BIOGAS
SAFETY & REGULATION

Discussion document for the workshop organized on 24 November 2010 in Paris

Compiled by Samuel Delsinne

(in collaboration with K. Arrhenius, J. Coenen, S. Evanno, R. Fouquet, L. Gauchet, A. Greninger, L. Hoffmann, J. Kay, C. Marchais, Y. Membrez, R. Moletta, R. Nedelec, M. Riotte, O. Salvi, C. Thiébaut)

Version 09 (9-Nov-10)

Table of Contents

I. Introduction

The development of new energies is experiencing a great development in the world and particularly in Europe. As a result, solar panels, wind turbines and other ecological technologies are more and more installed in many European countries and are constantly evolving. The main purpose of this development is to find an alternative energy replacing the fossil energy dependence which is more sustainable and reduce CO_2 emissions.
Thus, the impact on the environment is reduced and energy consumption is sustainable. But biogas has a special major advantage in addition. Indeed, it reuses the waste as raw materials. The production of biogas is positioned as energy which can not only generate a source of energy known as "clean" but also which can recycle waste.
In a context of sustainable development, the place of the biogas is therefore essential. However, the processes of anaerobic digestion or biogas are continually improving and new ideas for the uses of this gas continue to emerge. Thus, the risks corresponding to processes of biogas production from biomass or waste are still too little known.
Several questions appear about the optimization of the production, the safety, the harmonization of the regulations and the need to develop standards (at European or International Level).
To find answers to these questions, INERIS and EU-VRi have taken the initiative to organize a workshop with biogas aspects.
The present document helps to share knowledge, to structure questions, and to propose answers on further actions aiming at improving safety of biogas production and supporting the quick and sustainable deployment of this energy.

II. Problem framing

Producing biogas is a recent technology which has two main advantages. Indeed, for few decades, governments have tried to develop this new energy because it is a sustainable energy and its raw materials are from waste. This new development supposes regulation and studies about safety. Indeed we can find various issues related to biogas production and corresponding safety and regulation for different uses. In order to find answers to our study, we need to clarify the subject and frame the problem. In this way this section presents a set of questions that will help to structure the workshop and collect appropriate answers:

A. Different production processes for different ways of valuation

What are the various raw materials for the production of biogas and corresponding technologies?
Biogas could be produced from different biodegradable wastes such as agricultural waste, industrial waste or waste from water-treatment plants, with different processes of anaerobic digestion.

What are the gases produced according to the technologies and in which proportions are they produced?
With different sorts of raw materials and processes, the proportion of the various gases in the biogas might be different from one plant to another.

What are the methods and technologies to measure and monitor the production of biogas and the by-products?
With the aim of controlling the reactions of the process or of measuring the production of biogas, it is necessary to install devices and to implement procedures of monitoring.

What are the key parameters optimizing the efficiency?
As the anaerobic digestion is a recent technology regarding some kind of waste (e.g. MSW) but no for sewage sludge, it is supposed that the process will evolve and the biogas plants will be upgraded. Improvement will be made in some technical aspects of the process and in a few years it will be possible to find new sources or uses of biogas.

B. Uses of biogas

What are the different uses of biogas?
The biogas is mostly used to generate electricity but the potential of this gas is not restricted. For example, it could be used in vehicles as a fuel even in aviation (projects). Moreover, as there are different sorts of gases at the end of the process, other biogas such as CO_2 or nitrogen could be utilized in different ways.

How could industry integrate biogas in a distribution network as pipelines or vehicles?
With the development of biogas, it is possible that in a few years, biogas will replace little by little the fossil energy in house warming and in vehicles fuel. So it is interesting to think about the integration of biogas in gas-grid.

Concerning reuse, what are the different safe ways of cleaning gases?
Several kinds of gases are produced by the anaerobic digestion process. Some of them might cause hazards directly or after combustion, that is why it is important to remove those gases by treating the biogas. After that, the composition of the biogas is precisely known and the gas is safe to use.

C. Process safety and OHS

What are the different hazards in a biogas plant? (For workers, process and the environment)
It has been reported that a biogas plant could generate risks concerning the population, the environment or equipment of the plant, such as explosion, leak of toxic gases or corrosion of materials.

What are the different technical aspects to safely produce biogas?
With the consideration of all the hazards which could exist in a biogas plant, it is important to find solutions in order to make the process of producing biogas safer.

D. Regulation

What are the regulations in force in the various Member States?

- Are there some discrepancies or commonalities?
- What are the minimum requirements regarding safety?

It is interesting to compare the regulations in Europe or in the world, assess what are the main issues addressed in the various countries, and then determine a typical regulation for biogas production and uses.

E. Standardization/ guidelines

Is it necessary to create a specific standard or a guideline (at EU level) in order to harmonize the operational basis and its safety?

If yes, what could be the key issues of this standard or guideline?
There are several processes, several raw materials and several gases produced; thus, it could be interesting to see what could be the common procedures with the aim of harmonizing the production of biogas. Thus it will be possible to consider a standardization of biogas production and safety.

III. Issues to consider for the workshop

A. Background information

Unlike other renewable energy sectors, biogas production did not emerge from concerns on energy but rather from the environment (elimination of pollution, treatment of waste, control of greenhouse gas emissions). [A1]

The development of renewable energy is an important element of energy policy the European Union. The Renewable Electricity Directive (DIRECTIVE 2001/77/EC- [B1]) sets an indicative target of 22% renewable electricity in gross consumption of the EU in 2020 and the Biofuel Directive (DIRECTIVE 2003/30/EC- [B2]) provides indicative targets of 5.75% substitution by biofuels by 2010.

The EU's Strategic Energy Technology Plan (SET-Plan) is part of the Energy and Climate Change policy framework. It contributes to the overall policy objectives by proposing, developing and implementing an Energy Technology Policy for Europe. It complements EU policy in energy and climate change and can enable cost effective compliance with legally binding targets. These include the realisation of the internal market in electricity and gas; compliance with emissions' reductions and the revised and strengthened Emissions Trading Scheme; the increased contribution of renewables to the EU's electricity generation; the measures to enhance energy efficiency; the EU car emissions standards; the negotiation of a post-Kyoto international agreement; and the development of an external energy policy.
[A2]

Methanisation makes it possible to produce biogas from organic elements of vegetal or animal origin. Biogas is a gas rich in methane, the same element that constitutes natural gas. Biogas can be directly tapped in subsurface containment centers (landfills) or produced using digesters (we can also speak of methanisers in this case). All organic materials except lignin are capable of being transformed into biogas. Effluents can be methanised in sewage purification plants. Liquid manure, agricultural waste and energy crops can be methanised in small-scale biogas units on farms or in co-digestion units (collective units that treat different type of wastes associated with a significant share of liquid manure). Solid municipal waste and green waste can also be transformed into biogas in large-scale solid waste methanisation units.

European primary energy production from biogas reached 6 million toes (tons of oil equivalents) in 2007, i.e. a 21.2% increase with respect to 2006 (an additional 1 Mtoe) [Annex A]. The increase in biogas production principally benefited electricity produced in CHP (combined heat and power) units. With a 24.3% increase in 2007 (+ 2.3 TWh produced) CHP plant production reached 11.6 TWh, and represented a total electricity production which reached 19.9 TWh (+ 17.4%). Rubbish dump biogas continues to be the principal deposit exploited today: 50.6% of the total. With a14% share, sewage purification biogas is still behind all of the "other deposits" (principally agricultural biogas units). This type of biogas, the current driving force behind biogas growth in the EU, has the particularity of relying more and more on the development of dedicated energy crops (corn, etc.). These statistics only take into consideration biogas intended to be valorized, and not biogas that is burned-off in flare stacks. Current growth is not strong enough to reach the objective of the European Commission White Paper (15 Mtoe in 2010). At the same time, the trend towards increases in the price of raw agricultural materials should curb growth of agricultural biogas production. Taking this situation into consideration, it is estimated production at 8 Mtoe in 2010 (10% annual growth). This production will represent 5.4% of the target of the European Commission "Biomass Action Plan" (SEC(2005) 1573 – [B10])set at 185 Mtoe in 2010. For the future, the target for the share of renewable energies set by the European Union is 20% in 2020. In addition, Biogas is one of the renewable energies that has most benefited from the strong increase in fossil fuel prices these last two years.[A3] [Annex C]

[Gross electricity and heat productions are in annexes B and D]

Moreover, European Union regulations, limiting the discharge of waste in dump/landfills has played a large role in developing this sector, which today has widened its field of action into energy crops. For example, in Germany (the EU production of biogas), biogas employs 13 500 persons in direct and indirect full-time jobs and generates a turnover of 650 M€. However, this source of energy is still too poorly studied from a safety point of view. Indeed, only few studies have been conducted to define the potential risks involved in producing and using biogas.[A3]

