected parts

in installation rooms exposed to gas (CHP unit, gas purification, etc.)

- Closing of gate valves so that substrate cannot flow back into the feed system (e.g. pre-digester pit, animal shed)
- External feed facilities must be capable of being shut off in the event of system breakdown to prevent overfilling
- A drop in the fill level must not lead to an uncontrolled escape of gas, for example from the feed system

The latest applicable standard for electrical equipment of machines and the equivalent for safety-related parts of control systems must be used for the design of safety-related parts of the control system. A hazard and risk analysis must be performed in accordance with national guidelines.

Organisational protective measures

The requirements for safe functioning of instrumentation and control (I&C) equipment with a safety function must be established, determined and documented on the basis of a hazard assessment.

17. Requirements for electrical engineering

17.1. Equipotential bonding

The relevant national regulations apply to all electrical installations and switchgear.

In order to prevent the creation of potential differences, all electrically conductive plant parts must be connected to each other and to the protective conductor and the potential equalisation.

> **TIP**
> *It is always advisable to have the electrical installations checked by a qualified electrician prior to commissioning and at regular intervals. For details refer to the section on inspections and tests.*

Technical protective measures

The following protective measures must be taken in order to prevent potential differences:

- Cable entries and glands must be suitable for the respective ignition protection types. In addition, electrical installations must be designed and electrical equipment assembled and installed so as to ensure easy access for inspection, testing and maintenance.
- Electric cables and leads must be laid separately from pipes, with the exception of electric trace heating systems. Electrical installations must be designed to restrict the effects of electromagnetic fields to a safe level.
- Dangerous accumulations of electrically conductive dusts in or on electrical equipment must be avoided, for example by means of enhanced dustproofness for the equipment.
- Suitable measures must be taken to prevent the entry of ignition sources into hazardous areas via cables and leads. Cables and leads should be laid without interruptions in hazardous areas. If this is not possible, the connections must be made in enclosures with a protection type appropriate to the zone or they must be secured by means of appropriate junction boxes.
- Discharges of static electricity must be avoided if they are capable of being effective ignition sources.
- High charge-generating processes give rise to such high charge levels that spontaneous ignition-inducing discharges may occur. The use of objects or equipment made of insulating materials in hazardous areas should be avoided. If objects or equipment made of conductive or dissipative materials cannot be used, measures must be taken to prevent dangerous charging.

> **TIP**
> *Possible measures include conductive or dissipative coatings, conductive threads in textiles, limitation of surface areas or reliably effective organisational measures.*

Organisational protective measures

The plant operator must ensure that the only persons to have access to the hazard area of electrical installations are those who on account of their professional training, knowledge and experience are able to recognise the electrical hazards arising and take the necessary occupational health and safety measures, and that other persons are permitted to enter the hazard area only when accompanied by persons as described above.

The plant operator must also ensure that all electrical installations and equipment used are suitable for use under exposure to the stresses and loading from the operating conditions and environmental conditions at the workplace.

17.2. Protective measures in the event of a power outage

As part of a hazard assessment it is important to produce as comprehensive a list of potential hazards as possible for each biogas plant individually and to determine the necessary protective measures deriving from that for each specific situation. In the following the focus is set on the hazards arising and necessary countermeasures to be taken in the event of failure of the public power grid.

Technical protective measures

In order to be able to guarantee an emergency power supply for the biogas plant the first requirement is fault-tolerant installation (e.g. safe from floodwater or from substrate if it escapes inside the surrounding wall).

In addition, the electrical installation of the biogas plant must be checked for ‘quick-action’ activation of the agitators and other important components. In this regard consideration should also be given to power failures caused by thunderstorms, for example: if important components such as the programmable logic controller (PLC), frequency converter, 24-volt power supply units or emergency stop relays cannot be started quickly, further precautionary measures must be taken. Ideally, agitators or other important components can be started in parallel with the plant control system using a simple installation without a PLC and frequency converters (e.g. operation only with plug connector and motor protection).

In relatively large biogas plants with several parts to the plant (such as gas processing systems) the gas flare systems are not necessarily controlled by and supplied from the biogas plant. In such cases it should be examined how the gas flare system can be put into operation by ‘simple’ means in the event of a complete power failure.

In order to be able to guarantee a reliable supply of power it is also highly important to determine the power required to maintain the essential processes. This includes:

- Defining all processes that need to continue running in the event of a power failure
- Establishing the length of time for which the defined processes need to continue running in order to prevent any danger from arising
- Determining the power demand that needs to be met by an uninterruptible power supply (UPS):
  - information technology
  - alarm systems
  - telecommunications
  - safety lighting, etc.
- Determining the total amount of power needed to maintain operationally critical processes:
  - information technology (all of the above)
  - system control
  - agitators
  - gas-consuming equipment (if applicable including compressor)
  - lighting

Choosing the correct emergency power strategy is also important. Various options are presented in Table 6.

