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DESIGN, OPERATION AND MAINTENANCE OF LOCAL BIOGAS NETWORKS

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ABSTRACT

Biomass is an attractive source of energy, also for the gas industry. In particular waste from agricultural activities can be digested into a gaseous mixture, which can be used as a fuel.
Independent local networks are developed that collect biogas from various digestion plants and to transport this gas to a central upgrading plant followed by injection in a natural gas network. Alternatively the biogas can also be collected at one or various sites and transported to e.g. a rather large central CHP unit (e.g. industry). They can be mainly found in rural areas with one or more biogas producers, where the available capacity in the nearby gas distribution grid is limited and there is almost no heat demand nearby the biogas production site. This limits the possibilities of the more conventional biogas use for local electricity production or local upgrading and injection into the gas grids and has lead to the development of these new types of gas grids.

Due to their significant different characteristics compared to conventional gas distribution grids these networks may ask for a different approach in design, operation & maintenance. Whether or not current gas distribution regulations, standards and practices are valid and applicable for these local biogas grids needs to be further investigated. The main characteristics of the local biogas grids which differ significantly from conventional gas distribution grids are:

1. (Raw) Biogas has different physical properties
   - Biogas has a relatively high density which may effect leak survey procedures and safety measures during works
   - Biogas has different burning properties that are not in compliance with the current gas families
   - Biogas can have fluctuations in composition (due to changes in biomass feed or digestion process characteristics),
   - Biogas has high concentrations of CO_2 and H_2S, this has an effect on both pipeline material choice and odorisation.
2. Local biogas grids can be characterized as gas ‘producing’ grids, while conventional gas distribution grids can be characterized as gas ‘consuming’ grids
3. Biogas grids have a rather constant supply and off take of the gas while conventional gas distribution grids have to deal with seasonal fluctuations of the gas demand.

Although the local biogas networks may need a different approach in some aspects compared to conventional gas distribution grids, there are many similarities. It seems logical that the gas distribution companies take responsibility for the design, operation and maintenance of the local biogas networks when considering the safety risks of local biogas grids. Furthermore these local biogas networks offer an opportunity for gas distribution companies to ‘green’ the natural gas grid.

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INTRODUCTION

Biomass is an attractive energy source, also for the gas industry. In particular waste from agricultural activities can be digested into a gaseous mixture, which can be used as a fuel. However, this gas produced in a digestion plant cannot be used directly as a fuel. Certain aggressive components, like sulphurous compounds, have to be removed before the gaseous fuel can be used. The resulting gas is called raw biogas.
At first this raw biogas was used locally near the digestion plant in e.g. an engine to produce heat and electricity. Often this locally produced heat and electricity cannot be utilized fully. The efficiency of the use of biogas in this way is rather low.
Better energy efficiency can be obtained if the raw biogas is upgraded to a natural gas quality and injected in a gas grid as biomethane. All the potential energy of the biogas is used in that way. Of course an upgrading plant is necessary before injecting biomethane in the natural gas grid. For rather small digestion plants this upgrading is not economically feasible and the expertise on gas upgrading is not the core business of most biogas producers too.
For these reasons customized, independent local networks are developed that collect biogas from various digestion plants and transport this gas to a central upgrading plant followed by injection of biomethane (upgraded biogas) into a natural gas network. Alternatively the biogas can also be collected at one or various sites and transported to a large central CHP unit (e.g.in industry).

In Germany the new local biogas networks are called “Micro-Gasnetze”. In the Netherlands the term Biogas Hub is used, while in the US this concept is named Biogas Basin. These networks can be mainly found in rural areas with one or more biogas producers, when the available transport capacity in the nearby gas distribution grid is limited and where there is almost no heat demand nearby the biogas production site. This limits the possibilities of the more conventional biogas use for local electricity production or local upgrading and injection into the gas grids and has lead to the development of these new types of gas grids.

Due to their significant different characteristics compared to conventional gas distribution grids these networks may ask for a different approach in design, operation & maintenance. Whether or not current gas distribution regulations, standards and practices are valid and applicable for these local biogas grids needs to be further investigated.

