Biogas as a partial solution for energy shortages within a European gas grid infrastructure

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Abstract: This paper deals with biogas grid injection into the national gas grid system with the aim of upgrading the biogas to a new end-product called biomethane. This end-product which has now been cleaned has an additional benefit of an improved calorific heat value. The objective of this research document it to highlight the utilisation of this clean, locally produced energy source as a surplus energy in Central Europe. Biogas is predominantly used in the Scandinavian Countries as a transportation fuel because of the very low electricity price which makes vehicle fuel conversion more profitable. Depending on the geographical location and renewable energy driven reimbursements, biomethane can be used as a transportation fuel as well as for electricity generation, heating and refrigerating purposes. In Central Europe, biogas is mostly used for electricity production and co-generation using heat and cooling as a by-product. Biogas upgrade and injection is not very predominant in Central Europe, but still has enormous potential from a financial perspective, with fuel security and fuel production coming from renewable energy sources helping to achieve renewable energy targets.

Keywords: Biogas upgrade, gas grid injection, increased calorific values, gas storage potential

1 Introduction

Natural gas consumption across Europe is very dependent on fossil fuel imports which come mainly from Russia and are channelled through Ukraine. Natural gas is used for multiple applications with varying degrees of scale and complexity, including cooking, domestic and commercial heating purposes, heat and electricity production via combined heat and power systems, and fuel supply for the transportation sector. The current gas price per unit is measured in kWh which, when compared with heating oil as well as petrochemical fuels, is cheaper and therefore very competitive.

Since November 2013, which marked the beginning of the Ukraine crisis and the separation of the semi-Island Crimean Peninsula, there has been considerable tension in negotiations about future gas prices, as well as delivery and supply security, which is a vital component for a solid and functional industrialised economy. In 2014, 53% of fossil fuels were imported to Europe, with the bulk of gas imports (39%) coming from Russia, one of the major suppliers of natural gas (Holzner Marlene, 2014).

The political unrest referred to above showed that natural gas supply is a crucial part of the European economy and cannot be neglected. Biogas production from renewable energy sources like anaerobic digestion plants and landfill sites has huge potential in producing close to emission free and carbon neutral biogas. This will consequently increase fuel security and develop job creation in the biogas area, and will help in achieving national binding renewable energy 2020 targets and supporting waste management plans. It will also encourage farmers to use more bio-fertiliser from digested feedstocks as well as arranging better phosphorus and nutrient management, which will have a positive impact on the surface water table.

Decreasing gas reserves, along with increased demand from commercial and domestic gas users, creates a growing dependence on energy imports from outside the EU, and therefore there is a concern about future supply security. In addition, environmental concerns are being discussed more prominently in both public and political discourse. For that reason, biogas/biomethane represents a significantly under-utilised source of indigenous and renewable energy which can play a very important role for Europe in helping to meet the renewable energy targets 2020 for heat, transport and electricity, and also in ensuring a guaranteed energy supply.

2 Materials and Methodology

Biomethane, which originates from a diluted substance called “biogas”, comes mainly from anaerobic digestion or landfill sites. This gas has to be treated, cleaned, purified and dried. The end-product which is then called biomethane, has an equivalent calorific heat value to that of natural gas. Natural gas, which is the same product, contains mainly methane, but can remarkably enough have various names depending on origin and the state of the gas, which can occur either in gaseous or liquid form.

- CNG — Compressed Natural Gas (coming from fossil fuel sources)
- CBG — Compressed Biomethane Gas (coming from renewables)
- LNG — Liquefied Natural Gas (coming from fossil fuel sources)
- LBG — Liquefied Biomethane Gas (coming from renewables)
- Power to gas — Electrically produced Gas (coming mainly from renewable energy sources)

Methane, which after purification is the same end-product as gaseous coming from biomethane and natural gas, can also be synthetically produced from photovoltaic and wind energy generation, for example electrolysis technology such as that used by Audi in co-operation with ETOGAS GmbH in Germany (Strohbach, 2013).

A feasibility study was undertaken to see what impact injecting biomethane into the gas grid would have, what problems could occur and what limitations could eventually prevent any grid injection. This paper will discuss the technology in more detail in the biomethane upgrading technology section 2.3. The most common upgrading unit in Europe will be discussed along with practical methods used in the industry nowadays. Some calculations have been introduced, such as impact factors and heat transfer effect, to make the reader aware of any conditioning changes that could have a negative impact on upgrading efficiencies.