Table 6: Advantages and disadvantages of various emergency power strategies

	Advantages	Disadvantages
Fixed emergency power unit with own fuel store	▶ Availability Possibility of automatic start-up ▶ Fewer possibilities of error in commissioning	▶ Regular maintenance required
Mobile emergency power unit with own stock of fuel	▶ Can also be used for other purposes for short (!) periods	▶ Generally smaller than fixed units ▶ Requires basic electrical knowledge (needs a larger number of manual switching procedures) ▶ Greater workload involved in setting up in an emergency compared with a fixed emergency power unit (obtaining the unit and connecting cables to the biogas plant)
Mobile emergency power unit driven by tractor (PTO shaft connection)	▶ High level of availability ▶ Lower cost	▶ Requires even more basic electrical knowledge (rotating field? max. available output? equipotential bonding? power system stability, etc.) and needs a larger number of manual switching procedures ▶ Even greater workload involved in setting up in an emergency than with a mobile emergency power unit (obtaining the unit, cables and tractor) ▶ Tractor must match the unit (correct PTO shaft, correct rotational speed, sufficient output)

Organisational protective measures

A number of additional organisational measures must be taken into account in order to safeguard emergency power supply.

Drafting of an emergency plan for power failure comprising:

- organisation chart (organisational structure)
- determination of responsibilities and accountabilities including telephone numbers, in particular arrangements for on-call service and its tasks and powers
- task description
- alarm levels and decision-making channels (organisational procedures)
- determination of which workplaces can be used and which workplaces are exposed to risks (e.g. overpressure and underpressure safety device).

In addition, employees must be given regular instruction and briefings, with written proof, and hold exercises covering specific dangerous situations. The experience gained in these should be incorporated into the emergency strategy.

Inspection and maintenance plans must be regularly updated. It is also important to check regularly whether the design of the emergency power unit and uninterruptible power supply (UPS) meet the current capacity and quality requirements. Furthermore, regular checks/functional tests of the fuel are required.

The fuel quality of diesel in particular is liable to diminish on account of weather conditions and ageing.

It is likewise very important to compile a set of operating instructions with a comprehensive description of operation and maintenance (including plans for operation under emergency power and exercises). During emergency operation it is necessary to check whether all intended loads are receiving power (using a prepared checklist; including telephone connection). For this purpose, an individual should be nominated (if applicable an operational safety officer) who is responsible for operation and maintenance of the emergency power supply system.

The holding location should be specified and secured. Access to mobile emergency power units must be possible without hindrance. When the unit is put into service, a trained electrician must be present for an initial trial in isolated operation or an emergency power exercise. The emergency power unit must be properly earthed in order to prevent the tripping of residual-current-operated circuit breakers. The labelling of the switchgear cabinet must be easily comprehensible.

If the emergency power unit is potentially used for more than one business/type of business:

- ensure that in emergency operation each connected user is able to draw at least the minimum amount of energy from the emergency power supply defined in advance;
- make technical provisions to ensure that in emergency operation each connected user is able to draw only the maximum amount of energy from the emergency power supply defined in advance.

18. Requirements for lightning protection

The matter of lightning protection at biogas plants must be managed in accordance with national regulations and the regional risk of lightning strikes. There is a basic distinction between external and internal lightning protection. Internal lightning protection serves to prevent surge damage within the installation. External lightning protection by means of lightning rods serves to divert lightning strikes that would hit the protected installation directly.

Technical protective measures

Biogas plants should have at least internal lightning protection. A surge arrester (internal lightning protection) and consistent equipotential bonding are therefore required for the electrical installation and the facilities for electronic control, data processing and telecommunications. Experience to date suggests that external lightning protection (intercepting devices, arrester equipment, earthing system etc.) is not generally necessary.

Organisational protective measures

The matter of lightning protection should be taken into consideration in the hazard assessment carried out for the construction and operation of the biogas plant.

Further information concerning lightning protection can be found within the norm DIN EN 62305.

19. Requirements for rooms with substrate-carrying and/or gas-carrying plant parts

Rooms with substrate-carrying and/or gas-carrying plant parts include the CHP unit installation room, pump room, etc.

Technical protective measures

General requirements
As a general rule, maintenance and control stations and the controls of valves, agitation, pumping and flushing equipment should always be situated above ground level. If this is not possible, adequate technical ventilation must be provided with at least five air changes per hour.

Requirements for CHP unit installation rooms
If it is not possible to ensure that all gas-carrying plant parts in CHP unit installation rooms are permanently technically leak-tight, sources of ignition must be avoided and if applicable explosion protection zones must be designated. Explosion protection zones in installation rooms can be restricted or avoided by taking additional measures, such as a forced ventilation system with monitoring of the air flow or a gas warning device coupled with ventilation.

Depending on the nature of the gas, the detecting element of the gas warning device should be mounted above or in the vicinity of possible sources of released gas, taking into account the effects of the ventilation system in its various possible operating states. The evaluation units must be installed outside the room being monitored.

The forced ventilation system must be dimensioned such that a maximum possible gas volume is diluted to a maximum gas concentration of 20 % LEL in the installation room.

At an alarm threshold of 20 % LEL (0.9 % v/v CH_4) in the room air, the response should be visual and audible warnings and air intake or extraction at 100 % power.

At for example 40 % LEL (1.8 % v/v CH_4) in the room air, the response should be visual and audible warnings, air intake or extraction at 100 % power and automatic shut-off of gas supply outside the installation room.

The gas warning device continues to operate after the second alarm threshold is exceeded, i.e. it is not switched off.

If a technical ventilation system is installed it must be ensured that the exhaust air is extracted from the ceiling area. The exhaust air must be expelled directly into the atmosphere.