In this paper the design, operation and maintenance of local biogas networks will be evaluated and compared to the practices of conventional natural gas networks.

Definitions

- Raw Biogas
  Generic term used to refer to gases (for example landfill gas and sewage gas) produced by anaerobic fermentation or digestion of organic matter.
- Biogas
  Biogas after pre- treatment (crude H_2S removal and drying)
- Biomethane
  Upgraded biogas of the same quality as natural gas.

1. PHYSICAL PROPERTIES AND GAS COMPOSITION

Natural gas is formed out of organic material after a very long period of time at high pressures and temperatures. Biogas has a much shorter carbon cycle and is formed after fermentation of various biomass sources, for example household waste, cow manure and/or agricultural waste.
The origins of the differences and similarities between the operation, design and maintenance of local biogas grids versus conventional gas distribution practices can partly be explained by looking at the gas composition and physical properties of both biogas and natural gas. The gas composition also has an effect on the burning properties and this will also be shortly described in this chapter.

Gas composition

In Table 1 the gas composition of natural gas (Dutch L-gas quality) and biogas is summarized. Natural gas of Dutch L-gas quality consists mainly of methane and nitrogen; besides these main components also higher hydrocarbons (for example aromatic and aliphatic hydrocarbons) can be found. Biogas contains no higher hydrocarbons and has a high percentage of carbon dioxide. The nitrogen content of biogases is relatively low.

Natural gas as well as biogas contain smaller amounts of trace components, but their nature differs significantly. Many trace components found in biogas are not common in natural gas. The trace components found in the biogas depend mainly on the type of biomass used for digestion and the digestion process itself. Hydrogen sulfide can be found in relatively higher amounts in raw biogas from digestion with animal manure. Siloxanes and halogens can be found in all types of biogas, but biogases produced at landfill sites and sludge treatment facilities contain relatively higher amounts of these trace components (ref 1).

Another important difference between natural gas and raw biogas is the relative humidity. Raw biogas has a high relative humidity that mainly originates from the relatively wet nature of the digestion process.
Furthermore the composition of Natural gas is very constant, whereas the composition of raw biogas can fluctuate depending on changes in biomass feed or digestion process characteristics.

Table 1 Chemical composition of a typical natural gas and biogas

Chemical composition		**Natural gas (Dutch L-gas)**	**Raw biogas 55-70% methane**
Main components	CH4	81%	55-70%
	CO2	<1%	30-45%
	Ethane	2.85	none
	>C_2 hydrocarbons	3.41%	none
	N_2	1.,35%	0-5%
	O2	0.01 %	0-6%
Trace components	H2S	0-1 ppm	10- 2000ppm
	Others	Aromatics, Hg, He	H2, ammonia,siloxanes, halogenes, phosphines, VOCs
Relative humidity		15- 25 %	70-100%

Physical characteristics and burning properties

The differences in gas composition also result in different physical characteristics of natural gas and biogas. Methane is the main combustible component of both natural gas and biogas, and mainly determines the gas properties. First of all due to a lower percentage of methane and the absence of higher hydrocarbons the calorific value of biogas is considerably lower than that of natural gas. (see Table 2)

Another important characteristic is the density of the gas. The density of biogas is considerably higher than that of natural gas, caused by the high percentage of CO_2.

Table 2 Physical characteristics of a typical natural gas and biogas

Physical characteristics	**Natural gas (Dutch L-gas)**	**Biogas 55-70% methane**
Calorific value $_{lower}$ [MJ/m^3]	31.7	19-25
Relative density [kg/Nm^3]	~ 0.65	~ 1.0

The burning properties of biogas are different from those of natural gas; biogas will not burn properly in a normal natural gas burner. The carbon dioxide content results in an increase of the fuel/air ratio and also means that the flame speed is lower (see Table 3), making flames less stable.