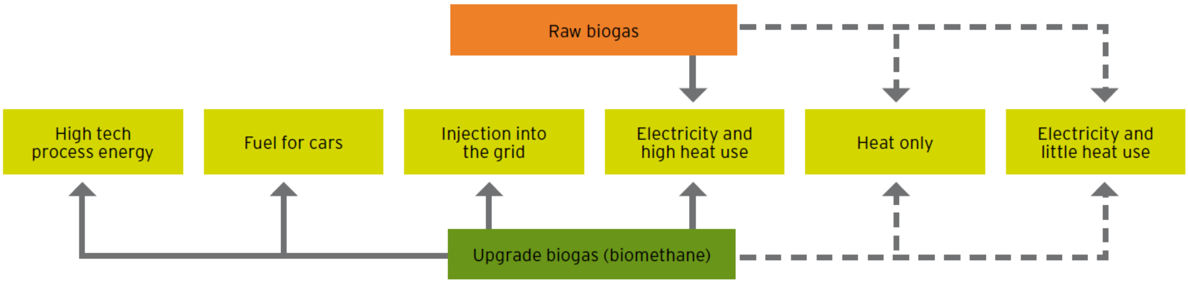
2.1 Biogas pathways and usage potential

Biomethane is a very flexible energy source that can be used for multiple purposes. The methane molecules are shaped in such a way that they can even be combined with other gases like propane, butane and hydrogen, this enormous opportunities for this type of energy in terms of storage applications in the gas network grid.

With this opportunity, biomethane can be used for several purposes with a wide range of pathways. In the figure below it can be seen that injected biomethane can be used as:

- Intermediate storage in the gas grid system
- Fuel for trucks and vehicles sold in filling stations
- Power generation for combined heat and power units
- Heat production for domestic and commercial applications
- Moderate heat usage with the main focus on power generation
- High tech process within the industry such as cooling via heat exchanger

The top specification of the image shown below represents raw biogas that can be used immediately without any enormous investment cost of upgrading units. The bottom grey arrows illustrate biogas which has been upgraded. This will subsequently increase its applications but requires more capital investment and is only applicable for bigger biogas production plants above 0.75 Mega Watt energy capacity production.



(Figure 1 – Raw biogas pathways and utilisation potentials; Source: AEBIOM, 2016)

2.2 Biomethane storage potential

Biomethane has an under-unutilised storage potential that could be used in having natural gas widely available in Europe. Biogas production from anaerobic digestion plants and landfill sites can be collected, purified and injected into the gas grid.

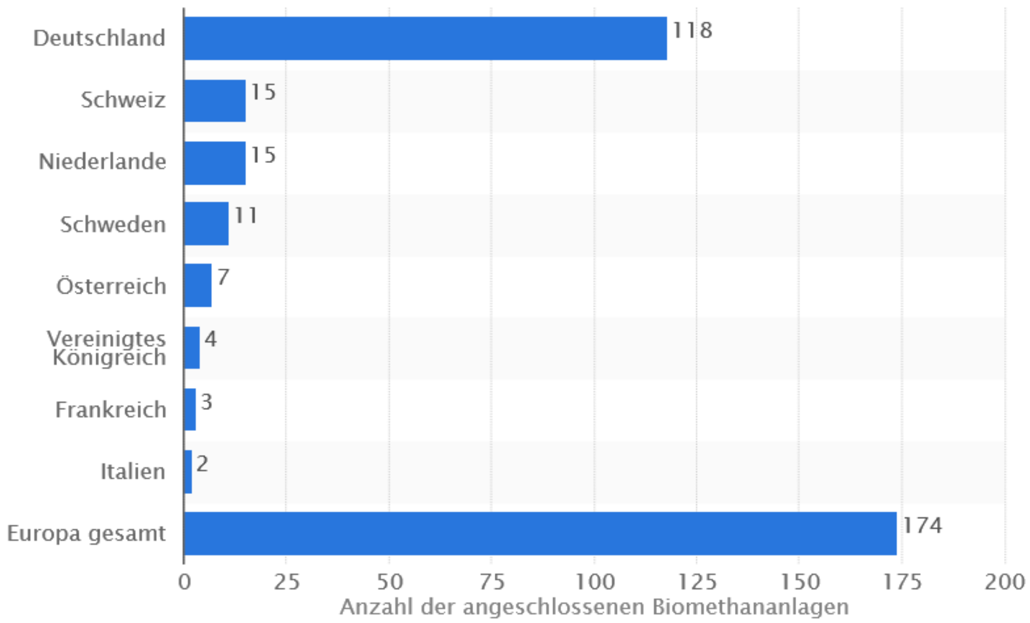
In order to inject methane into the German gas grid system, there must be compliance with several regulations which specifies chemical compositions, wobbe index, calorific value, sulphur content, level of odourisation, etc. These very defined requirements are described in the information leaflet G 260 published by Deutscher Verein des Gas- und Wasserfaches e.V. (DVGW, 2008). Every country has its own rules and gas grid requirements; therefore regulations cannot be generalised and assessed according to geographical location. In the Netherlands, low gas (L-gas) is utilised, and this is also used for small local grid systems in the western part of Germany, but energy heating characteristics are totally different and imports to Germany only come from the Netherlands. The Irish gas grid has, at this particular time, no own-gas grid standards established and is using the British gas standards as a co-reference point.