TIP

The minimum free cross-section ‘A’ of the air inlet/air outlet of CHP unit installation rooms is obtained from the following equation:

A = 10P+175A = free crosssection (cm^2)
P = maximum declared electrical output from the generator, kW_{el}

Examples:
22 kW_{el} = 395 cm^2 and 30 kW_{el} = 475 cm^2

Further requirements for CHP unit installation rooms:
CHP unit installation rooms must be dimensioned such that the combined heat and power units can be properly installed, operated and maintained. This is generally the case if the CHP units are accessible on three sides. Doors must open in the direction of escape. If CHP units are operated inside containers, later replacement should be possible without difficulty. The air flow parameters prescribed by the CHP unit manufacturer should be reliably achievable in the CHP unit installation room.

The CHP unit must be mounted on its foundations and installed such that the unit’s vibrational load is below the vibration levels permissible for continuous operation.

For further information about installation rooms, refer to DIN ISO 10816-6.

Floor drains must have oil traps. Alternatively, a collection tank to catch the entire volume of oil must be positioned beneath the engine.

It must be possible to shut down the CHP unit at any time by means of an illuminated switch outside the installation room. The switch must have a clearly visible, durable label ‘Emergency Stop Switch – CHP Unit’ and must be accessible. The same requirements also apply to electrically operated shut-off valves.

Two shut-off valves must be installed in the gas line upstream of each engine unit. The valves must close automatically when the engine stops. The interspace must be regularly checked for leaks. If the supply line to the engine has a constant upstream pressure > 5 mbar (5 hPa) even when the engine is stopped, automatic interspace monitoring is required.

Doors must open outwards and must be lockable.

Organisational protective measures

The gas warning device must be maintained in accordance with the manufacturer’s instructions. Gas warning systems must be tested regularly, at least once a year. Operating instructions must be drawn up for cases where the alarm is triggered by the gas warning device or a fault in the gas warning device.

Classification of Ex zones

Technically leak-tight gas-carrying plant parts combined with adequate organisational measures, periodic inspection for leaks. Monitoring of the installation room for potentially explosive atmospheres: e.g. at 20 % of LEL triggering of alarm and maximisation of fan output (at least five air changes per hour), at 40 % of LEL automatic shut-off of gas supply.

No zoning necessary

Inspections and tests

In order to make plant operation lastingly safe, both initial and various periodically recurring inspections and tests must be carried out for the entire plant, parts of the plant and the documentation.

The inspections and tests can be divided into the following separate segments:

- structural safety
- explosion protection
- pressurised systems
- electrical installations
- water resources protection
- pollution control
- functional safety
- fire protection
- business organisation

The inspections and tests must be performed by specially trained experts or by persons qualified to conduct inspections and tests. In addition to the necessary training and specific knowledge (including professional experience in the field of biogas), the inspectors must have at their disposal the requisite test and inspection equipment. Proof of compliance with these requirements should be provided.

With due regard for the respective national requirements, the following types of inspection and testing are recommended for biogas plants:

1. Document inspection: checks to ensure that the documentation is complete, correct and up-to-date.
2. Visual inspection and functional test: checks to ensure that the technical and organisational safety precautions are complete, correct and in proper working order.

> **! TIP**
> *Given the large number of different periodically recurring inspections and tests it makes sense to draw up an inspection and test plan showing all the necessary inspections and tests and the contact details of the inspector/test engineer required in each case.*

The German Biogas Association considers the following on-site inspections and tests on biogas plants to be the minimum required (see Table 7).

Table 7: Minimum inspections and tests recommended by the German Biogas Association

Test object	Test frequency
Fire extinguishers	Every 2 years
Safety equipment (e.g. gas warning equipment, ventilation systems and inerting equipment)	At least once a year
Apparatus, protection systems and safety systems	Every 3 years
Explosion protection testing (general)	Prior to commissioning and periodically at least every 6 years
Inspection for compliance with water legislation	Prior to commissioning, then every 5 years, in water protection areas every 2.5 years
Safety-related testing	Prior to commissioning, then every 3 or every 5 years (depending on approval)
Electrical testing of switchgear / 'E-Check' inspection	Every 4 years
Pressure vessels	External inspection every 2 years

The results of the inspections and tests are to be documented in a test report, which must include at least the following information:

1. Identification of the plant
2. Date of inspection or test
3. Type of inspection or test
4. Basis for the inspection or test
5. Scope of the inspection or test
6. Effectiveness and function of the protective measures taken
7. Result of the test and date of the next periodically recurring test
8. Records and test certificates must be kept at the site of the plant being monitored for the entire duration of use of the plant. In addition, it is advisable to keep a copy at a different location.