Table 3 Burning properties of a typical natural gas and biogas

Burning properties	**Natural gas (Dutch L-gas)**	**Biogas 55-70% methane**
Wobbe index [MJ/m^3]	43.4-44.4	22-28
Flame speed/Burning velocity [cm/s]	38	Approximately 25
Optimum air- to-fuel ratio	8.7:1 (10.5% Natural gas in air)	5.5:1 (15% biogas in air)
Combustion temperature	700 ˚C	Approximately 650˚C
Flammability limits	5.8 -15.9%	9-17%

Combustion equipment is typically designed to burn a gaseous fuel within a particular gas family. Internationally three gas “families” or ranges of fuel gases based on the Wobbe-Index have been agreed on.

Natural gas is covered under the second gas family. The first gas family covers town gas, containing mainly hydrogen, methane and nitrogen. The third gas family covers liquefied petroleum gases (LPG). Biogas has not been covered in the current gas families. However with a Wobbe range between 22 and 28 MJ/m^3 biogas has a range similar to the first gas family, see Figure 1.

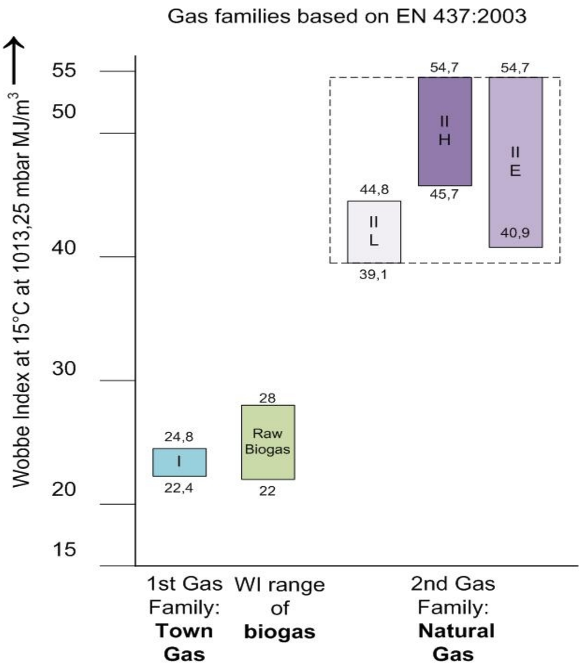


Figure 1 Biogas and the gas families

2 SAFETY ASPECTS

In the previous chapters a close look has been made on the chemical composition and physical characteristics of both biogas and natural gas. In this chapter an elaboration will be made about their effects on safety measures. The similarities and differences between safety issues of natural gas and biogas will be described.

Explosion risks

It is well-known that both biogas and natural gas both form flammable mixtures with air. Both gases will burn in the open and be explosive in confined spaces. The warning signs for highly flammable gas are used for both biogas and natural gas (see Figure 2).
As can be concluded from the previous chapter (see Table 3) the explosion limits of biogas and natural gas are quite similar.

Figure 2 Warning signs of highly flammable gas for biogas and natural gas

The main difference is that natural gas vapors will disperse, because the density of natural gas is lower than that of air whereas biogas has a density almost equal to that of air. This might increase explosion risks and could also affect conventional leak survey procedures.
Up to now almost no research has been done on the dispersion of heavier gases like biogas leaking from buried underground pipelines. However this aspect can have an important effect on the risks and detectability of gas leaks from biogas pipelines and should be further investigated.

Exposure and inhalation risks

Apart from the risk of fire and explosion, one of the lesser known safety risks posed by gas leaks is the risk of suffocation. This is especially important regarding the safety of employees of the gas distribution company working on the gas grid with possible release and inhalation of natural gas. The methane in the gas can displace the oxygen in our lungs, quickly leading to unconsciousness.
When comparing the chemical composition of natural gas and raw biogas the risk of exposure during works on a local biogas pipeline can be expected to be even higher than that of natural gas. (Raw) Biogas is known for its relatively high concentration of hydrogen sulfide. Hydrogen sulfide is a highly toxic gas, that even in small amounts can be hazardous. At low concentrations, hydrogen sulfide causes irritation to the eyes, nose and throat, and in high concentrations it can be rapidly fatal due to lung paralysis. In Table 4 the toxic symptoms of various concentrations and exposure times are summarized.