Apart from gas quality, odourisation needs to be added to comply with regulations in the event of a leak. Furthermore, gas pressure is also a very important factor which needs to be adjusted and synchronised to local grid injection points. Over and under pressure cannot be tolerated and for that reason pressure synchronisation is a rigorous part of grid injection.

2.3 Biomethane upgrading technologies

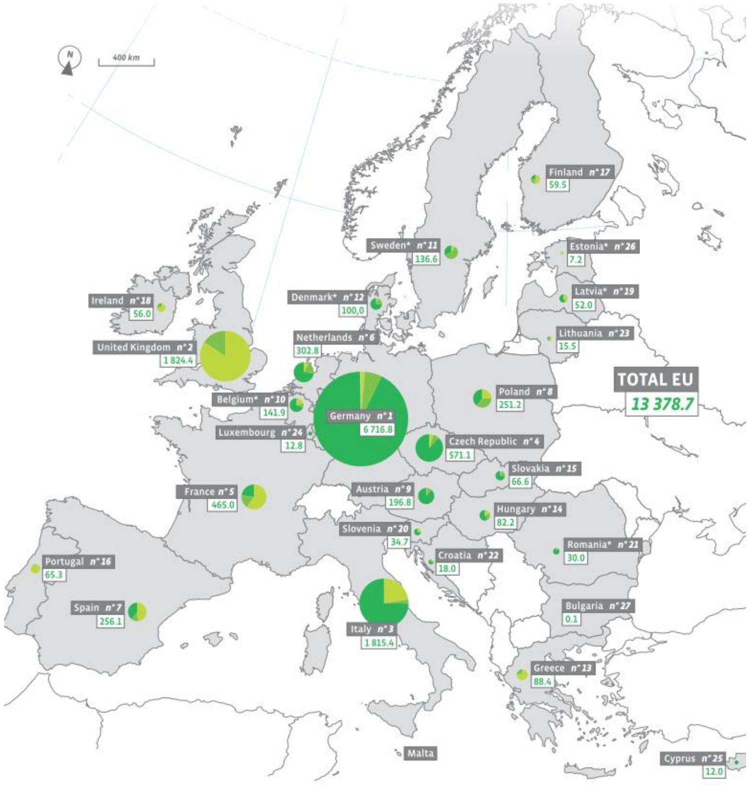
Biomethane upgrading plant installations in Europe are still in low triple figures even though there have been thousands of installed biogas plants in Europe. In 2013, there were 174 biogas upgrading plants installed and the majority are being connected to the gas grid (Statista, 2013). This, however, still represents only a minority, with a 1.3% share of upgrading plants in comparison with a total number of 13,378 installed biogas plants across Europe (EurObserv'ER, 2014). It can be concluded that the majority of these plants are being used for combined heat and power applications with very little emphasis focused on biogas upgrading facilities. This is due to low associated reimbursement incentives. Every country has different guidelines and strategies for moving towards a more sustainable eco-society which, from an investor's point of view, is naturally driven more by profit than environmental considerations. This can easily be regulated by incentives and governmental legislation which give preference to more favourable technologies.

Sweden has very low electricity prices in general; prices are among the lowest in Europe due to the fortuitous availability of many hydropower generation plants. The low electricity price has placed Sweden's biogas production in a more unique situation, in that the profit margin in upgrading biogas is more economical than for sole power generation. This is one of the major reasons why the transportation area in Sweden has already exceeded its renewable energy target shares on the mobility sector and is, therefore, a leading example in this area.