Upgrading of biogas to biomethane

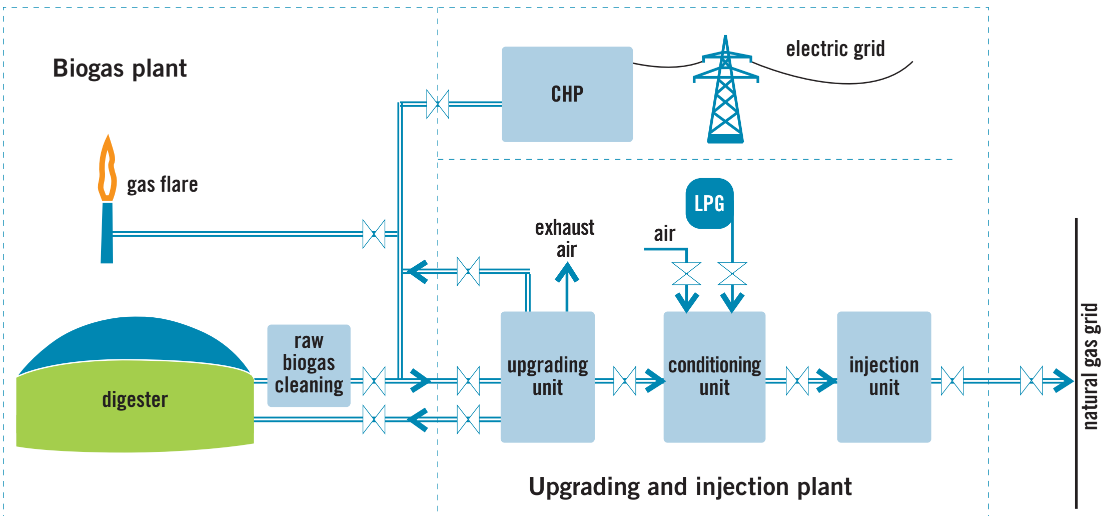
The raw biogas produced in the plant is subjected to basic cleaning prior to utilisation in the CHP unit (see figure 13) . This generally consists of dewatering (drying), H_2S reduction and the removal of suspended solids. However, if biogas is intended to be used as a substitute for natural gas, as a fuel or in compressed form in pressure cylinders, further upgrading of the gas is required, which mainly comprises the separation of methane and carbon dioxide and the further reduction of undesirable gaseous constituents (H_2S, NH_3 and other trace gases). Biogas upgrading requires an additional technical facility, the safety aspects of which are explained in the following.

As raw biogas is a mixture of various desirable and undesirable constituents, basic cleaning and fine cleaning are required. Basic cleaning of the raw biogas usually takes place at the biogas generating plant (digester), and fine cleaning or purification at the biogas upgrading plant. In order to adapt the upgraded biogas (biomethane) to the quality standards of the natural gas grid and/or the requirements of natural gas consumers (natural-gas vehicle, gas burner, CHP unit etc.), further conditioning (for example adjustment of the methane content and calorific value etc.) should be carried out, depending on national regulations. This treatment takes place in biogas conditioning plants. Before the upgraded biomethane is injected into the specified natural gas grid, further steps are required: pressure adjustment, pressure protection, gas metering and if necessary odorisation.

Biogas upgrading unit

Depending on the respective national requirements (laws, ordinances and sets of regulations), different parts of the biogas upgrading plant may have different operators and may be subject to stakeholders with different areas of competence: the biogas plant operator, gas supplier/gas grid operator and/or the competent authorities. Responsibilities in the various parts of the plant should be defined according to these areas of competence, and set out in writing.

Figure 13: Process flow chart for a biomethane upgrading and injection plant



The relevant qualifications held by the responsible operators and the personnel assigned to the work must also meet national requirements. The same applies to specialised companies involved in the planning, construction, operation and maintenance of the plants. Regular training measures should be obligatory in order to keep technical knowledge up-to-date with the latest findings and technical requirements. For organisational reasons it is advisable to draw up a plan of the organisational structure for the plant as a whole.

In addition, a plan of organisational procedures should be drawn up (recording of faults: checking, causes etc.) along with operational documentation (briefings, inspections, tests, incidents, work instructions etc.).

To be documented:

- *briefings and instruction sessions held*
- *inspections and tests*
- *incidents*
- *work instructions*

Technical protective measures

The odorisation (addition of an odorous substance as a warning) of natural gas/biomethane is an important safety measure because purified natural gas/biomethane is almost odourless. In order to ensure that leaks in pipes or parts of the indoor gas installations are noticed promptly, for safety reasons specific prescribed warning odours are added to the natural gas/biomethane. The smell of the odorised gas must therefore not be familiar to people from their everyday lives, for example from kitchens or a domestic setting.

The upgraded biomethane must be adapted in accordance with the odorisation requirements of the gas grid into which it is to be injected. This usually involves the use of highly volatile, typical-smelling organic sulphur compounds such as tetrahydrothiophene (THT), which smells like rotten eggs, and mercaptan mixtures.

National regulations must be observed in the planning, construction and maintenance of pipework in biomethane plants and external areas, and in the selection of materials. All such work must always be carried out by specially trained personnel.

The choice of plant components should be made according to practical requirements at the plant (gas quality, corrosive constituents of the gas, internal pressure, climate, geographical location). Potential deformation, deflection and linear expansion must be taken into consideration when installing the pipes, in accordance with site-specific regulations. If it is expected that condensate will be formed (mainly applicable to biogas pipes), the pipes should be laid on a gradient and fitted with condensate separators at the low points of the installation.

It is particularly important that building entry points for gas pipes are corrosion-resistant and strain-free. Pipes carrying gas must always have corrosion protection, ignition protection and equipotential bonding, and they must be clearly identified by colour-coding or labelling.

If gas pipes are potentially exposed to mechanical damage (for example from vehicles or other traffic), they must be protected accordingly by collision impact protection guards. If gas pipes are laid on land belonging to a third party or public property, permissions/concessions for crossing the land (e.g. roads and railway lines) and laying the pipes must be taken into consideration.

Gas pipes must be checked to ensure they are in faultless condition prior to installation. National guidelines regarding pipe covering, pipe routing and filling of the pipe trench (e.g. in sloping locations) must be observed.

Gas pipes must be subjected to a pressure test after initial installation and after any significant changes, with due consideration for the relevant regulations (test procedure, test duration, test medium, test pressure, person permitted to perform the test etc.). If the operating pressure changes during use, any regulations relevant in such circumstances must be observed.