Table 4 Toxic symptoms of various H_2S concentrations and exposure times

H_2S concentration	Time after which toxic symptoms occur
< 100 ppmv	After several hours of exposure
> 100 ppmv	One hour exposure
at 500 ppmv	After 30 minutes of exposure (life threatening)
at 1000 ppmv (0.1 vol%)	Within few minutes of exposure
at 5000 ppmv (0.5 vol%)	Within seconds of exposure

To reduce the safety risks of relatively high concentrations of hydrogen sulfide in biogas, it is strongly advised to apply crude hydrogen sulfide removal to reduce concentrations to lower levels.
The toxicity of biogas, even after crude hydrogen sulfide removal (the remaining H_2S concentration after removal can still be above 100 ppm), can affect the safety of people working on the gas system and additional safety measures compared with conventional work procedures should be taken.

Detectability risks

An important safety measure in conventional gas distribution is the odorization of the natural gas. On its own, natural gas has no scent. By adding chemicals like THT (Tetra Hydro Thiophene) or ethanethiol (a mercaptame) natural gas gets its distinctive smell. Odorization of the natural gas is done for the public safety. The ability to smell the gas alerts or warns when there is a gas leak long before the explosion limit is reached.
(Raw) biogas on the other hand has its own distinctive smell caused by the olfactory of the hydrogen sulfide amount, the so-called “rotten-eggs” smell. At a concentration of 0,00047 ppm this odor can already be smelled by over 50% of people. At higher concentrations this smell can even make odorization with THT useless because the odor can be suppressed by the amount of hydrogen sulfide.
Other trace compounds in the biogas can also cause distinctive smells, even in very small amounts (few ppms). These components are categorized as VOC’s (Volatile Organic Compounds). From research done in Sweden the following specific aromatic organic compounds were identified in biogas from domestic waste (ref. 2):.

- Cymene (spicy smell), formed by rearrangement and dehydrogenation of limonene and other monoterpenes
- Limonene (smell of oranges), originating from citrus fruit waste
- Pinene (pine smell), originating from plant waste (especially conifers)

These compounds have also been identified from biogas produced at landfills (ref. 3).
It should be noted that these aromatic organic compounds also have toxic effects even in small amounts, and may add to the toxicity of biogas. More research should be done to the safety risks of this kind of VOCs.
If the biogas cannot be odorized according to conventional gas distribution practices additional safety measures should be taken to reduce the risk of undetectable gas release from the pipelines.

Pipeline integrity aspects

For the gas distribution grid the effect of natural gas on pipeline integrity has been studied for many years. With current natural gas compositions the applied pipeline materials in the gas distribution grids like steel, PE, PVC and cast iron are not expected to suffer integrity loss from effects of compounds in the natural gas.
(Raw) Biogas has high concentrations of CO_2 and H_2S and when not dried the combination with a high humidity of the biogas results in a highly corrosive environment. Drying and crude H_2S removal before injection into the biogas pipeline will reduce the risk of corrosion significantly. In most countries PE or steel are prescribed or advised for biogas pipelines.
It is advised to implement drying and crude H_2S removal when distributing biogas by pipeline to reduce the risk of negative effects on pipeline integrity.

Another argument for drying the biogas is that the water content of undried biogas can lead to plugging and biofouling in the pipelines and components in the grids (for example pressure regulators).

A less well-known effect of biogas is that the high concentration of CO_2 in the biogas might have an effect on the reparability of the biogas pipelines, due to diffusion of CO_2 in the plastic pipeline material. This is an aspect that needs more research.
Other trace components, especially the VOCs, might also have a negative effect on pipeline integrity.

3 GRID CHARACTERISTICS

In this chapter the grid characteristics of conventional gas distribution grids and local biogas grids will be discussed. The grid configuration, specific components and load management issues are the main topics in this chapter.