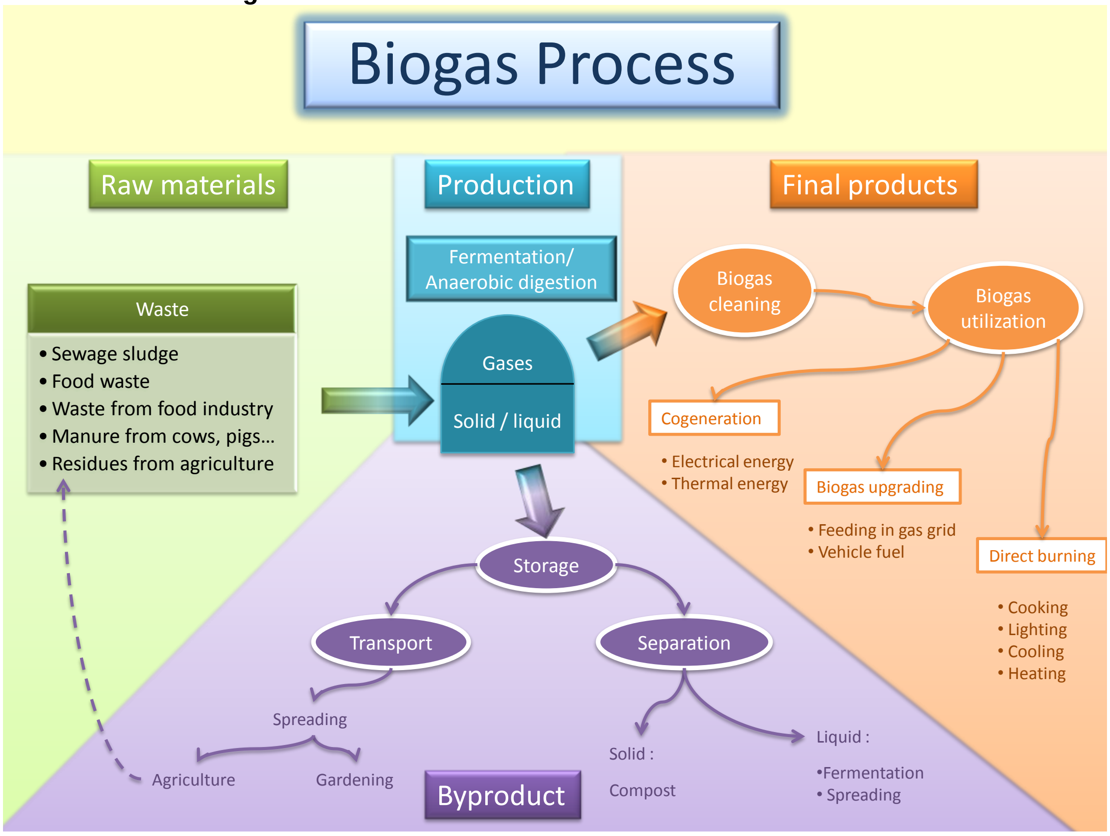
B. Production

1. The various raw materials and processes

The main idea of the anaerobic digestion is to produce gas from waste. Biogas is the name of the gas produced and a biogas plant or anaerobic digester is the place that it is produced. The anaerobic digestion is the process which transforms organic matter into biogases such as methane and carbonic dioxide. Wastes used must be organic and biodegradable in order to be digested by microorganisms in the absence of oxygen. Various types of organic waste can be found and therefore the following step of the production of biogas will differ because of the various raw materials. So there are several processes for the production of biogas, because it depends on the raw materials, but the main idea is still the same: to produce gas from waste. Also in Scotland, a number of whisky distilleries are taking up the technology.
Indeed, biogas could come from several sorts of raw materials:[A4]

- Sewage sludge
- Food waste
- Waste from food industry
- Manure from cows, pigs etc.
- Residues from agriculture
- ”Energy” herbs and plants like maize
- Distillery by products
- Organic fraction of municipal solid wastes

Generalities on biogas:

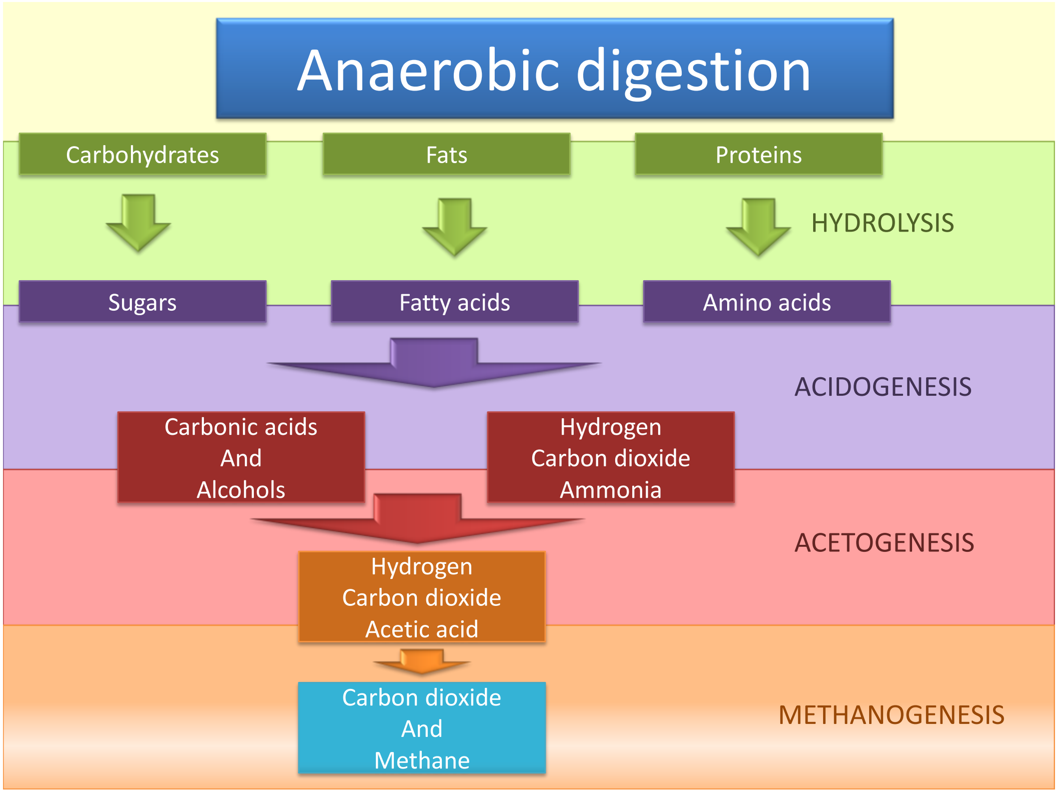


If we consider the fact that there are different sorts of raw material, we could think that the amount of biogas or the quality of the biogas which will be produced from manure from animals will be different as the one produced from waste from the food industry. Thus, the biogas production is so variable from one plant to another. It is also important to highlight the difference between biogas plant and anaerobic digester. (Biogas from landfills and biogas from digesters)

The biogas production is sliced up in four major steps:[A1]

- Hydrolysis: large polymers are broken down by enzymes
- Acidogenesis: acidogenetic fermentations are most important, acetate is the main end product. Volatile fatty acids are also produced along with carbon dioxide and hydrogen.
- Acetogenesis: Breakdown of volatile acids to acetate and hydrogen.
- Methanogenesis: Acetate, hydrogen are converted to methane and carbon dioxide.

Process of anaerobic digestion:



Those steps are included in the main process that we could find in a bibliographical study which is the anaerobic digestion. But some projects propose a different process like using aerobic/anaerobic digestion. Thus, there is not only one process.[A5]
For anaerobic digestion of farm wastes, usually, there is not "aerobic /anaerobic/aerobic", but anaerobic and sometimes anaerobic as a post treatment (composting).

Issues:

Are all these processes equivalent regarding safety?
What are the critical phases / steps?

2. Relevant parameters

Moreover in the anaerobic digestion process we can find several parameters:[A1]

- Humidity of the substrate: wet or dry
- Range of temperature: mesophilic or thermophilic
- Stage of fermentation: single stage or multiple stage
- Stock flow: continuous or discontinuous
- pH control and temperature control

Those examples illustrate the production variability, and we can believe that the yield of the production will depend not only on the raw materials used but also with the process. In addition to the constant improvement of the technical aspects, technology becomes increasingly complex and it is then

necessary to control, measure and monitor the continuous and instantaneous production with special devices. Those devices need to be reliable, accurate and long-lasting.
Quality or quantity of the gases produced seems to be also different:
It depends on raw materials, sort of process, if gases are upgraded and how, or if other gases are removed and how. We previously saw that different raw materials or processes can produce biogas with different yields.
But in general, the biogases produced are methane (50-75%), carbon dioxide (25-50%), nitrogen (0-10%), hydrogen sulfide (0-4%), hydrogen (0-1%), ammonia (0-500 ppm) and oxygen (0-2%).[A1]
Sometimes industries add air in the biogas in order to remove H_2S. This is one reason of the residual oxygen in the biogas.

Trace compounds of biogas from different biogas production plants:

Biogas	CH4 (%)	CO2 (%)	O2 (%)	N2 (%)	H2S (ppm)	Benzene (mg/m^3)	Toluene (mg/m^3)
Landfill	47–57	37–41	<1	<1–17	36–115	0,6–2,3	1,7–5,1
Sewage digester	61–65	36–38	<1	<2	b.d.	0,1–0,3	2,8–11,8
Farm biogas plant	55–58	37–38	<1	<1–2	32–169	0,7–1,3	0,2–0,7

Note: b.d.: below detection

Source: [C1]

Biogas contains small amounts of H_2S and some other pollutants. H_2S is poisonous when inhaled. Furthermore, when water is present, H_2S forms sulphuric acid (H_2SO_4), which is highly corrosive, rendering the biogas unusable. There are different ways to remove the unwanted gases, which mostly target the removal of CO2. [B4] [Annex H]:

- Chemical/ physical absorption
- High pressure water scrubbing
- Pressure swing adsorption
- Cryogenic separation
- Membrane separation
- Addition of air into the biogas
- Addition of $FeCl_2$ in the digester

In this part there are a lot of technical aspects which depend on each other: Various raw materials mean different processes, different processes mean different amounts of gases, and different amount of gases mean different sorts of up-grading or removing… And finally, it appears impossible to fix a global yield in order to study all uses of biogas or to identify clearly hazards and risks in a biogas plant.

Issues:

What are the safety critical parameters?
Is it relevant to establish a regulation on the production of biogas or to think about a possible standardization?

3. Profile of biogas plant/ producers

Throughout the world, a countless number of designs of biogas plants have been developed under specific climatic and socio-economic conditions. Choosing a design is essentially part of the planning process. It is, however, important to familiarize with basic design considerations before the actual planning process begins. This refers to the planning of a single biogas unit as well as to the planning of biogas-programs with a regional scope.

The performance of a biogas plant is dependent on the local conditions in terms of climate, soil conditions, the substrate for digestion and building material availability. The design must respond to these conditions. In areas with generally low temperatures, insulation and heating devices may be important. If bedrock occurs frequently, the design must avoid deep excavation work. The amount and type of substrate to be digested have a bearing on size and design of the digester and the inlet and outlet construction. The choice of design will also be based on the building materials which are available reliably and at reasonable cost.

High sophistication levels of biogas technology require high levels of skills, from the planner as well as from the constructor and operators. With a high training input, skill gaps can be bridged, but the number of skilled technicians will get smaller the more intensive the training has to be. In addition, training costs compete with actual construction costs for scarce (project) resources. Higher technical sophistication also requires more expensive supervision and, possibly, higher maintenance costs. To which extent prefabricated designs are suitable depends largely on the cost of labor and transport.[A6]

There are various types of plants. Concerning the feed method, three different forms can be distinguished:

- Batch plants
- Continuous plants
- Semi-batch plants

Batch plants are filled and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling, but batch plants require high labor input. As a major disadvantage, their gas-output is not steady.

Continuous plants are fed and emptied continuously. They empty automatically through the overflow whenever new material is filled in. Therefore, the substrate is generally fluid and homogeneous, even though solid feeding is quite common for farm biogas plants. Continuous plants are suitable for rural households as the necessary work fits well into the daily routine. Gas production is constant, and higher than in batch plants. Today, nearly all biogas plants are operating on a continuous mode.
Up to now, usually farm digesters are fed in semi-continuous mode (several feedings per day).