Documentation for pipes:

- *details of the design of the gas pipes (pressure, nominal diameter ...)*
- *structural analysis records*
- *certificate of competence from the executing companies*
- *up-to-date working drawings and plans of present inventory of facilities and equipment*
- *pipe book (documentation of welding work, verification of quality requirements)*
- *test reports/acceptance certificate*

When work is carried out on the gas installation it must be safely depressurised to the open air and must be inerted. A clearance measurement should be carried out prior to work on the gas installation in order to rule out hazardous Ex zones. Following maintenance/repair work and prior to resumption of operation, the relevant unit should be subjected to a leak test and functional test. The necessary tests must be performed by qualified professionals and must be documented. If necessary, oxygen contained in the gas system must be removed and the system must be flushed with process gas prior to resumption of operation. The resumption of operation must be agreed and coordinated with the persons responsible for the upstream and downstream parts of the plant.

Only approved specialised companies/skilled workers are permitted to perform welding work on pipes and gas-carrying systems. Detailed descriptions of equipment, devices, procedure testing, performance of the welding work and testing of the weld are given in national regulations (in Germany: DVGW GW 350 and G472). Welding work on gas-carrying plant parts is not permitted in installation rooms (exceptions may be possible if justified).

The relevant national regulations must be observed when work is carried out on pressurised plant parts.

Organisational protective measures

If condensate is expected to arise, the pipes and condensate discharge systems must be regularly maintained and cleaned. Pipes above ground level must be checked for leaks on an annual basis. Shorter intervals should be planned for compensators and other specialised components where necessary (hazard assessment). Every two years pipes laid above ground (including pipe protection) should be checked to ensure that they are in good condition and for external corrosion. If necessary, the UV protection of plastic pipes should be repaired.
Biomethane plants and their components must be maintained and serviced in accordance with the manufacturer's instructions (method, intervals etc.). Essentially a distinction is drawn between three types of maintenance:

- planned maintenance (fixed intervals)
- condition-based maintenance (after assessment of the state of the plant)
- corrective maintenance (initiated because a fault has arisen)

Before any maintenance work is carried out, an individual hazard assessment is required, with specified protective measures. This must be agreed with all plant operators (biogas production, cleaning, conditioning and injection).

All persons assigned to perform maintenance work on the installations must be qualified, approved and reliable and must have received special instruction. This applies both to the plant's own staff and to external companies and workers. German regulations require, for example, that certain activities, namely functional testing, maintenance, repair and resumption of operation, must always be performed by two persons, at least one of whom must have the necessary expertise and the other must at least have received relevant instruction.

Maintenance and repair work should be systematically prepared. This means that necessary protective equipment (e.g. respiratory protection, warning devices, fire extinguishers etc.) must be made available. It is also advisable to draw up a work programme and overview plan in which all relevant activities and plant components are plainly apparent. Where necessary, automated processes in the system should be switched to manual operation before maintenance or repair work is carried out.

An individual person must be named as being responsible for safe operation and the safety of the plant, and be granted the necessary powers. To avert danger, an on-call service must be arranged at the plant itself or through an external service provider so that constant standby backup service is ensured (24 h/7 days). In Germany, for example, the on-call service must be present at the plant within max. 30 minutes in order to be able to respond to faults in good time.

Instrumentation and control (I&C) systems must be checked by a qualified professional at least once a year and after each maintenance operation to ensure that they are in working order. The operator of the plant must draw up a test plan for this purpose.

All tests, measurement reports etc. must be documented in writing or electronically and kept as long as necessary (at least two maintenance intervals). Structural changes at the plant must be documented. Other tests must be performed in accordance with the general test requirements for biogas plants (electrical safety, explosion protection etc.).

Recommendations for safe plant operation

As biogas is covered by very different areas of law (agriculture, waste management, energy industry, health and safety at work etc.) and is a relatively young technology, in many countries there are no biogas-specific competencies or laws, ordinances or regulations. The same is true in particular for the field of international standardisation. Initial efforts are being made to develop an internationally coordinated set of rules and standards on biogas (ISO TC 255 'Standardisation in the field of biogas').

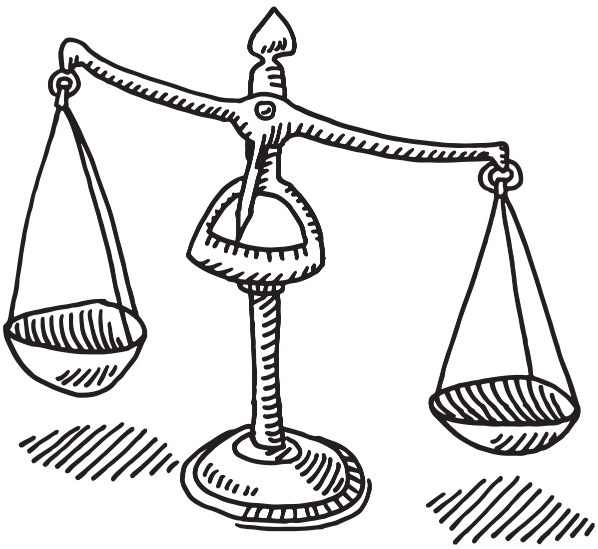


ILLUSTRATION: : ISTOCK_FRANK RAMSPOTT

Established and recognised industry associations have a crucial role to play in agreeing, developing, introducing and implementing safety-specific standards. The interests and needs of the stakeholder groups in the biogas industry can thus be pooled to best effect and the maximum degree of acceptance established. The German Biogas Association, for example, has conducted debates on the subject of safety within its own working group on safety ever since the foundation of the association, and has issued recommendations accordingly. The working group is made up of experts working in an honorary capacity from various safety-related fields of the biogas industry. The working group supports the German Biogas Association and its members in dealing with questions and problems.