Grid configuration

The grid configuration of a gas distribution grid is a result of the optimization of minimal distribution cost versus desired flexibility, safety and expandability. Costs of distribution are lower when using higher pressures, because distribution pipelines diameters can be smaller while distributing the same amounts of gas. On the other hand due to safety reasons, the closer the building density the lower the pressures in the pipeline should be. This results in a division between a higher pressure part with pipelines transporting the gas from the city gate station (CGS) to the distribution stations (DS) and industrial customers, and the lower pressure grid after the distribution stations distributing the gas to the households.

These same principles can be applied to local biogas grids. Most local biogas grids are located in rural areas and therefore will have pressures that correspond with the transport part of the gas distribution grids. In rural areas with agricultural activity it is advised to increase the minimum depth of cover for biogas pipeline to decrease the risk of damaging the pipeline by plowing or other agricultural excavation activities.

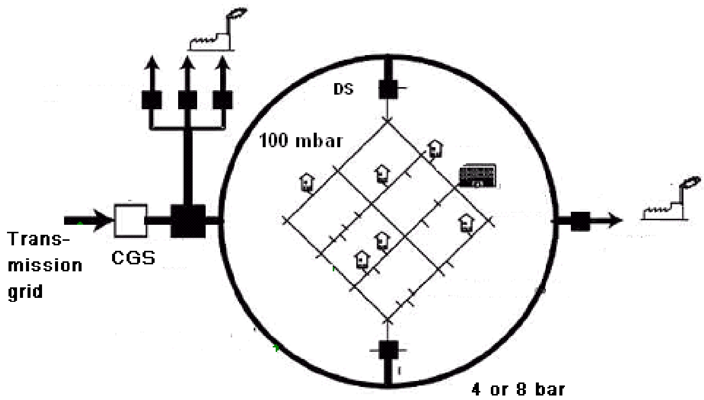
Another aspect that is important in the configuration of gas distribution grids is reliability (security of delivery) of the grid. In gas distribution grids reliability is increased by adding redundancy to the grid in the form of a “ring”. The “ring” layout ensures delivery of gas when a part of the transport pipeline that delivers gas to the district stations fails (gas leak) or has to be shut down (for repairs). Furthermore gas distribution grids are highly “meshed” due to the large number of connections. The resulting grid layout of gas distribution grids is schematically represented in Figure 3.

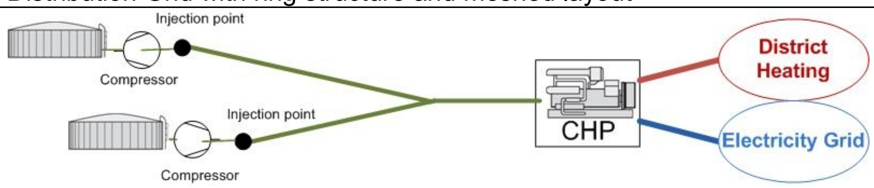
Local biogas grids only have a relatively limited number of connections compared to conventional gas distribution grids. One or more (maximum approximately 25) biogas producers that inject the biogas into the grid and in general only one exit point, for example a CHP unit or an upgrading plant. This results in a grid configuration that consists of only one up to a limited number of gas pipelines, see Table 5. The layout of these local biogas grids can have the shape of a “fish bone” (one or more suppliers connected to a central biogas pipeline to one exit point) or a “star” (one or more suppliers each connected by their own biogas pipeline to a central upgrading and exit point).