(*Figure 2 – European wide connected biomethane upgrading plants to gas grid system; Source: Statista, 2013*)

A total number of 13,378 biogas plants were installed throughout Europe, as shown in figure no. 3 below, with more biogas production coming from biogas plants (dark green colour) and less from landfill sites (lighter green colour). Biogas production from Germany, followed by Italy, the United Kingdom, and Czech Republic have the majority market, accounting for 80% of EU production. Central Europe is therefore very well placed directly in a biogas production area and has a huge opportunity to decrease power generation from conventional electricity production and shift it towards biofuel generation via biogas upgrading.



(*Figure 3 – Installed biogas plants across Europe; Source: EurObserv'ER, 2013*)

2.4 Biomethane upgrading requirements in Europe

Upgrading of biomethane is a very established technology that can be divided into three different categories. These cleaning methods can be classified as adsorption, absorption and permeation through pressure swing, chemical, physical, and membrane-technology. The choice of technology depends very much on size, scale, capital availability, operating conditions and whether an economical heat source is available. The most prevalent technology is water scrubbing and pressure swing absorption, but chemical, physical scrubber and cryogenic separation have become more common over the last three to five years (Fredric Bauer, 2012).

Compound	Unit	France		Germany		Sweden	Switzerland		Austria	The Netherlands
		L gas	H gas	L gas grid	H gas grid		Lim. inject.	Unlim. Inject		
Higher Wobbe index	MJ/Nm³	42.48–46.8	48.24–56.52	37.8–46.8 46.1–56.5					47.7–56.5	43.46–44.41
Methane content	Vol-%					95–99	>50	>96		>80
Carbon dioxide	Vol-%	<2		<6			<6		≤2[6]	
Oxygene	Vol-%			<3			<0.5		≤0.5[6]	
	ppmV	<100								
	Mol%									<0.5
Hydrogen	Vol-%	<6		≤5			<5		≤4[6]	<12
$CO_2+O_2+N_2$	Vol-%					<5				
Water dew point	°C	<-5[1]		<t[4]		<t[5]-5			<-8[7]	-10[8]
Relative humidity	ρ						<60 %			
Sulphur	mg/Nm³	<100[2] <75[3]		<30		<23	<30		≤5	<45

[1] At MOP (Maximal Operating Pressure) downstream from injection point
[2] Maximum permitted
[3] Average content
[4] Ground temperature
[5] Ambient temperature
[6] Mole percentage
[7] At 40 bars
[8] At 10 bars

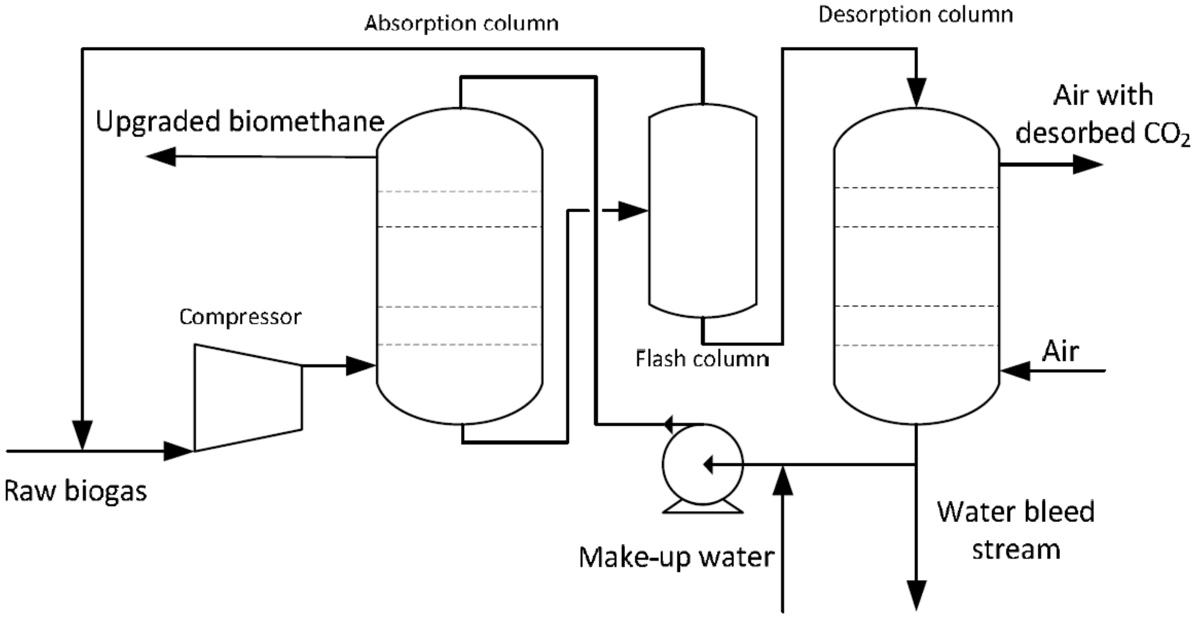
(*Table 1 – Selected standard requirements for grid injection or for utilization as vehicle fuel; Source: (Anneli Petersson, 2009)*)