In the international context there are very different ways of dealing with the consequences of accidents. In some countries every accident, however minor, is registered and taken seriously, and the causes are retraced in order to avoid accidents in future if at all possible. In these countries biogas plants are mostly operated safely these days. In other countries this is not the case; all too often, the principle tends to be 'life is cheap'. The people responsible are not consistently held to account. These differences in safety culture are a crucial factor in the safe operation of plants. Efforts to establish and implement regulations on safe biogas operation should be pursued as rigorously as possible in all countries.

One highly significant element of the legal framework that is meant to guarantee safe biogas operation is the issue of responsibility. In many countries when accidents occur there is a very thorough investigation of what caused the accident and who is responsible for it. If the accident is serious, the police, expert appraisers, the fire brigade, employers' liability insurance association or other institutions are usually involved in the investigation. The question of who is financially liable for the damage is also relevant to insurance companies. If rules and regulations have been ignored, those responsible may be subject to severe penalties (financial or even imprisonment).

Unfortunately, in many countries the matter of responsibility is not defined, or the rules and regulations are not consistently applied. One quite crucial recommendation is therefore that in every country where industrial biogas plants are operated it is essential to define who is responsible in the event of an accident. These rules must be rigorously enforced.

It is usually the case that the operator of biogas plants bears a high degree of responsibility. He is responsible for safe operation of the plant and is generally personally liable. If construction work has been executed poorly, approval has been granted inadmissibly or other rules and regulations have been breached, other companies or institutions may also be responsible.

Recommendations for safe plant operation

1. Recommendations for the legal framework

- In order to prevent overlaps in relation to safety-related issues and areas of competence, ideally the subject of safety at biogas plants should be dealt with by just one ministry and its associated authorities and agencies.
- In Germany, all aspects of the law concerning construction, waste management, the environment and occupational and industrial health and safety that are relevant to the construction and operation of a biogas plant are examined as part of the licensing process for biogas plants. In many countries, however, there is no legal instrument that provides for similarly comprehensive inspection and regulatory approval.
- If structures are set up in the new biogas markets that establish comprehensive or even biogas plant-specific licensing procedures, it would be particularly important to include safety-related and functional aspects (such as expert planning, design of the plant, choice of components etc.) in the licensing process. This could also be reviewed by technical experts, if it is unrealistic for official government inspections to occur.
- In order to minimise or prevent problems with differing or uncoordinated procedures for the licensing and supervision of biogas plants, it is highly important for biogas plants to be treated in the same way across the whole country. It is therefore advisable to develop a uniform regulatory framework that applies nationwide (law, ordinance or technical code). The regulatory framework should define a state of the art for biogas plants that is in line with international requirements. It should contain all relevant requirements in one central body of rules and regulations, be easily accessible and easy to understand, and it should be updated at regular intervals.
- In order to ensure the safe operation of biogas plants it is advisable to consider introducing an expert appraiser system for biogas plants to examine the licensing of biogas plants and to be able to supervise the planning, construction and operation of biogas plants at the time of commissioning and at periodic intervals. The experience gained from the appraisals should be collected and analysed. The findings can then form the basis for any adjustments that need to be made in the regulatory framework.
- Experience from cases of damage or accidents should be recorded and then evaluated on the basis of uniform criteria. The results can also provide useful information in finding solutions to problems and opportunities for optimisation. The latest findings and insights from the biogas industry should be made easily accessible in regular publications and technical information sheets and at conferences.
- To ensure the safe operation of biogas plants, it makes sense to comply with the European standards and guidelines mentioned in this publication, such as DIN EN 60529 (Degrees of protection provided by enclosures (IP code)).
- Constructively positive cooperation between planners, operators, authorities and national biogas associations (through working groups, position papers, sharing of experience etc.) is crucial in promoting the safe operation of biogas plants.

2. Training in the industry

- Operators of biogas plants should have completed recognised operator training and safety training prior to start-up. The content of this training should be chosen according to plant-specific parameters (size, substrates etc.) and national regulations.
- The operators' previously acquired expert knowledge in the field of biogas should be refreshed at regular intervals.
- Specialised companies involved in planning, construction, operation and maintenance should be able to call upon defined and verifiable expert knowledge, which should also be regularly refreshed.
- Work on dangerous parts or components should be performed by qualified and if necessary supervised specialised companies.