If straw and dung are to be digested together, a biogas plant can be operated on a semi-batch basis. The slowly digested straw-type material is fed in about twice a year as a batch load. The dung is added and removed regularly.[A6]

Concerning the construction, three main types of simple biogas plants can be distinguished:

- fixed-dome plants
- floating-drum plants
- lagoon-based plants

But also other types of plants play a role, especially in past developments. In developing countries, the selection of appropriate design is determined largely by the prevailing design in the region. Typical design criteria are space, existing structures, cost minimization and substrate availability. The designs of biogas plants in industrialized countries reflect a different set of conditions.

Biogas could be produced at different scales: a small-scale by farmers and large-scale by industrials. A lot of parameters depend of the scale such as design, process, and raw materials [Annex E]. Moreover, using the technology of biogas production requires knowledge in order to control the process of the production. But in Switzerland, courses exist at different levels teaching biogas plant operators and managers of wastewater treatment plants. These have a federal certification.

Issues:

What is the education in the various countries?
How to obtain a permit to operate a plant?
Is education for operator appropriate?

C. Uses

One of the most interesting advantages of producing biogas is that it has several applications and uses. Indeed, because biogas is composed of multiple gases, it is not only used for energy.

1. Combustion

The first application of biogas is heat when it burned. The Lower Heating Value of the combustion is between 6.0 and 7.0 kWh/m^3, whereas the LHV of the natural gas is around 10.3 kWh/m^3 [A7]. This heat could be used in the process but biogas could also generate electricity. The electricity yield of cogeneration is around 35%. The yield depends on raw materials and type of biogas plant. And during combustion, some toxic gases are generated. Hence, it is necessary to study the composition of the gas and to remove toxic gases or future toxic gases before combustion.

2. Injection in natural gas grid

From a technical point of view, those yields are worse than some other forms of energy production and that is why the one from biogas still needs to be improved. But for the moment, biogas is a good alternative for replacing fossil energy, because it is a renewable and ecological energy. As yields need to be improved, the safety in biogas applications needs to be further studied. For example, the integration in gas-grid biogas might cause risks as the AFSSET (Agence Française de Sécurité Sanitaire de l'Environnement et du Travail) explains in its report in 2008, but there is no additional risk when compared to natural gas.[B6]

State of the art in some European countries:

In Germany, the feeding of biogas into the natural gas grid is an efficient energy solution, even if the sites where gas is used are far away from the sites where it is produced. Feeding gas into the grid is facilitated via a compressor, a device raising the pressure level of the biomethane to that of the gas in the closed pressurised lines of the grid. Given European regulatory realities, new gas producers have the opportunity to feed gas into the conventional gas grid. For biogas generators, this multiplication of the possible number of consumers is attractive. For purposes of feeding-in, however, the gas must be up to the quality specifications of the relevant legal provisions and may only deviate within the range of these quality standards. Such standards are obtained using technologies for reconditioning gas. Because a non-negligible quantity of energy is necessary for gas compression, the energy balance and the economic feasibility of the compression and feed-in process must be reviewed on a case-by-case basis. With regard to feeding biomethane into the natural gas grid, it is necessary to distinguish the exchange gas and accessory gas. The difference lies in the quality of the gases. An exchange gas has the same qualitative standards as conventional natural gas and can be exchanged in the grid as such. Accessory gas possesses a composition that is not equivalent to that of the natural gas, and can therefore only be mixed into the grid beneath a certain threshold. Regulations distinguish between low-quality natural gas ("Erdgas L") and high-quality natural gas ("Erdgas H"). Erdgas H possesses a higher methane content, and is used mainly in the GUS federal states and extracted principally in the North Sea. Erdgas L contains roughly 89% flammable gases (primarily methane, but also small amounts of ethane, propane, butane, and pentane), while Erdgas H contains about 97% flammable gases (the same as those listed for Erdgas L). The types of natural gas available in Germany vary with geography. Similarly, the degree to which biomethane is upgraded depends on the region from which it comes.[A8]

In Sweden, there are 38 sites of biogas injection (Laholm, Helsingborg, Göteborg, Stockholm) and several projects of injection because of an economic context very propitious. It is possible to add propane in order to increase the Wobbe Index. [B6]

In Switzerland, since 1995, some experiences of injection have been gained. It is not allowed to inject biogas from landfills in gas-grid and to improve the quality of combustion for the other biogases. Also there are currently 15 sites of biogas injection. There are two types of injection:

- unlimited injection, for a biogas pure at 96% of methane
- limited injection, for a biogas composed at least 60% of methane. [B6]

In Austria, biogas is injected since 2005 in Lisbod and there are several projects in progress. However, it is not allowed to inject biogas from landfills. [B6]

In France, some experimentation has been performed since 1998 and a project is in progress in Lille Sequedin. [B6]

In The Netherlands, since 1987, landfill biogas is injected in four sites and biogas from sewage sludge since 2006. Moreover, experimentation on several up-grading processes has been managed. [B6]

Furthermore at least 7 operations in Sweden, more than 30 in Germany, 5 in Austria have been reported but to compare them it is necessary to clarify the definition of an injection site.

In Luxembourg 3 large cooperative biogas units are in construction. They will mostly rely on the treatment of organic household/municipal wastes and agricultural residues. The biogas will be upgraded to biomethane using either the water scrubbing or amine absorption techniques.

In a nutshell, several projects have been carried out in order to establish specifications for integrating biogas in gas-grids. Those assessments have to be shared to propose a common regulation in Europe.
The various requirements are in annex G.

3. Biogas for vehicles

The biogas could also be used as a fuel in Natural Gas Vehicle. There are currently strong incentives for increased use of renewable fuels in the transport sector worldwide. Some bioethanol and biodiesel production routes have limitations with regard to resource efficiency and reduction of greenhouse gases. More efficient biofuel systems are those based on lignocelluloses and novel conversion technologies. A complementary strategy to these is to increase the production of biogas from the digestion of organic residues and energy crops, or from byproducts of ethanol and biodiesel production. Compared with other biomass-based vehicle fuels available so far, biogas often has several advantages from an environmental and resource-efficiency perspective. This provides the motivation for further technological development aiming to reduce costs and thereby increase economic competitiveness of biogas as a vehicle fuel.[C9]
But the biogas needs to be highly purified. Thanks to this technique, replacement of diesel or petrol by biogas reduces the emissions and also the engine noise considerably [B6]. This is an interesting aspect, because the number of vehicle users is growing days after days. But the integration of biogas as a fuel is a recent application and only few projects work on it in Europe. (14 cities) [B7]. Those projects try to study the application with a city scale. But is this possible in a larger scale?
The biogas process is the most complicated of the three biotechnological processes. A complex consortium of microorganisms catalyses the degradation of complex organic molecules, which results in the production of methane and carbon dioxide as well as some heat.
This process remains technically underdeveloped and several crucial aspects need to be addressed. The volumetric productivities need to be raised substantially and the conversion rate of generated digestate improved to reduce the volume of biofertilizer generated. Overcoming these limitations will result in the production of increased amounts of gas, while generating less biofertilizer with a higher nutrient content. The volumetric productivities of processing the biomass feedstock to the final biofuels will strongly influence the investments needed to make the technology commercially viable.

In the future there will be an increased demand for land for the production of biomass for food and animal feed, chemicals, materials and energy. Therefore, it is important to prioritize processes, production systems and products that are efficient with regard to the land area used and the use of organic byproducts and wastes, and also according to their environmental impact, particularly in terms of reduction of greenhouse gas emission. Based on these criteria, biogas vehicle fuel stands out as a promising alternative, together with the 'second generation' vehicle fuels that are based on lignocellulose. Compared to the majority of the liquid biofuels in use today, biogas often has a far better performance with regard to both area efficiency and life cycle emissions, and it is therefore a strong potential candidate for becoming one of the most sustainable vehicle fuels in the near future.[C9]

Using biogas for vehicle is a promising solution but before using this method for public vehicle, some research on safety is necessary.

4. Other uses

Other gases could be used in applications like the carbon dioxide in greenhouses. Moreover methane might be reformed in order to produce bio-hydrogen.

Issues:

What are the best cases to valorize biogas, including safety aspects?

D. Main hazards

We can find some risks in a biogas plant such as explosion, toxicity (leak of H_2S) and microbiological risks. The construction of a biogas plant and its maintenance should be well monitored in order to manage risks. Prevention of people from being expose to those risks and checking of all materials (including corrosion) should be realized with the aim of making the production of biogas safer.

1. Explosion

The risk of explosion is the most studied because it is related to the production and use of an explosive gas which is composed mainly with methane. But some explosions happened in the past like in Riedlingen, Walzbachtal, Deiderode and Daugendorf [Photo in annex I]. It means that the risk of explosion is always present in a biogas plant because of the mixture air/biogas [Annex F].
A recent incident in the UK was caused by the substrate foaming up and ripping the digester hood.
Example of some gases explosion properties:

Gases	LEL (%v)	UEL (%v)	Flame speed (m/s)
Acetylene	2.5	82	2.66
Carbon monoxide	12.5	74	-
Hydrogen	4.1	74.8	2.6
Methane	5	15	0.39

NB: The flame speed depends on the mixture of the gas – Some values will be added later.

Source: [A14]

2. Toxicity

The second major risk is toxicity related to the leak of H_2S, because this gas is very toxic and we know that this gas is one of the most abundantly produced in anaerobic digestion. The most important case of this risk was the accident which happened in Zeven in November 2005. Four people died because of the exhaust of a cloud of hydrogen sulfide in unusually high concentrations.

It has been reported also that biogas plants could cause environmental disasters such as in Barßel in September 2002. 20 tons of fish were killed because high quantities of substrate were spread in the environment.

Example of some gases toxicity thresholds:

Gases	In European Union TLV	In European Union STEL	In United States TLV	In United States STEL	LD(50) in mg/ m^3
Ammonia	14	36	17	24	7600 during 2 hours
Carbon monoxide	55	-	29	-	2670 during 4 hours
Dichloride	-	1.5	1.5	1	1185 during 1 hour
Hydrogen sulfide	7	14	14	21	617 during 4 hours

NB1: TLV: Threshold Limit Value based on normal 8-hour workday – STEL: Short-Term Exposure Limit. (in mg/ m^3)
NB2: LD(50): Lethal Dose measured with a group of rats - Those values might be carefully compare because of the various exposure times.

Source: [A13]

In order to have a better use of biogas or to avoid the spread of contaminant gases, the methane has to be removed from other gases such as ammonia, siloxanes… Then those gases once separated might be accidentally released into the atmosphere and generate toxic risks.