Even though biomethane is theoretically equivalent to natural gas, it can vary greatly in quality and particularly in composition ratios. Every country has its own requirements and standards which can have deviations in, for example, oxygen levels in volume % measured by factor six. The sulphur concentration level in Austria has to be below 5 mg/Nm^3 in comparison to France, which has a maximum allowable concentration of 100 mg/Nm^3. This represents a variation difference of 20 times the maximum allowable amount in Austria (Anneli Petersson, 2009).

Some countries measure composition in parts per million (ppm), molecules in percentage (Mol%) and volumes in percentage (Vol%). This does not facilitate a straightforward comparison between countries, which dilutes any representation characterisation expressed in percentages using different mathematical methods.

2.5 Biomethane upgrading unit via water scupper technology

In the image below a schema showing the workings of a water scrubber can be seen. The raw biogas inlet on the left passes through a series of columns. The pressure variations from the flash chamber between the columns separates the methane from carbon dioxide. Water is circulated inside the system by high pressure with air injection in the desorption column on the right hand side.



(Figure 4 – Water scrubber technology; Source: Biogasuppgradering – Granskning av kommersiella tekniker, 2013)

Henry's law describes the theoretical calculated amount of absorption of carbon dioxide and methane in water (Eq. 1) which defines the correlation with partial pressure of gas and the concentration of gas in a liquid contact with the gas (Stumm, 1996).

$$C_A\,(M) = K_H\,(M/atm) * p_A\,(atm) \qquad (Eq.\ 1)$$

The removal of the last molecules of carbon dioxide from the biogas in contact with water is the most difficult part of any upgrading unit. The water flow will be determined by the solubility of carbon dioxide (Swanson, 2011). This can be described in (Eq. 2) in the case of molecule extraction and water flow throughput.

$$Q_{water}(l/h) = \frac{Q_{CO_2}(g)(mol/h)}{C_{CO_2}(aq)(M)}$$ (*Eq. 2)*

The total amount of carbon dioxide that needs to be removed is described by the quantity of flow rate and gas composition ratio. The consideration of solubility by Henry's law was given in Eq. 1 above.

$$Q_{water}(l/h) = \frac{Q_{biogas} * \%CO_2(mol/h)}{K_H * p_{tot} * \%CO_2(M)}$$ (*Eq. 3)*

Q_{biogas} is the total biogas flow where % of CO_2 is the expression of percentage of carbon dioxide in the produced biogas, while P_{tot} is the workable pressure in the water scrubber column. It is important to highlight that these calculations are only applicable at a constant pressure and temperature during operation (Sander, 2011). Once temperature begins to rise from 10ºC to 25ºC, efficiency drops by as much as 50%. The relationship of efficiency and temperature has been expressed in Eq. 4 below.

$$K_H(T_2) = K_H(T_1)\exp\left[C\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right]$$ (*Eq. 4)*

Report results and performance ratios were published by Petersson & Wellinger in 2009. In their report temperature was analysed ranging from 10ºC to 40ºC with the conclusion that temperature should be as close as possible to 10ºC. This is not always easily achievable, which could have an impact on drying and cooling (Petersson, 2009). The cooling on the other hand consumes energy that potentially could have been sold on in the form of electricity units and, therefore, a careful analysis of power consumption needs to be considered.

2.6 Biomethane injection

There are several technical and economical restrictions in injecting biogas to the gas grid system. Firstly an access to the gas grid needs to be established. The distance from the biogas production facility should not exceed 3 km to grid injection point (Gil-Carrera, 2015). Secondly, a biogas plant needs to be of a certain size due to the high capital costs required. This makes smaller plants less feasible for this type of investment. Thirdly, investment opportunities are determined by several factors, like feedstock price and availability, electricity price reimbursements coupled with heat incentives, size of biogas plant, etc.