Annexes

Annex 1: Hazard assessment

General information about the biogas plant						
Operator:			**Tasks assigned [date]:** **Number of employees:**			
Date: **Persons involved in the hazard assessment:**						
Signatures:						
1. General part						
1.1 General hazards - organisation						
Area of activity	**Hazard**	**Protection measure**		**Fulfilled**		**Implemented Who / when**
			Yes	**No**	**Not required**	
Responsibility	Tasks, responsibilities and competences are not clear or not arranged properly.	The operator is responsible for all tasks, responsibilities and competences. Deviations are documented.	☐	☐	☐	
		Outside firms are instructed by the operator.	☐	☐	☐	
Selection of employees	Employment of unqualified persons (damage to health, property damage).	Identification of occupational aptitude before employment.	☐	☐	☐	
		Company eligibility criteria (e.g. education) are defined and considered.	☐	☐	☐	
		Necessary driver's licenses are checked.	☐	☐	☐	
		New employees receive induction training.	☐	☐	☐	
Work without appropriate education and training	To endanger oneself, other employees or other persons.	Only employees with suitable further training perform relevant tasks.	☐	☐	☐	
		Employees take part in relevant further training measures.	☐	☐	☐	
		Only suitable and trained persons are employed.	☐	☐	☐	
Safety instruction	No recognition of hazards or no consideration of protection measures.	Employees receive instruction regarding possible hazards and protection measures before starting work.	☐	☐	☐	
Working time	Working time, relaxation time and breaks are not adhered to.	Core working hours must be adhered to.	☐	☐	☐	
		Breaks must be adhered to.	☐	☐	☐	
First aid	Lack of first aid after accident or sudden illness.	First aid material is available.	☐	☐	☐	
		Emergency telephone numbers are known.	☐	☐	☐	
		Trained first aider is attainable.	☐	☐	☐	

Annex 2: Instruction record for subcontractors and employees for maintenance, installation and repair work

Location/place of work (e.g. plant)	BIOGAS PLANT	
Job order (e.g. agitator repair)	.... Responsible client/employer	
Period of work	Date ....from ....to expected finish... ☐ Consultation on current situation required daily before commencing work	
Type of work / job order	☐ Electrode welding .... ☐ (Shielding gas)... ☐ (Stick electrode) .... ☐ Oxyacetylene welding/brazing................................. ☐ (Flame) cutting .... ☐ Grinding/cut-off grinding....................................... ☐ Other:..	
Executed by	☐ Outside company: Responsible site manager of outside company: .... ☐ Biogas plant's own staff member:	☐
	Contractor possesses the required expertise	☐
General information	If employees of other employers are exposed to high levels of danger, the employers concerned must appoint a coordinator in writing to agree on the protective measures: Coordinator	☐
	Maintenance work performed on the basis of a hazard assessment.	☐
	The contractor has informed the client and other employers about hazards arising from his work for employees of the client and other employers.	☐
	Personal protective equipment: selection and if applicable mandatory use (safety footwear, ear protection, fall protection, flame-retardant clothing, chemical-resistant protective clothing, protective gloves, goggles, breathing mask etc.).	☐
	Observance of information signs, mandatory signs and prohibition signs.	☐
	Note: In the area of the receiving equipment, toxic, very toxic, carcinogenic, mutagenic or reprotoxic deposits may be present as a result of the addition of additives and auxiliary materials (e.g. trace elements). In this case it is necessary to follow the stipulations on the safety data sheet, especially regarding personal protective equipment, and only suitable and instructed personnel must be appointed to the task.	☐
	Machinery secured to prevent accidental start-up and labelled?	☐
	Note: There is often no connection to the mobile phone network inside steel and reinforced concrete tanks.	☐
	Transport and escape routes kept clear.	☐
	Fire extinguishers, first-aid boxes and electrical distribution boxes not blocked.	☐

Job induction	Work procedures, possible hazards, proper use of safety precautions and environmental protection equipment discussed. Emergency plan handed out.	☐
	All commissioned work always performed under supervision. Unsupervised lone working forbidden.	☐
	Attention drawn to areas with a potentially explosive atmosphere.	☐
	Attention drawn to possible hidden hazards (e.g. residual energy, hidden cables/pipes, elevated work equipment, pressurised pipes etc.).	☐
	No bypassing or manipulation of safety equipment on machines or buildings (e.g. bridging of safetyoriented contact switches, wedging of fire doors etc.).	☐
	Any (occupational safety) deficiencies detected to be reported to the operation site manager immediately.	☐
	Briefing on all hazardous substances present, e.g. on the basis of safety data sheets.	☐
	▶ Additives and auxiliary materials (trace elements etc.).	☐
	▶ Flammable liquids.	☐
	▶ Ignitable materials (solids, dust, insulation materials).	☐
	▶ Risk of explosion from gases/vapours.	☐
	▶ Danger of asphyxiation from oxygen-displacing gases CO_2.	☐
	▶ Toxic hazard from poisonous gases such as H_2S and NH_3.	☐
	▶ Other hazardous substances	☐
	Working areas to be secured with barriers and warning notices such that no one is endangered.	☐
	Compliance with operating instructions, e.g. for wheel loaders, machinery and equipment.	☐
	Prohibition of alcohol and other intoxicants.	☐
	Smoking bans in all marked areas.	☐
	Safe use of electric tools, ladders etc. has been explained, attention drawn to need for visual inspection prior to use.	☐
	Emergency measures for incidents posing an environmental risk explained.	☐
Other:		☐
Mandatory work equipment and occupational safety equipment	☐ Ladders, climbing aids ☐ Fall protection ☐ Helmet ☐ Ear protection ☐ Eye protection ☐ Special lamps (IP protection class, ATEX?) ☐ Special means of communication (IP protection class, ATEX?) ☐ Special hoists for tools and welding gas cylinders	☐
	Provision of a rescue station with rescue/recovery equipment.	☐
	Provision of first aid equipment.	☐
	Eyewash bottle, wound disinfectant, burns first aid kit.	☐