3. Microbiology

The microbial risk is also important and several studies have emphasized this risk. Introducing the biogas produced into systems constructed for natural gas is currently causing a debate about the risks of introducing pathogens to the gas systems. Finally, risks for disease transmission from processed (upgraded and dried) biogas can be judged as being low. The possible exposure of working personnel is probably the most significant risk. However, this group could be easily identified and informed about potential risks and how they can be managed. The risk of inhaling pathogens when using gas is overshadowed by the risk of gas intoxication and explosions or similar, since these effects would probably occur before a dose of pathogens high enough to cause an infection had been ingested. The biogas produced in the systems analysed is therefore considered safe to use even in kitchen cookers.[C3]
Furthermore the microbiological risks also exist at the beginning of the process. I.e. in the handling by the personnel of organic (waste products)

Issues:

Are the risks of biogas known by the operators?
Are the safety management systems in place adequate?

E. Learning from experience – Accident records

1. Accident data bases

Generally, there is a lack of communication of accidents and their analysis. In fact, when accidents occurred in biogas plants, in general, only the local media describes the circumstances of the accident and little information on the analysis of the causes is disseminated. There is a lack of feedback and learning from experience.

2. Results of research in some data bases

Several accident databases report about accidents involving biogas productions or uses, such as ARI, FACTS.
After a search on ARIA [A9] and FACTS [A10] websites, here are feedbacks of some accidents:

08/11/2005 - GERMANY – RHADEREISTEDT

In a production of biogas from organic waste recovery, an offshoot of hydrogen sulfide (H_2S) kills three people and a truck driver who came to unload waste from a slaughterhouse. A severely intoxicated person is hospitalized. The extremely high concentration of H_2S in the lobby complicates the response of firefighters and a dozen have suffered of poisoning. An important aeration (more than 24 h) will be required before allowing access to the building. Arriving in the evening, the truck from The Netherlands was parked outside the hotel until morning. The tragedy occurred when the load of the truck was unloaded within a closed hall to reduce odor nuisance, in a pit of 100 m^3 with 2 agitators whose lid can be closed because of the failure electric motor that actuates it. The materials discharged (waste slurries sulfide, pH close to 8.5 and a temperature of 60 °), are guts and viscera of pig. (loaded 24 hours earlier and as usual).
The reaction between these substances and materials already in the pit (waste animal or dairy, low pH according to the analysis conducted after the accident) would be the cause of the strong release of H_2S. The temperature of the environment and the functioning of the agitation would have favored the dispersal of toxic gas in the lobby of unloading. Moreover, the extraction device located at the bottom of the pit which rejects stale air outside through a biofilter would have been insufficient. An investigation has been conducted.

07/01/1999 - FRANCE - LA ROCHETTE

In a recycling unit of biogas from the anaerobic treatment plant of a paper mill, an explosion (5 kg of TNT) buffer destroyed a balloon of flexible material 10 m and their associated piping supplying a boiler or steam flare safety. The balloon exploded, the railings are bent in a radius of 3 m, the tiles are destroyed within a radius of 20 m, cladding and windows on the unit up to 130 m fly into pieces away. There has been no victim. The balloon will be blocked and downhill into depression. Air would be entered by Teflon joints rubbing on the central axis. The biogas has come back and then has formed the explosive mixture which has been ignited by the pilot flame of the flare. An accidental production of hydrogen in the digester and an act of malice were also discussed. Expertise was made. Safety devices were then installed (analyzers, valves, etc..).

12/03/1997 - ITALY - PESCHIERA DEL GARDA

In a municipal sewage plant wastewater, an explosion occurred during repair work in a concrete silo of a biogas plant. Residue gas and welding operations are the cause of the accident. Two workers were thrown out and killed, and a third one falls to the bottom of the building and was seriously injured. The roof of the silo has been blown.

We can see that safety devices are sometimes not sufficient and some problems appear during maintenance. It is necessary to learn from those experiences in order to never do these mistakes again. That is why it is necessary to communicate accident feedback and risks assessment.

Issues:

Is it necessary to establish a permanent network sharing information on causes of accidents involving biogas?
Are the accidents/ risks discussed in the biogas associations?
Is there a feedback to the operators? At European level?
Does a similar information network exist for natural gas?

F. Regulation

1. Situation in different European countries

The upgrading and feeding of biogas into the natural gas grid is currently not subject of consistent European regulation. The parameters and basic conditions, however, are phrased in Directive 2003/55/EC of the European Parliament and of the European Council of 26 June 2003 concerning common rules for the internal market in natural gas and repealing Directive 98/30/EC. In Chapter 1 of this Directive, biogas and gas from biomass are explicitly included in the scope of the regulation. In Paragraph 24 of the Preamble, the European Parliament and the European Council declare the following:

"Member States should ensure that, taking into account the necessary quality requirements, biogas and gas from biomass or other types of gas are granted non-discriminatory access to the gas system, provided such access is permanently compatible with the relevant technical rules and safety standards. These rules and standards should ensure that these gases can technically and safely be injected into and transported through the natural gas system and should also address the chemical characteristics of these gases."[A8]

As of 2009, not all European countries have implemented regulations on the upgrade and feed-in of biogas.

Germany:
The political framework for the feed-in of biogas to the natural gas grid in Germany is defined by a variety of regulations which reflect the complex value chain stages with different challenges on every stage. An overview can be found here.
The most influential parameter is the ongoing implementation of the Energy and Climate Programme of the German Federal Government. Since upgraded and fed-in biogas is currently not yet on a competitive basis with natural gas, the Energy and Climate Programme provides a toolbox to develop the market demand.

The legal framework envisages a broadly diversified application field for biomethane, including pure heat applications, combined heat and power generation with state-guaranteed feed-in tariffs according to the Renewable Energy Source Act (EEG), as well as applications as biofuel in natural gas-dedicated vehicles.
The Energy and Climate Programme consists of 29 courses of action focusing on climate protection. The central measures in context with the injection of biogas are listed in the following:
Section 2: Amendment to the Renewable Energy Source Act (EEG)
The amendment to the EEG became effective on January 1 2009.
Section 9: Regulations on the injection of biogas into natural gas grids
This section was implemented on April 12 2008 by means of the ordinance to promote the use of biogas in the existing gas network. The ordinance includes the following measures:

* Gas Network Access Ordinance (GasNZV)

* Gas Network Tariffs Ordinance (GasNEV)
* Incentive Regulation Ordinance (ARegV) and
* Electricity Network Tariffs Ordinance (StromNEV)

With the commencement of the adapted Gas Network Access Ordinance on April 12 2008, the conditions for the feed in of biogas to the natural gas grid were decidedly improved. Moreover, in Paragraph 41a, the ordinance defines the goal early phrased in the Energy and Climate Programme on the promotion of the injection of biogas: Until the year 2020, up to 60 billion kWh biogas are to be fed every year into the natural gas network, and 100 billion kWh biogas until 2030. This dimension corresponds with the potential for this technology as determined in an influential study by the German Technical and Scientific Association for Gas and Water (DVGW) of 2006.

Section 14: Renewable Energy Heat Act (EEWärmeG)
The Renewable Energy Heat Act (EEWärmeG) also became effective on January 1 2009.

Section 17: Promotion of biofuels
* Amendment of the Biofuel Quota Act
* Ordinance on requirements regarding the sustainable generation of biomass for biofuel applications: Biomass Sustainability Ordinance (BioNachV)

The law on renewable energy was amended on the 6th of June 2008. From 2009 onwards, the degression of the feed in tariff for biomass will be changed from 1.5% to 1%. The feed in tariff for one kWh of electricity coming from biomass for plants under 150 kWe will amount to €c 11.67/kWh. The premium for electricity produced from agricultural biogas will be raised from €c 6/kWh to 7 for plants below 500 kWe. To this will be added a premium for production units using more than 30% liquid manure (€c 4/kWh for plants under 150 kWe and €c 1/kWh for plants under 500 kWe) or a premium of €c 2/kWh if the main source is waste coming from the cleaning of natural green spaces for units below 500 kWe. The premium for cogeneration will be raised from €c 2/kWh to 3 for plants below 20MWe and the technology premium will be maintained. Another innovation will be that units producing purified biogas will benefit from a premium which will depend on the plant efficiency: €c 2/kWh for units producing 350 Nm^3 per hour and €c 1/kWh for units producing up to 700 Nm^3 per hour. The new law also foresees the increase of the feed in tariff for electricity produced from landfill gas for units up to 500 kWe, thus passing from €c 7.11/kWh to €c 9/kWh and the continuation of the €c 6.16/kWh tariff for plants up to 5MW. The tariff will remain unchanged for sewage sludge biogas: €c 7.11/kWh up to 500 kWe and €c 6.16/kWh up to 5 MW. In parallel, the German government passed a new law on 12 March 2008 concerning injection into the gas network, in order to promote the injection of biomethane (purified biogas). The aim of this new law is to replace 10% of natural gas consumption with biogas as of 2030. As for electricity produced from renewable sources, the law gives biomethane suppliers priority for injecting their output into the natural gas network. It also stipulates that a large share of the costs shall be borne by the network operator and not by the supplier.

Switzerland:
In Switzerland, the SVGW (“Schweizerischer Verband des Gas- und Wasserfaches“, Swiss Association for Gas and Water) has published the Directives G 13, “Directives on the injection of biogas into the natural gas network”. These directives define requirements for the quality of biogas from fermentative processes and of similar gases if an injection into the natural gas network is planned. Furthermore, the directives define requirements regarding the feed-in technology plants. The overall goal of the directives is to ensure the reliability of the feed-in plants, the natural gas distribution networks as well as installed gas units.
The directive SUVA (Safety in biogas plant) is another regulation of Switzerland.

France:
The renewable energy objectives in France are defined by the *13 July 2005* law which plans that 10% of the French energy needs will be insure by renewable sources by 2010. 3 clear targets are defined in order to meet the overall objective. Firstly, the share of national renewable electricity production should reach 21% of the electricity consumption by 2010. In 2007 this share is about 12.8% (source: the 10th worldwide electricity production from renewable energy sources). Secondly, a 50% increase in the heat production coming from renewable sources. And thirdly, a 7% increase in the share of biofuels used for transport.

Two important instruments have been put in place to fulfil the objectives. A system of purchase prices for the renewable electricity sector and an income tax credit (reimbursement by the tax departments) for household equipments.
A new law on environment perspectives named 'Grenelle 1' is in way to be voted by the French assembly. This law confirms the willingness of the country to diversify its energy sources and to meet the long-term target of 20% of renewable energy by 2020.