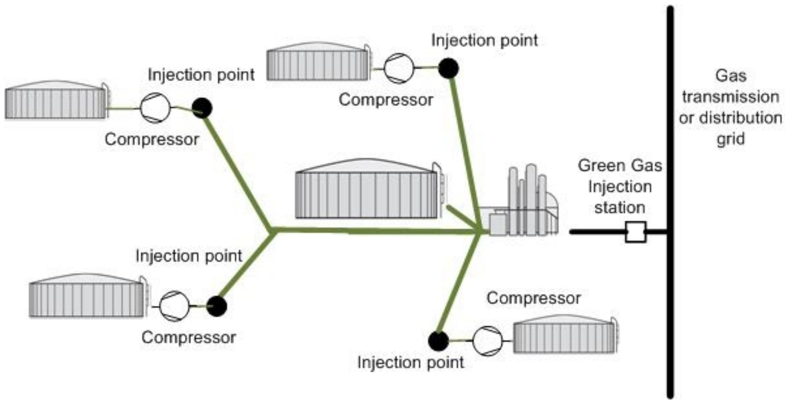
At the city gate station and distribution stations pressure regulation systems and safety valves are important measures to ensure the pressure in the grid will not exceed the maximum allowable inlet pressure. Shut off valves are placed at several points in the gas distribution systems to enable isolation of parts of the gas grid in case of calamities.
For safety reasons it should be advised to apply this kind of safety measures in the design of local biogas grids. This means there should at least be a pressure regulation systems present at the injection point of the biogas pipeline. Furthermore it would be wise to apply shut off valves at strategic points in the biogas grid.

Important components in local biogas grids which are uncommon in gas distribution grids are compressors or blowers.. At the point of injection into the biogas pipeline the biogas needs to be pressurized to enable the transport by pipeline, whereas natural gas entering the gas distribution grids already has a high pressure and even is depressurized due to safety reasons.
Compressors are not new to the gas sector, and the inclusion of compressors in local biogas grids should therefore not give many problems in the operations and maintenance, although it may increase maintenance costs. Depending on the length of the pipeline is some cases blowers (up to 1,8 bar) can be sufficient to transport the biogas by pipeline.

Figure 3 Grid configuration of the natural gas distribution grid and local biogas grids

<table>
<tr><td></td><td>Grid Configuration</td></tr>
<tr><td>(Dutch) Gas Distribution Grid</td><td>


CGS = City Gate Station
DS= Distribution Station
Distribution Grid with ring structure and meshed layout</td></tr>
<tr><td>Local Biogas grids</td><td>


“Fish bone” structure


“Star” structure</td></tr>
</table>

Grid Characteristics

There is a big difference between local biogas grids and conventional gas distribution grids. Local biogas grids can be characterized as gas 'producing' grids, while conventional gas distribution grids can be characterized as gas 'consuming' grids. In Table 5 the grid characteristics of gas distribution grids and local biogas grids are summarized.

Another important deviation between local biogas grids and conventional gas distribution grids can be found in gas metering aspects. In conventional gas distribution the gas quality and quantity are measured at the City Gas Station. The gas quality of the natural gas injected into distribution grids is very constant. At the (domestic) end-users only the gas volume is measured for billing purposes (the energy content is calculated with standardized assumptions on temperature and calorific value). Biogas composition can fluctuate much more, and therefore can have a fluctuating calorific value. Furthermore each biogas producer can produce biogas with a different composition and calorific value.
For correct billing, gas metering of both quality and quantity should at least be done at the exit point. In the case of multiple gas producers it is advised to also measure the quality and quantity of the biogas at the injection point for correct allocation.

Table 5 Grid characteristics of natural gas distribution grids and local biogas grids

Grid characteristics	**(conventional) Gas Distribution grids**	**Local Biogas grids**
Entry and exit points	• One entry point (CGS) • Many exit points (>100 , large number of end-users)	• One or more entry points (between 1 and 25) • Only one or two exit points
Grid load pattern	• Demand based • Seasonal (Delivery at CGS follows demand)	• Supply based • Constant in time
Capacity of the grid determined by	• Minimal gas demand after CGS (entry point) • Pipe diameter • Pressure	• Minimal gas demand at exit point • Pipe diameter • Pressure
Grid pressure	At entry point (CGS) the gas is reduced in pressure. The pressure is further decreased at the distribution station and next at the end user to a pressure suitable for the gas appliances	The gas needs to be pressurized at the biogas producer before injection into the pipeline
Gas metering	At entry point (CGS) the gas quality is measured, at the end user only gas quantity (volume in m^3) is measured for billing purposes	Gas quality needs to be measured at biogas production site (in the case of multiple gas producers) and/or at exit point for billing purposes