The upgraded biogas also needs to be cooled to a certain temperature, ideally below 25ºC. After purification, dehumidifying, drying and odourisation needs to take place. The process of odourisation of biomethane involves adding an odorant substance which is also occasionally referred to as a "stanching agent". The concentration level should have the right quantity of mixture according to legally binding legislation. In general, an end-user should smell the leaked gas once a concentration level of more than 1% of ambient air is present. The odourisation standards are very similar across EU member states (Cagnon, 2011).

After all these steps have been achieved, biomethane ultimately has to be checked to ensure it complies to all parameters described in the technical allowable specification norm, which can vary from country to country. In some cases propane needs to be added to comply with wobbe index and minimum required calorific value. Once all factors have been correctly treated for, a final check through a verification unit, which is normally tempered and operated by the local gas grid operator, takes place. This ensures injected gas complies with current legislation before being injected. If there is any variation or there are values beyond maximum allowable limits, the gas has to be re-circulated and re-treated inside the system or, in a worst case scenario, flared off.

All gas grid operators have their own local gas pressure limitations that need to be adjusted, and this is the responsibility of the biogas producers. Therefore, not only the quality of gas including calorific value is important, but gas pressure and injection quantity also need to be considered in advance, before grid injection can take place. The European Biogas Association is working very closely with the European Committee to standardise all gas legislation into one document. There are currently two documents developed, prEN 16723-1 "Specifications for biomethane for injection in the natural gas network" and prEN 16723-2 "Automotive fuel specifications". Both documents have up to this point passed the draft and approval stage but are not legally binding yet (Büthker, 2015).

2.7 Biogas usage and opportunities across Europe

A biogas study was undertaken in conjunction with the NGVA Europe European Project. It researched how much biogas and LNG can be injected into the local gas grid, what impact it would have and what limitations and constraints are present. Biogas injection is at this time an under-utilised energy source with <1% of biogas present in the natural gas grid. Some scientists maintain a view that the gas grid could accommodate up to 5% of biogas and up to 1% of hydrogen but this is not universally agreed. With so many different standard variations it is difficult to form a definite decision on that.

(*Figure 5 – Connected gas grid infrastructure linked across Europe; Source: Gas High Way, 2013*)

Individual countries within Europe are very well connected to each other via the gas grid, inter connector electricity cables, broadband and even water supply pipes, so that gas blending is inevitable. However, with so many different standards in place, coupled with gas grid pressure differences, a joint up thinking plan needs to be established once quantity of gas injection coming from biogas, landfill gas, synthetic power to gas production, hydrogen and LNG increases their market share.

3 Results and Conclusion

In summary, it can be concluded that the focus on power generation was driven by high reimbursement tariffs like Renewable Energy Feed in Tariffs (REFIT). Heat usage was mostly neglected and supported investment acted only as an additional bonus. Since the German government has changed the German Erneuerbare Energien Gesetz (EEG) – Renewable Energy Act in 2014, heat consumption needs to be factored in their business plan in order to avail fully electricity reimbursement (Gabriel, 2014). This certainly has changed business focus in a more positive way towards the higher utilisation of heat and power as a whole. Prior to these changes, projects were driven more by economics than ecological factors.

Biomethane production from renewables has the potential to deliver all the above mentioned environmental benefits, as well as strengthening fuel supply in a moderate way and contributing towards price stabilisation and the creation of additional jobs. Biomethane can be used for direct gas grid injection, transported via gas mobile units from isolated anaerobic digestion sites and used in the transportation sector.

There are several transportation options in distributing locally produced biomethane. It can be compressed and sold off onsite in the form of vehicle fuel, injected to the local gas network or liquefied, which is called liquefied natural gas, and transported for distances above 400 km by shipping containers in supply to LNG filling stations.

Having highlighted the pros and cons of biogas production and upgrading technologies, it can be concluded that gas injection from any source of renewable energy will only have a marginal role to play in terms of fuel supply. Nevertheless, in the medium term it could be the right way forward in injecting more sustainably produced biogas into the gas grid. Legislation and natural gas standards need to be equalised between European countries to make it feasible and more practical in discharging gas to other gas district regions. Only unified legislation would help in improving the flexibility of moving gas between several countries in order to strengthen a gas grid system in the long term.

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