The production of primary energy from biogas is equally divided between biogas from landfill sites (161.3 ktoe in 2007) and biogas from waste treatment plant (144.2 ktoe). Other biogas sources represent only 1.2% of the total (3.78 ktoe). An order dated 10 July 2006 defines the feed-in-tariff of electricity produced from methanisation biogas. It varies from 9 c€/kWh for installations of less than 150 kWe to 7.5 c€/kWhfor installations of more than 2 MWe. In addition, there is an energy efficiency incentive of 3 c€/kWh for installations that optimise heat recovery and/or electricity generation. This rate is not applicable to landfill site biogas which (under an Order dated 1st October 2001) benefits from a buying price of between 4.5 c€ and 5 c€ per kWh, plus an energy incentive of between 0 c€ and 0.3 c€ per kWh.

Currently, the feed-in of biogas to the natural gas grid is not permitted in France, although (or possibly precisely because) the feed-in of upgraded landfill gas was carried out in context with the MONTECH project in 1998. This project, however, was stopped due to discussions on the necessary gas quality and possible gas network contamination.
The "L'Agence Française de Sécurité Sanitaire de l'Environnement et du Travail" has spoken in favour of the injection of biomethane into the natural gas grid on October 29 2008 with the prospect of applying it as biofuel. A specific regulatory framework coming from the AFSSET conclusions on the admission of biogas to the natural gas network has not yet been published. The technical conditions for the access to the natural gas grids of the gas network operators are, however, already created in such a way as to principally allow the injection of renewably generated gases.

Sweden:
In Sweden, the SS 155438 standard "Motorbränslen – Biogas som bränsle till snabbgående ottomotorer", which became effective in 1999, regulates the quality criteria for biogas utilised as biofuel.
Biogas Type A refers to vehicles without oxygen sensor; Type B applies to vehicles with an oxygen sensor, also called lambda sensor. Similarly, this standard also applies to the injection of biogas into the natural gas networks. Comparably to the injection of substitute gas in Germany, however, an adaptation of the fuel value is required before access to the gas network is permitted.
The backdrop of this regulation focusing on usage as vehicle fuel is twofold: the biomethane produced in Sweden is almost exclusively used as biofuel, and the Swedish gas network infrastructure is less developed than it is, for example, in Germany. Thus, it has so far been possible to inject biogas into the natural gas network only in some areas on the Swedish west coast. Only a few injection projects have therefore been implemented so far.
No rules are regulating injection of biogas to the gas grid. Upgraded biogas is only injected into the distribution grid and not the transmission grid. In general the rules for natural gas are valid for plants connected to the natural gas grid. Deals about injection and connection are closed between plant owners and grid owners. Deals also cover amounts, price and quality of the gas. Work is in progress concerning e.g. quality responsibility.
The green gas principle is used and biogas can be sold anywhere along the natural gas grid even though the costumer does not receive biogas, but gets natural gas. There is work in progress around this subject.

In Sweden the biogas production has been more or less constant the past years, which is also true for the total number of plants. However, there is a change in where the biogas comes from. The production from landfills decreases as expected, while the production from sewage treatment plants and co-digestion plants increases.

Upgrading of biogas and injection to the gas grid
In Sweden, there are 8 sites of injection in Sweden among the 40 upgrading plants (it seems that the number of injection sites have been mixed up with the number of upgrading plants). There are 115 filling stations. In Sweden the biggest environmental benefit is gained, by upgrading biogas and

replacing fossil transport fuels. 19% of the produced biogas is utilized as vehicle fuel. During 2007, 28 million of Nm^3 biogas was sold as vehicle fuel, which is more than the amount of natural gas (about 25 million Nm^3) sold as vehicle fuel in 2007. 14400 vehicles (buses, heavy cars, light cars) were riding on gas (biogas and natural gas) in 2007. End of December 2007 there were 86 public gas filling stations and 27 gas fill-ing stations for buses, now those numbers have reach a total of 115 filling station
Policy measures
The introduction of biogas as vehicle fuel in Sweden has been realised by many governmental and local support measures, such as:

- A 30% investment support from governmental investment programmes to many biogas plants;
- A special investment support of M€ 15 for biogas filling stations during 2006 and 2007;
- Exemption of biogas use as vehicle fuel from tax;
- Relative low natural gas tax of 1.4 €ct/kWh (3.9 €/GJ) compared to a tax of 7.7 €ct/kWh (21.4 €/GJ) for petrol;
- Free parking for biogas cars in several cities like Gothenburg;
- Readiness of the gas suppliers in trying to keep the biogas price about 20-30% below the equivalent price of petrol, as long as the market for biogas as vehicle fuel is under development.
- New car tax since October 2006. Tax based on fuel and CO_2 emissions. Gas models reduced with about 50% compared to petrol.
- Obligation to provide biofuels at filling stations.
- 1100 € subsidy for new Eco-cars.
- Exception from congestion tax in Stockholm from 1 August 2007 for gas vehicles, ethanol and electricity hybrids.

Regarding the environmental targets, the government's policy is that 85% of all new governmental cars should be Eco friendly, as well as 25% of all new emergency services vehicles.

Austria:
Renewable energy policy in Austria exists on three levels: the Federal level, the regional level of the provinces (*Bundesländer*) and the local level of municipalities. Important contributions from renewable energy sources regard large hydropower for electricity, biomass for heat and power and solar thermal installations. On the Federal level the programme *klima:aktiv* (started 2004 by the Federal Ministry of Agriculture, Forestry, Environment and Water Management) aims at reducing CO_2-emission and increasing the penetration of renewable energy sources. Regarding renewables, focus is on biogas and biomass, solar thermal and heat pumps. Typical for the Austrian programmes is that they are easily accessible through the internet and through telephone hotlines.
The *klima:aktiv* programme has biogas as one of the priorities. Special focus in this programme is on providing information (conferences, networking events, training), communication and research.
In 2007 62 waste landfill gas recovery plants, 134 sewage sludge digesters, about 350 (agricultural) co-digestion plants, 25 industrial anaerobic waste water treatment plants, and about 15 biowaste digestion plants from municipalities were in operation in Austria. These plants produced between 265 and 414 million Nm3 biogas, from which 45% from (agricultural) co-digestion plants, and 47% from landfills and sewage sludge. Based on the feed-in tariffs set in 2006, it is possible to get a subsidy of 17 €cents/kWh with an installed capacity of 100 kW or less guaranteed for 10 years. As a result of economic pressure through increased raw material costs, rarely new plants were opened in 2007.

In Austria, the injection of biogas is possible either via the existing gas network or via a local micro gas network.
The injection of landfill gas or sewage gas into the public gas grid is currently generally not permitted.
The political framework for the injection into the public gas grid is defined in the following legal regulations:
The Gas Economy Act ("Gaswirtschaftsgesetz") obliges gas grid operators to grant grid access to biogenic gases. These gases do need to fulfill the quality criteria defined in the "General Distribution Network Conditions" to ensure safe transport within the Austrian gas network. Regulations G 31 and G 33 define these criteria.
ÖVGW Regulation G 31 (ÖVGW = Austrian Association for Gas and Water) defines all those parameters and quality criteria, which are necessary to ensure safe transport. Moreover, the regulation

determines the required gas fuel value data. The quality criteria phrased in the regulation refer to the characteristics of the imported gas.
ÖVGW Regulation G 33 applies to the injection of biogas based on renewable processes into the natural gas networks. This regulation therefore defines the quality of renewable gases and the quality control which are preconditions for the feed-in.

Besides the fact that some aspect of the production of biogas in general has a regulation, there is no specific regulation for biogas plants.
Indeed, there are regulations at the plant construction, at the safety level as ATEX or at economic level. But as regards the safety to the production and use, the regulation is virtually nonexistent.

2. ATEX Directive

Because there is methane in biogas, biogas production is concerned by the ATEX directive.

There are two ATEX directives (one for the manufacturer and one for the user of the equipment):[A11]

- The ATEX 95 equipment directive 94/9/EC, Equipment and protective systems intended for use in potentially explosive atmospheres;
- The ATEX 137 workplace directive 99/92/EC, Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres.

INERIS is a major referent in the implementation of these guidelines to scale European and international.

Regarding equipments, some companies provide devices, which are used in biogas production, with the ATEX labels. But at small-scale of biogas production, those devices are hardly used.

Concerning the workplace, obligations are complex and require special attention. Safety measures have to be well managed because of the presence of possible explosive atmosphere and in order to satisfy the minimum requirements.

3. BREF – "Slaughterhouses and Animals By-products Industries" [B8]

The BREF has been published in May 2005, by the European Commission. This report is a Reference Document on Best Available Techniques in the Slaughterhouses and Animal By-products Industries and particularly on Biogas production.

In single stage digesters, biogas cannot be produced from pure animal material because the nitrogen content is too high. Animal waste must, therefore, be mixed with other organic matter to reduce the nitrogen content. In Denmark, approximately 75 % of the biomass resource for anaerobic digestion is animal manure, with the remainder mainly originating from food processing, including slaughterhouses, although some segregated domestic waste is also treated [C4]. Animal by-products, manure and the sewage sludge from slaughterhouses can all be treated [C5].

It is also reported in this report that there is a risk of an accident release of CH_4, which is a greenhouse gas and has a global warming potential 30 times greater than that of CO_2. But the advantages associated with biogas production from slaughterhouse by-products include: a reduction in the concentration of impurities in waste water, low excess sludge production and the production of a biologically stable excess sludge that can be used as a fertilizer. The solid residues from biogas production from animal by-products may be composted. The use of such compost is subject to the restrictions specified in ABP Regulation 1774/2002/EC.
For each unit of electricity generated from biogas, 1.5 units of heat may be produced as hot water at over 80 ºC. The energy-rich gas can be used, e.g. in slaughtering or animal by-products production, as a substitute for conventional primary energy. Biogas is reported to make no net contribution to the greenhouse effect [C6].

This document reports that a biogas plant could generate noise pollution. Indeed, large-scale mechanical equipment such as compressors, used to aerate the process fluid and filtration plant may be potential sources of noise pollution [C7].

4. Results of commonalities and differences

The first commonality which we can see in the different regulations is that governments want to increase the number of biogas plants and the use of biogas for the next years in order to enforce the European directive and energy plans. But differences appear at the next step: the price of energy, such as electricity, is not the same in the various countries of Europe. It results that specifications and requirements are different, because legal amount of energy production is linked to its price. Concerning the thresholds of dangerous trace compounds in biogas, regulations are broadly similar.
Finally, the main problem of biogas related to safety, is that regulations are enforced for large-scale production but there is a lack of enforcement of those one for small-scale production and, in general, it is because of a problem of skills.