Special measures to prevent danger during work where sparks are generated	The following certificate of competence is present (e.g. welder's certificate for welding work on gas pipes):	☐
	Removal of flammable objects and materials, including dust deposits, within a radius of ...... m	☐
	(also in adjacent rooms = vapour-proof? Empty conduits, cable ducts, doors, ventilation ducts?)	☐
	Biogas removed from vulnerable areas?	☐
	Covering over at-risk flammable objects next to and beneath the workplace.	☐
	Safe sealing of openings, pipes and passages to adjacent at-risk areas and tanks connected in the gas system.	☐
	Removal of potentially flammable cladding and insulation materials.	☐
	Establishment of equipotential bonding (antistatic set) and humidification.	☐
	CAUTION: Particular attention to be paid to small secondary fires caused by welding beads and angle grinder sparks.	☐
	Elimination of risk of explosion in tanks and pipes by inerting of pipes with N_2 or CO_2?	☐
	Protective ventilation, active ventilation significantly below LEL Fan output: ....m^3/h Space to be ventilated:..m^3 volume Vent tube (spiral ventilation hose) .... m long (distance from fresh air intake point to Ex zone/gas outlet point)	☐
	Venting/extraction of gases (only use explosion-protected/ATEX blowers, e.g. to be loaned from fire brigade)	☐
	Clearance measurement with a gas detector (e.g. multi-channel gas monitor) by an expert: battery charged, checked and ready for operation, etc.? Measurement of atmosphere in working area with adequate safety distance, e.g. $CH_4 < 0.5\%$; $O_2 > 20\%$, $CO_2 < 0.5\%$, $H_2S < 10$ ppm, $NH_3 < 5$ ppm	☐
	Provision of a fire watch with extinguishing equipment.	☐
First response equipment for fighting incipient fires	☐ Fire extinguishers (note: if possible keep several different extinguishing agents ready!) ☐ water ☐ foam ☐ CO_2 ☐ ABC dry powder 0BC dry powder ☐ water hose (connected) with spray nozzle?	
Permission	**The listed safety measures are to be implemented.** The relevant regulations on industrial safety and health, hazardous materials and accident prevention (in Germany: BetrSichV, GefStoffV, TRGS 529 and DGUV) must be observed. In particular DGUV Regulation 113-001 (formerly BGR 117-1) applies to inspecting and working in tanks, digesters, pits, shafts and narrow spaces below ground level.	
.... Date	.... Signature of responsible employer/operator of biogas plant	.... Signature of person carrying out the work

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The German Biogas Association unites operators, manufacturers and planners of biogas plants, representatives from science and research and all those interested in the industry. Since its establishment in 1992, the association, which has more than 4,800 members, has become the most influential organisation in the field of biogas worldwide. The Association works closely with various international organisations and provides knowledge from seasoned biogas experts. This is gained from the experience gathered with about 9,000 biogas plants in operation in Germany over several decades.

The Association has excellent expertise and knowledge in nearly all aspects of biogas, biogas plants and biogas plant operation and is involved in all official German and various international bodies where standards or regulations for biogas plants are discussed and defined. One example is its contribution within an ISO (International Organisation for Standardisation) working group to define terms, definitions and classifications of biogas systems.

The issue of safety at biogas plants has been a statutory goal of the Association since its foundation, and is addressed through the following activities:

- evaluation of scientific findings, practical experience and actual incidents
- organisation of a working group on safety and associated sub-groups
- drafting of quality standards (e.g. safety rules for biogas plants) for the planning, construction and operation of biogas plants
- promotion of knowledge-sharing through conferences and training courses
- publication of knowledge through its own specialist journal, technical texts and presentations

The training of biogas plant operators has become increasingly important in recent years. In light of this, three German associations, the German Technical and Scientific Association for Gas and Water (DVGW – Deutscher Verein des Gas- und Wasserfaches e.V.), the German Association for Water, Wastewater and Waste (DWA – Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.) and the German Biogas Association established the Biogas Training Network in October 2013.

The main aim of the Biogas Training Network is to provide standardised, proficient training and continuing professional development for biogas plant operators and individuals involved in the operation of biogas plants throughout Germany. At the time of its foundation, the Biogas Training Network began with five training establishments. As of July 2016 there are 16 training organisations offering the training to obtain the operator qualification for biogas plant safety. To date, more than 3,500 people have been trained through the Biogas Training Network.

Year of foundation: 1992 · number of employees: 43

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The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is a global service provider in the field of international cooperation for sustainable development. GIZ has over 50 years of experience in a wide variety of areas, including economic development and employment, energy and the environment, and peace and security.

As a public-benefit federal enterprise, GIZ supports the German government – in particular the Federal Ministry for Economic Cooperation and Development (BMZ) – and public and private sector clients in around 130 countries in achieving their objectives in international cooperation. With this aim, GIZ works together with its partners to develop effective solutions that offer people better prospects and sustainably improve their living conditions.

In the area of renewable energy, GIZ is currently executing more than 170 projects in over 50 countries, and more than 20 of these focus on biogas or have a biogas component. These projects' activities include the support of legal framework conditions for biogas, the analysis of different substrates for use in biogas production, capacity development, cooperation with the private sector and the support of biogas pilot projects.

Year of foundation: 2011 · number of employees: 16,400

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- **Sustainable Energy for Food – Powering Agriculture**
- Energetic utilization of urban waste in Mexico (Enres)
- Renewable energies and energy efficiency in Central America (4e)
- Promoting climate-friendly biogas technology in Brazil (Probiogas)
- South African-German Energy Programme (SAGEN)
- Support for the Moroccan Solar Plan (DKTI 1)
- Promotion of least cost renewables in Indonesia (LCORE-INDO)

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