The main advantage of conventional gas distribution grids is the flexibility offered by the availability of capacity in the transmission grid, underground storages and gas production fields. The supply of gas is easily adapted to the demand for natural gas.
In local biogas grids the supply of gas is constant and changes in demand cannot be easily reacted on. The sensitivity of the biogas production plant and the gas grid infrastructure together result in a need for more flexibility. This aspect should be taken in consideration during design and operation. Measures have to be taken to anticipate on discrepancies between supply and off take of the biogas. For example when the upgrading plant has to be maintained.
The challenge of designing and operation of a local biogas grid is to match the continuous supply of biogas to the grid and potential fluctuations in gas demand. There are currently two options available to build a little flexibility into local biogas grids.

- Small scale gas storage (gas buffer)
- Flaring installation

Small scale gas storages are relatively expensive and also have limited capacities. At the existing local biogas grids that contain a gas storage, the storage only provides a buffer of the daily biogas production as a maximum.
Flaring installations are cheaper than gas storages and more generally applied at the biogas producers sites in local biogas grids. However flaring is unattractive for a biogas producer, because the energy content in the biogas (its main value) is blown into the air.

CONCLUSIONS

Although the local biogas networks may need a different approach in some aspects compared to conventional gas distribution grids, there are many similarities.
The approach taken in conventional natural gas distribution will be suitable for the distribution of biogas. Points of consideration for the design, maintenance and operation of a local biogas grid are:

- How to deal with the increased safety risks?

  The safety measures currently taken in natural gas distribution operations, maintenance and design should at least be applied when distributing biogas. Additional measures should be developed for the specific characteristics of biogas (toxicity, higher density and possible odorisation problems).
- How to provide flexibility in the operation and design of local biogas grids?

  The adaptation of gas supply to gas demand is not a great issue in the natural gas distribution sector. There are technical solutions currently available, but their cost effectiveness should be improved. Developing new small scale gas storage technologies or others solutions might provide new opportunities.

  Communication with the different parties involved in the biogas grid (both producers and end-users) is a very important aspect, when dealing with the flexibility issues.

Furthermore it is strongly advised to implement drying and crude H_2S removal when distributing biogas by pipeline to reduce both the risk of pipeline integrity and safety (toxicity). Drying the biogas of the biogas is also an effective measure to prevent plugging and biofouling in the pipelines and components in the grids (for example pressure regulators).

Although biogas grids are commercial activities for which gas distribution companies are legally not liable for, it seems logical that the gas distribution companies take responsibility for the design, operation and maintenance of the local biogas networks when considering the safety risks of local biogas grids. There are two main arguments to support this:

- Gas distribution companies have years of experience and expertise in distributing natural gas safe and efficiently, and therefore have a lot of knowledge and expertise on issues that are of importance for the distribution of raw biogas, for example gas safety, gas quality issues and load management.
- Gas distribution companies have 24/7 trouble shootings services available, that enables a fast response and repair in case of incidents.

At last these local biogas grids also offer a great opportunity for gas distribution companies to “green” the natural gas grid and expand their product and service range.

Further research

There still are knowledge gaps in certain issues of dealing with the distribution of biogas. The knowledge gaps that were identified in this paper are:

- The dispersion of heavier gases like biogas and the effect on explosion risks and leak service procedures

- The toxicity of aromatic organic compounds and their (possible) effect on odorisation and pipeline integrity
- Diffusion of CO_2 in plastic pipeline materials and the effect on reparability

Pipeline Integrity aspects and the effects of trace components not commonly found in natural gas are studied in one of the pipeline integrity projects of the Dutch EDGaR Gas Research Programme. The dispersion of heavier gases and possible toxicity is planned to be studied in a safety project of the Dutch EDGaR Gas Research Programme.

Acknowledgements

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Energy Delta Gas Research

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