Issues:

Can we define some safety minimum requirement in regulation?
Is the implementation of the ATEX directive enough controlled?
Are there actions needed to support the implementation of safety regulations?

G. Standardization/ Guidelines

The application of standards makes an industry more efficient and safer and this could be an interesting solution to improve safety in biogas plants.
For larger biogas programs, especially when aiming at a self-supporting dissemination process, standards in dimensions, quality and pricing are essential. Standard procedures, standard drawings and forms and standardized contracts between the constructor, the planner, the provider of material and the customer avoid mistakes and misunderstandings and save time. There is, however a trade-off between the benefits of standardization and the necessity of individual, appropriate solutions.

But nowadays there is no biogas standard. The Standardization Administration of China has made a proposal to the International Organization for Standardization (ISO) for a new field of technical activity on biogas in January.[B9]
The table of contents of this standard would be:

- Biogas glossary
- Designing, construction, commissioning and check and test of small biogas facilities (household biogas pool)
- Designing, construction, commissioning and check and test of large- and middle-scale biogas plants
- Designing, manufacturing, installation and inspection of biogas equipment
- Designing, manufacturing and inspection of products for biogas application
- Designing, manufacturing, installation and inspection of equipment and facilities for biogas power generation
- Comprehensive use of digested solid and liquid
- Appraisal on technical, economical and environmental benefit of biogas facilities

The European Committee for standardization has created a working group in order to find a common standard on the Injection of non-conventional gases into gas networks. The reference of this group is CEN/TC 234/WG 9. The injection of biogas into gas grid is concerned by this research.

Issues:

Do we need a standard on biogas production and use, in particular for the safety aspects?
Is the BREF document "Slaughterhouses and Animals By-products Industries" enough?

IV. Recommendations from the workshop

Remarks and questions about this document from the Programme Committee:

The education of operator is a real problem! They don't have enough knowledge in order to understand what happen in their plant and constructor does not help them!

A safety guidance document would be useful. Injection into the gas grid / use for vehicles / bulk transportation may be good candidates for standardization.

To what extent does biogas burning undo carbon fixing?

Is there a possibility to use just the hydrogen and condensed phase products (avoiding methane and CO_2)?

Is there fire or explosion risk associated with processes using dry feeds?

What are the causes and consequences of losing control of the reaction?

What are the safety consequences of changing the feedstock?

Given the diverse nature of processes / raw materials / end use and local features would such a standard be more of an informative safety document?

To what extent does existing legislation (ATEX, etc) and guidance already cover the processes?

What is the risk of static spark generation from the hood?

What are the causes / consequences of uncontrolled thermal activity in the digester or air entrainment into the hood?

Regarding the leaks of toxic gases, is there dispersion modeling or validation?
Is it possible in a biogas plant to have risk of asphyxiation due to a too important amount of CO2 or CH_4?

Do we need a standard on biogas production and use, in particular for the safety aspects?
This is quite difficult to judge if there is enough documentation as information are spread out in many reports. There is clearly a need to gather available information regarding risks, safety. The interests for a report gathering the necessary information are several: from an education point of view as well as clearer guidelines. Moreover it will underline the lack or gap of knowledge.
On possible standardization:
There is probably a lack of knowledge that must be filled before considering a standard. Which compounds are produced depending on the substrate that is digested, what happen with them under different removal and upgrading techniques? Are they eliminated? With extensive data it will be possible to define levels for some contaminants.
How to obtain a permit to operate a plant?
Plants need to obtain an environmental permit from the County Administrative Board where the plant will be built, they need to describe the plant, study the environmental aspects and consequences, the emissions… There will be an inspection before they can run the plant.

There is no specific education program to work in a plant except for the gas manager. It may be interesting to check the need for such an educational program as the employees came from different backgrounds.

Other comments:

The document does mention odor problems. This is a relatively important issue in Sweden as there are some complaints from the neighbors and it can affect the acceptance level for such activities.

Is the fact that it is not allowed to inject biogas from landfill in gas-grid in Switzerland, really forbidden or because of feasible reason?

Among the constructive considered conditions the presence of groundwater and the environment of the implantation site chosen must be added. To define the types of biogas plants, we usually begin by distinguishing the state of the reaction (liquid or dry). The feeding method is a criterion that can be simplified by removing the semi-batch which did not match to any commercialized technology and perhaps adding the percolation process. With regard to building systems, the distinction between fixed and floating dome is too limited.

Bibliography

A. Websites

[A1] - www.eubia.org/108.0.html

[A2] - http://ec.europa.eu/energy/technology/set_plan/set_plan_en.html

[A3] - www.energies-renouvelables.org/barometre.asp

[A4] - www.unu.edu/unupress/unupbooks/80434e/80434E0j.htm

[A5] - www.3a-biogas.com/infocenter/executive_summary.htm

[A6] – http://www.arizonaenergy.org/AltEnergyClub/Biogas%20-%20Application%20and%20Product%20Development.htm

[A7] - www.biogas-renewable-energy.info/biogas_composition.html

[A8] - www.biogaspartner.de/index.php?id=10093&L=1

[A9] - http://www.aria.developpement-durable.gouv.fr/

[A10] - http://www.factsonline.nl/

[A11] - http://www.ineris.fr/fr/ressources/recherche/atex

[A12] - www.eurobserv-er.org

[A13] - http://www.osha.gov/SLTC/healthguidelines

[A14] - http://www.reptox.csst.qc.ca/RechercheProduits.asp

B. Document in Portable Document File (PDF) version

[B1] – http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:283:0033:0033:EN:PDF

[B2] – http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:123:0042:0046:EN:PDF

[B3] - www.lth.se/fileadmin/energiportalen/Filer/Om_Energiportalen/Invigning/Posters/Energy_analysis_of_biogas_production_Maria_Berglund_P_l_B_rjesson.pdf

[B4] - students.chem.tue.nl/ifp24/BiogasPosterWEB.pdf

[B5] – http://www.afsset.fr/upload/bibliotheque/058412092985118807049572120143/biogaz_oct08.pdf

[B6] - www.iea-biogas.net/Dokumente/Biogas%20upgrading.pdf

[B7] - http://213.131.156.10/xpo/bilagor/20040115134708.pdf

[B8] - http://eippcb.jrc.ec.europa.eu/reference/brefdownload/download_SA.cfm

[B9] –
http://publicaa.ansi.org/sites/apdl/Documents/News%20and%20Publications/Links%20Within%20Stories/ISO%20TSP%20211%20%28Biogas%29.pdf

[B10] – http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0628:FIN:EN:PDF

[B11] - http://www.kas-bmu.de/publikationen/kas/KAS_12.pdf

[B12] - http://www.ineris.fr/centredoc/dradrc93-scenarios-accid-methanisation-web.pdf

[B13] - http://www.ineris.fr/centredoc/Rapport_Biogaz_web.pdf

[B14] - http://www.ineris.fr/centredoc/methaniseur_agricoles_medad_Biogaz_web.pdf

[B15] - http://www.ineris.fr/centredoc/reacteur-pilote-methanisation-web.pdf

[B16] - http://www.ineris.fr/centredoc/risques-sanitaires-biogaz-web.pdf

C. Books

[C1] - S. Rasi, A. Veijanen, J. Rintala. Trace compounds of biogas from different biogas production plants, Energy, Volume 32, Issue 8, August 2007, Pages 1375-1380

[C2] - A. Jaffrin, N. Bentounes, A. M. Joan, S. Makhlouf. Landfill Biogas for heating Greenhouses and providing Carbon Dioxide Supplement for Plant Growth, Biosystems Engineering, Volume 86, Issue 1, September 2003, Pages 113-123.

[C3] - Bjorn Vinneras, Caroline Schonning, Annika Nordin. Identification of the microbiological community in biogas systems and evaluation of microbial risks from gas usage, Science of The Total Environment, Volume 367, Issues 2-3, 31 August 2006, Pages 606-615.

[C4] - 152, Danish Institute of Agricultural and Fisheries Economics, 1999

[C5] - 148, Finnish Environment Institute and Finnish Food and Drink Industries' Federation, 2001

[C6] - 207, Linkoping Gas AB, 1997

[C7] - 144, Det Norske Veritas, 2001

[C8] - Martina Poeschl, Shane Ward, Philip Owende, Prospects for expanded utilization of biogas in Germany, Renewable and Sustainable Energy Reviews, Volume 14, Issue 7, September 2010, Pages 1782-1797

[C9] - Pal Borjesson, Bo Mattiasson. Biogas as a resource-efficient vehicle fuel, Trends in Biotechnology, Volume 26, Issue 1, January 2008, Pages 7-13.

V. Acknowledgments

This document was elaborated by Samuel DELSINNE (EU-VRi) under the supervision of Sébastien EVANNO (INERIS) and Olivier SALVI (EU-VRi) to provide background information and input for thoughts for the workshop, and with the contribution of the members of the Programme Committee, who are here acknowledged for their contribution:

Participant	Company	Country
ARRHENIUS Karine	SP Technical Research Institute	Sweden
COENEN Joep	RHODIA	Netherlands
EVANNO Sébastien	INERIS	France
FOUQUET Rémi	MEEDDM	France
GAUCHET Lucille	MEEDDM	France
GRENINGER Aude	GDF-SUEZ	France
HOFFMANN Lucien	CRP Gabriel Lippmann	Luxembourg
KAY Jake	HSL	United Kingdom
MARCHAIS Caroline	ATEE / Club Biogaz	France
MEMBREZ Yves	EREP SA	Switzerland
MOLETTA René	MOLETTA METHANISATION SAS	France
NEDELEC Ronan	SIAAP	France
RIOTTE Michel	SIAAP	France
THIÉBAUT Charles	MEEDDM	France

Mais aussi DELFOSSE Philippe de CRP Gabriel Lippmann du Luxembourg

VI. Annexes

A. Primary energy production of biogas in the EU in 2006 and 2007

PRIMARY ENERGY PRODUCTION OF BIOGAS IN THE EUROPEAN UNION IN 2006 AND 2007 (IN KTOE)

	2006				2007			
Pays/ Countries	Décharges/ Landfill gas Sewage sludge gas	Stations d'épuration/	Autres biogaz/ Other biogases	Total/ Total	Décharges/ Landfill gas Sewage sludge gas	Stations d'épuration/	Autres biogaz/ Other biogases	Total/ Total
Allemagne/Germany	383,2	270,2	1 011,7	1 665,3	416,4	270,2	1 696,5	2 383,1
Royaume-Uni/UK	1 318,5	180	–	1 498,5	1 433,1	191,1	–	1 624,2
Italie/Italy	337,4	1	44,8	383,2	357,7	1	47,5	406,2
Espagne/Spain	251,3	48,6	19,8	319,7	259,6	49,1	21,3	329,9
France/France	150,5	144	3,6	298,1	161,3	144,2	3,7	309,2
Pays-Bas/The Netherlands	46	48	47,1	141,1	43,2	48	82,8	174
AutricheIAustria	11,2	3,5	103,4	118,1	10,7	2	126,4	139,1
Danemark/Denmark	14,3	21	57,6	92,9	14,3	21	62,6	97,9
Belgique/Belgium	51	17,6	9,1	77,6	48,1	18	12,5	78,6
Rép. tchèque/Czech Rep.	24,5	31,1	7,8	63,4	29,4	32,1	17	78,5
Pologne/Poland	18,9	43,1	0,5	62,4	19,1	43	0,5	62,6
Grèce/Greece	21,2	8,6	–	29,8	38	9,8	–	47,8
Finlande/Finland	26,1	10,4	–	36,4	26,4	10,3	–	36,7
Irlande/Ireland	25,4	5,1	1,8	32,3	23,9	7,9	1,7	33,5
Suède/Sweden	9,2	17,1	0,8	27,2	9,2	17,1	0,8	27,2
Hongrie/Hungary	1,1	8	3,1	12,2	2,1	12,4	5,7	20,2
Portugal/Portugal	–	–	9,2	9,2	–	–	15,4	15,4
Slovénie/Slovenia	6,9	1,1	0,4	8,4	7,6	0,6	3,8	11,9
Luxembourg/Luxembourg	–	–	9,2	9,2	–	–	10	10
Slovaquie/Slovakia	0,4	6,9	0,4	7,6	0,5	7,6	0,5	8,6
Estonie/Estonia	3,1	1,1	–	4,2	3,1	1,1	–	4,2
Lituanie/Lithuania	–	1,5	0,5	2	1,6	0,8	_	2,5
Chypre/Cyprus	–	–	0	0	–	–	0,2	0,2
UE/EU	**2 007,3**	**867,8**	**1 330,8**	**4 898,9**	**2 905,2**	**887,2**	**2 108,0**	**5 901,2**

Source: [A12]

B. Gross electricity production from biogas in the EU in 2006 and 2007

GROSS ELECTRICITY PRODUCTION FROM BIOGAS IN THE EUROPEAN UNION IN 2006 AND 2007* (IN GWH)

	2006			2007		
Pays/ Countries	Centrales électriques seules/Electricity plants only	Centrales fonctionnant en cogénération/ CHP plants	Électricité totale/ Total electricit	Centrales électriques seules/Electricity plants only	Centrales fonctionnant en cogénération/ CHP plants	Électricité totale/ Total electricity
Allemagne/Germany	–	7 446,0	7 446,0	–	9 520,0	9 520,0
Royaume-Uni/UK	4 424,0	463	4 887,0	4 795,6	503,4	5 299,0
Italie/Italy	1 061,9	241,8	1 303,7	1 125,6	256,3	1 381,9
Espagne/Spain	610,3	56	666,3	631,1	56	687,1
France/France	487,3	35,4	522,7	505,3	35,7	541
Pays-Bas/The Netherlands	146,1	215,2	361,3	274,2	223,2	497,4
Autriche/Austria	424,1	23	447,1	469,8	22,8	492,6
Danemark/Denmark	1,6	278,4	280,1	1,6	293,3	295
Belgique/Belgium	158,3	120,6	278,9	152	127,4	279,4
Rép. tchèque/Czech Rep.	63,1	112,8	175,8	80,3	142,6	222,9
Grèce/Greece	69,3	38,5	107,9	91,3	84	175,3
Pologne/Poland	0	160,1	160,1	0	160,1	160,1
Irlande/Ireland	108,4	13,6	122	101,9	16,9	118,8
Portugal/Portugal	25,2	7,4	32,6	58	7,3	65,4
Slovénie/Slovenia	8,6	26,1	34,7	8,9	39,2	48,2
Suède/Sweden	–	46,3	46,3	–	46,3	46,3
Luxembourg/Luxembourg	–	32,6	32,6	–	36,6	36,6
Finlande/Finland	0,9	21,4	22,3	0,9	21,4	22,3
Hongrie/Hungary	–	22,1	22,1	–	22,1	22,1
Estonie/Estonia	1,1	13	14,1	1,1	13	14,1
Lituanie/Lithuania	–	5,4	5,4	–	6,3	6,3
Slovaquie/Slovakia	–	4	4	–	4	4
Chypre/Cyprus	0	0,2	0,2	–	1,4	1,4
UE/EU	**7 590,3**	**9 382,9**	**16 973,2**	**8 297,7**	**11 639,5**	**19 937,2**

Source: [A12]

C. Scenario of the EU Commission to increase biomass energy using

ANNEX 3 – A scenario to increase biomass energy using current technologies

mtoe	**Current (2003)**	**Future (2010)**	**Difference**
Electricity	20	55	35
Heat	48	75	27
Transport	1	19	18
TOTAL	69	149	80

This scenario is drawn from the 2004 communication "The share of renewable energy", expanded to the EU-25. It is compatible with achievement of the Community's targets of: a 12% overall share of renewable energy; a 21% share of renewable energy in electricity generation; and a 5.75% market share for biofuels.

The Commission believes this scenario can be achieved in the three sectors sectors – electricity, heat and transport – through the measures in this action plan – if not in 2010, the year for which these targets were set, then within a year or two of that date.

This is the scenario that serves as the basis for the impact assessment on this Communication.

Source: - Biomass action plan - {SEC(2005) 1573}- [B10]

D. Gross heat production from biogas in the EU in 2006 and 2007

GROSS HEAT PRODUCTION FROM BIOGAS IN THE EUROPEAN UNION IN 2006 AND 2007* (IN KTOE)

Pays/ Countries	2006			2007		
	Unités de chaleur seules/Heat plants only	Unités fonctionnant en cogénération/ CHP plants	Chaleur totale/ Total heat	Unités de chaleur seules/Heat plants only	Unités fonctionnar en cogénération/ CHP plants	Chaleur totale/ Total heat
Royaume-Uni/UK	61,9	–	61,9	61,9	–	61,9
France/France	44,4	5,8	50,2	47,4	5,8	53,2
Italie/Italy	–	38,6	38,6	–	40,9	40,9
Pologne/Poland	6	28,1	34,2	6	28,1	34,2
Rép. tchèque/Czech Rep.	10	13,9	23,9	9,6	14,3	23,9
Danemark/Denmark	3,7	17,1	20,9	4,7	18,8	23,6
Allemagne/Germany	8,7	14,5	23,2	8,7	14,5	23,2
Finlande/Finland	2,5	19,7	22,1	2,5	19,7	22,1
Suède/Sweden	4,7	11,7	16,4	4,7	11,7	16,4
Espagne/Spain	14,7	–	14,7	14,7	–	14,7
Belgique/Belgium	1	12,9	13,9	1,6	12,6	14,2
Autriche/Austria	4,7	4,2	8,9	4,3	4,2	8,5
Luxembourg/Luxembourg	–	4,4	4,4	–	5	5
Grèce/Greece	–	2,9	2,9	–	3,5	3,5
Irlande/Ireland	1,5	2,6	4	1,5	1,9	3,4
Slovaquie/Slovakia	2,3	0,9	3,2	2,3	0,9	3,2
Hongrie/Hungary	–	2,6	2,6	–	2,6	2,6
Estonie/Estonia	0,1	0,9	1	0,1	0,9	1
Pays-Bas/The Netherlands	–	1	1	–	1	1
Lituanie/Lithuania	–	0,3	0,3	–	0,3	0,3
Chypre/Cyprus	–	0,02	0	–	0	0
UE/EU	**166,2**	**182,1**	**348,3**	**170,1**	**186,8**	**356,9**

Source: [A12]

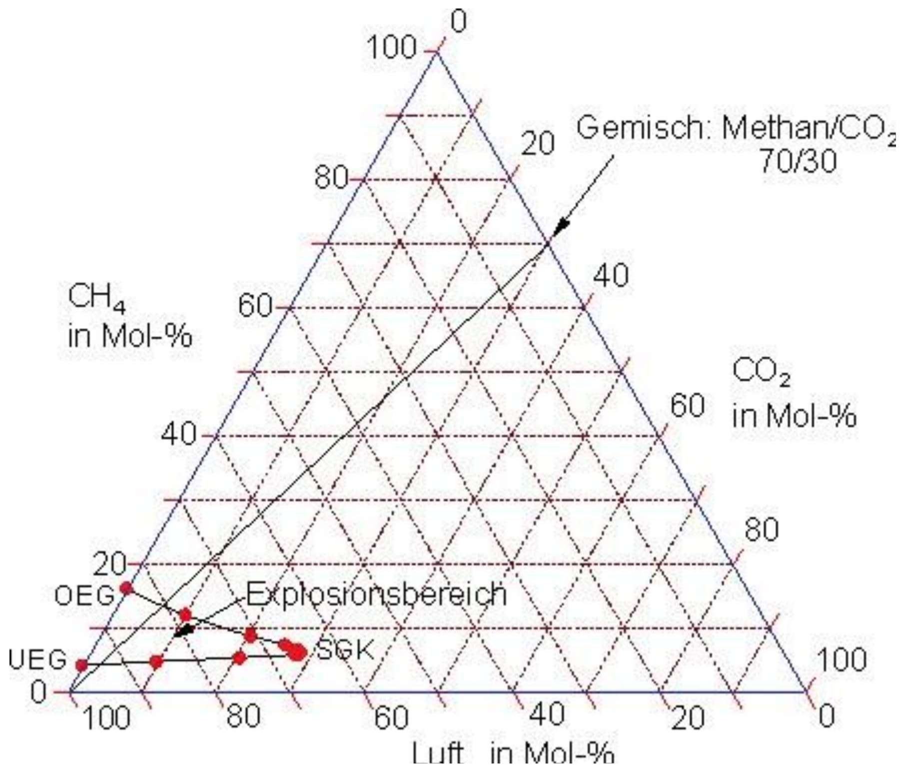
E. Energy yield by scale of biogas plant

	Energy yield by scale of biogas plant (GJ/tDry Matter)	
	Co-digestion small-scale biogas system	Co-digestion large-scale biogas system
Biogas yield (GJ/tDM)	8,9	16,4
(1) Combined Heat and Power (CHP)–electricity generation without heat utilization	2,9	–
(2) CHP—electricity generation with heat utilization	4,1	–
(3) CHP—electricity generation, heat and cooling energy utilization	4,7	–
(4) Stirling engine—electricity generation and heat utilization	4	–
(5) Micro gas turbine—electricity generation and heat utilization	3,9	–
(6) CHP with waste heat utilization in Organic Rankine Cycle technology	3,2	–
(7) Fuel cell technology for electricity generation	–	8,3
(8) Upgrading biogas (bio-methane) for injection into gas grid	–	16,4
(9) Upgrading biogas for utilization as transportation fuel	–	16,4

Notes: the data are based on energy audit of biogas production system in the respective scale of operation. The blank entries indicate that respective technology was unviable for the scale of biogas operation considered.

Source: [C8]

F. Explosive limit of methane in the air



Source: [B11]

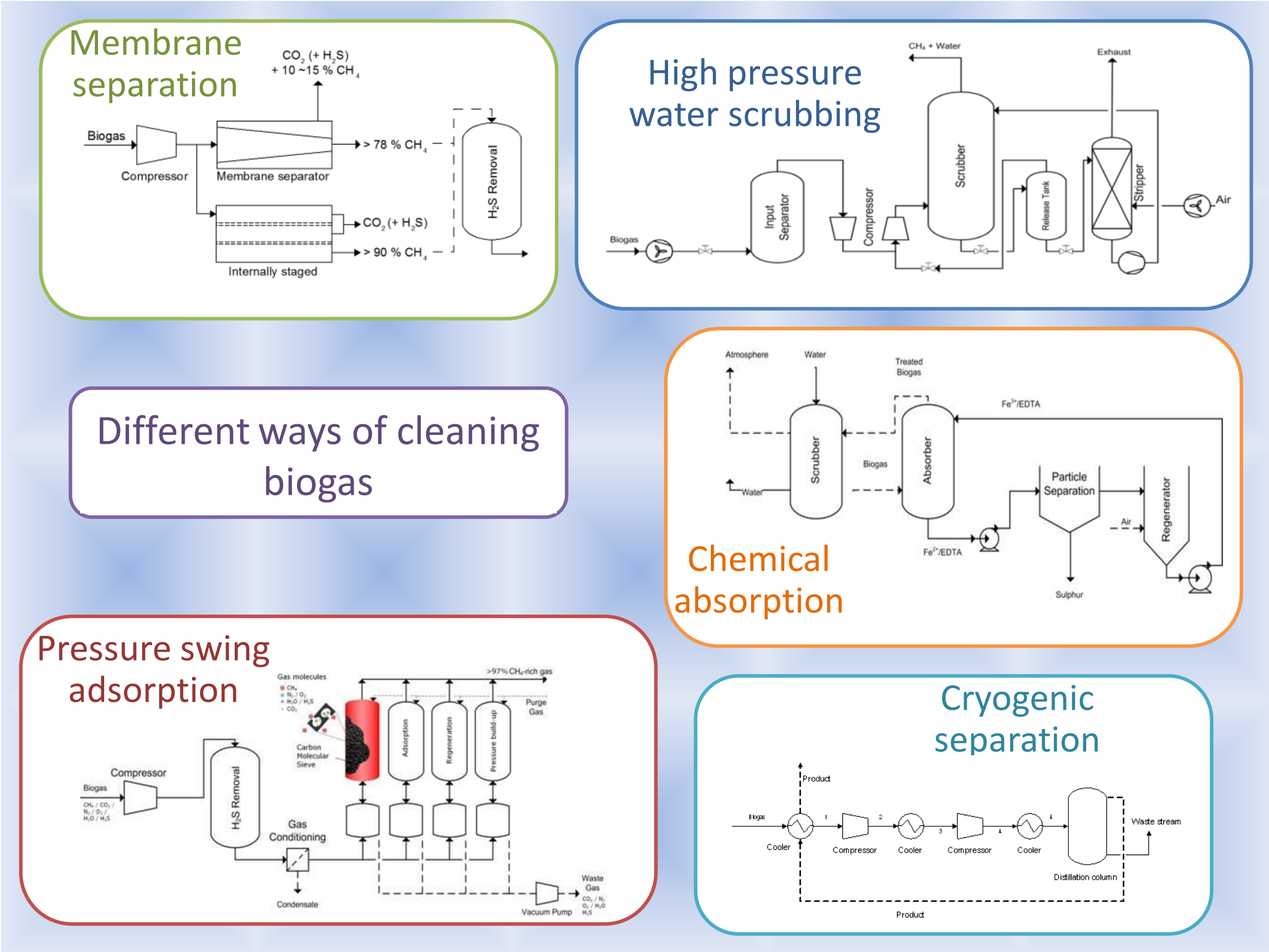
NB: I there similar diagrams with all components of Biogas (mixture with CH_4, CO, H_2, H_2S…)?

G. Comparison of requirements of various European countries for injection in gas-grid

Physical properties	F	A	CH	S	D	NL	Unit
Calorific upper value	38.5-46.1 (H) 34.2-47.8 (L)	38.5-46.1	38.5-47.2	39.6-43.2	30.2-47.2	31.6-38.7	MJ/m3
Wobbe-index	49.1-56.5 (H) 43.2-46.8 (L)	47.9-56.5	47.9-56.5	45.4-48.6	37.8-46.8 (L) 46.1-56.5 (H)	43.46-44.41	MJ/m3
Qualities	**F**	**A**	**CH**	**S**	**D**	**NL**	**Unit**
Water dew point	<5	<-8 (40 bar)	60% humidity	<-60	Ground temp	<-10 (8bar)	℃
Water				<32 mg/m3			
Temperature (in the injection gas)				-20 +20		0-40	℃
Sulphur (in total)	30	10	30	23	30	45	mg/m3
Inorganically bonded sulphur (H2S)	5	5	5	10	5	5	mg/m3
Mercaptans	6	6			15	10	mg/m3
THT	15-40		15-25		good	> 10 nominal 18	mg/m3
Ammonia		none		20		3	mg/m3
Chlorine containing compounds	1	none			none	50	mg/m3
Fluorine containing compounds	10	none			geen	25	mg/m3
HCl		none				1	ppm
HCN		none				10	ppm
Hg	1						µg/m3
CO	2					1	% mol
CO2 in dry gas networks (max)	2.5	3	6	3	6	6	% mol
CO2 in gas networks						n.a.	% mol
BTX						500	ppm
Aromatic hydrocabons						1	% mol
O in dry gas networks	0.01	0.5	0.5	1	0.5	0.5	% mol
Hydrogen	6	4	5	0.5	5	12	% mol
Methane number						> 80	
Methane		> 96	> 96	> 97		-	% mol
Dust		Techn. free		< 1 µm	Techn. free	Techn. free	
siloxans		< 10 (mg/m3)				5 ppm	

Source: AFSSET report in 2008 – [B5]

H. Different ways of cleaning biogas



Source: [B4]

I. Explosion of a Biogas plant in Daugendorf. 16/12/2007

Photo: Thomas Warnack (Thomas.Warnack@T-Online.de)

J. Review of previous project and initiatives on biogas production

Title	Acronym	FP	Date(start/ end)	Link URL	Coordinator
European biogas initiative to improve the yield of agricultural biogas plants	EU-AGRO-BIOGAS	FP6	2007-01-15/ 2010-01-14	http://www.eu-agrobiogas.net	Universität für bodenkultur wien
An integrated approach for biogas production with agricultural waste	AGROBIOGAS	FP6	2006-06-01/ 2009-05-31	http://www.landscentret.dk	Dansk landbrugsradgivning landcentret Jørgen hinge (mr) +4587405574
Biowaste and Algae Knowledge for the Production of 2nd Generation Biofuels	BIOWALK4BIOFUELS	FP7	2010-04-01/ 2014-03-31	http://www.biowalk4biofuels.eu/	Universita degli studi di roma la sapienza Silvano simoni (dr) +390687452030
Biofuels technologies european showcase	BITES	FP6	2007-12-03/ 2009-12-02	http://www.biofuelshowcase.eu/	Itabia
Biogas market expansion to 2020	BIOGASMAX	FP6	2006-01-01/ 2009-12-31-extended to September 2010	http://www.biogasmax.eu	Lille métropole communauté urbaine
Optimisation of the energy valorisation biomass matter according to the philosophy of a natural park	ENERGATTERT	FP5	2005-01-01 /2013-12-31	http://ec.europa.eu/energy/renewables/bioenergy/doc/anaerobic/nne5_227_2001.pdf	Au pays de l'attert
Three step fermentation of solid state biowaste for biogas production and sanitation (3A-BIOGAS)	3A-BIOGAS	FP5	2002-12-01 / 2004-11-30	http://www.3a-biogas.com/infocenter/executive_summary.htm	Mueller abfallprojekte gmbh Horst müller (mr) +43773220910
Process integration of biogas and fuelcell technology via simulation of the gas purification process (PROBAT)	PROBAT	FP5	2002-10-01 / 2006-09-30	http://www.ist-world.org/ProjectDetails.aspx?ProjectId=2ba44750593149cd8910daee684e402a&SourceDatabaseId=081fd37e0ca64283be207ba37bb8559e	Profactor produktionsforschungs gmbh Christoph kendelbacher (dr.)

NOTES ABOUT THE RESEARCH

The key word used during the research was: Biogas-methanisation-methanation
Those words were used alone or in association with these words: risks-security-safety-hazards-explosion-regulation-legislation
There are 220 project linked to the biogas.
There are few recent or active projects (2005-2010) in the database of CORDIS connected with biogas. (Approximately 20) (Most of them are included in the FP5/FP6)
For the recent or active projects, a few of them are connected with security, risks, safety or regulation. (Not very much linked: 9; More linked: 2)
There is no project directly linked to the risks in a biogas plant.

Review of INERIS initiatives:

- Accidental scenario and modeling of effect distances connected with agricultural-scale and industrial-scale biogas plant. (INERIS DRA-09-101660-12814A)- [B12]
- Main minimum safety requirements of biogas transport in gas-grid, in the context of the French regulation. (INERIS DRA-10-104107-00247A)
- Comparative study of hazards and risks connected with biogas and natural gas. (INERIS DRA-06-46032)- [B13]
- Risk study related to agricultural biogas plant operation (INERIS DRA-07-88414-10586B)- [B14]
- Development of a 5 Liter biogas pilot (INERIS DRA-09-104108-13976A)- [B15]
- Health risks related to injection of biogas from WWTP (wastewater Treatment Plant) in gas-grid – preliminary works. (INERIS DRC-09-104115-15559A)- [B16]