Project ‘BIN2GRID’

Turning unexploited food waste into biomethane supplied through local filling stations network
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Report on good practice of biomethane usage as a transportation fuel

WP 6 – Task 1 / D 6.1

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Bin2Grid website: www.bin2grid.eu
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1 Good practice for usage of biomethane and CNG vehicles

CNG has already proven itself in Europe as a transportation fuel. The next step is to make CNG in the form of biomethane renewable. This allows the transport to get renewable in the future. According to the national regulations biomethane has the same substance of content as natural gas, that’s why CNG vehicles can also be operated with biomethane. Below therefore good practice examples of previously proven CNG vehicles and biomethane are presented. The CNG examples can also be operated with biomethane.

1.1 Switzerland

In Switzerland vehicles can be fuelled with “Naturgas” at corresponding filling stations. This “Naturgas” is a mixture of natural gas and biomethane with a minimum biomethane content of 10%. In Switzerland there are about 140 filling stations where natural gas/biomethane can be used for fuelling. (Erdgasfahren, 2015)

![Figure 1: “Naturgas”-petrol station, (erdgasfahren, 2015)](image)

1.2 Magarethen am Moos (Austria)

After starting up the biomethane gas station in a world unique project three Steyr tractors, which were equipped with a standard diesel engine, in 2008 were modified to a combined operation "Biodiesel - BIOMETHANE". It was two tractors with a roof solution (biomethane gas cylinders on the roof) and one tractor equipped as tank version with an underfloor solution - for all three tractors, a removable tank was front built for the tractor fork, which can optionally be appended. In operation, the tractors drive with about 65% biomethane and 35% biodiesel. Thus one has for the first time proved that even with diesel engines a modification to "biomethane" is possible and economically may well make sense. After nearly 5 years of experience in real operation could be established that the tractors have around 20% more power and 15% less consumption.

This reduces the consumption costs for the fuel to below 50%. (EVM, 2015)
1.3 Rechnitz (Austria)

The purest biogas produced in this innovative system is used for fueling of modified vehicles and the company's own waste disposal trucks. After the establishment of the biogas processing plant, currently takes place the modifying of the company's truck fleet on biogas operation and the establishment of a gas station, either on the company's internal and public use. (Büro für erneuerbare Energie Ing. Leo Riesenbauer, 2015)

1.4 Norrköping (Sweden)

The filling station for buses has 22 slow-fill fuel posts and provides 16 buses with gas. (Biogas East, 2008)
Figure 4: Slow filling station (Biogas Netzeinspeisung, 2015)

Such slow filling stations are usually used for vehicle fleets for companies as for example trucks or taxis. The different between slow filling and fast filling stations like at public filling stations is that the compressor for a slow filling station has less power (costs less). Therefore a longer fuelling time must be accepted but vehicles can be fuelled when they aren’t required e.g. overnight and at the next day the tank is full.

To be noted that if more than one vehicle is attached to the gas mains, all vehicles are filled with the same pressure. A consequence of this is that, if a number of vehicles are being filled while a new vehicle with lower pressure in the tanks attaches to the gas mains, filling of the other vehicles will stop until the new vehicle has reached the same pressure as the others.

1.5 St. Gallen (Switzerland)

The vehicles used by the Taxi Frosch GmbH type VW Passat EcoFuel convince primarily by a very good environmental balance, which is mainly due to its unique drive system. So the Passat TSI EcoFuel goes preferably with natural gas / biogas and then automatically switches to operation with petrol when the three gas tanks are empty. The exclusive use of natural gas / biogas has for Taxi Frosch course the highest priority, so the refueling times are designed so that no liter of gasoline must be used. (Taxi Frosch, 2015)

Figure 5: Biomethane taxi ( Taxi Frosch, 2015)
1.6 Lille (France)

Using municipal bio-waste to supply municipal buses in Lille

This project is the first case of injection of biomethane in the gas grid in France. The project started in the 90’s when the CUDL (Urban Community of Lille), an intermunicipal group of communes in charge of both public transportation and several waste water treatment plants, decided to use biogas from sludge treatment as a fuel for their buses. In 1995, a first filling station was established and diesel buses were converted in order to run on biomethane. By 1998, 4 buses were running on biomethane. (http://www.energy-cities.eu/db/lille_113_fr.pdf)

Figure 6: First pilot for biomethane as bus fuel (CUDL)

In 1999, it was decided to progressively move from diesel to CNG for public buses in order to reduce both nuisances and air emissions. In 1992, a global waste strategy was voted, including the decision to organize bio-waste recovery through anaerobic digestion. At first, the gas was supposed to be directed to the bus station, yet it was then decided to have it injected in the grid, preventing from having to deal with the issue of storing the gas (the gas being produced continuously while the filling of the buses occurs during the night). The anaerobic digestion plant started running in 2007. The first injection of biogas in the grid was achieved in 2011.

The AD plant processes about 108,000 t/yr of bio-waste from households, public markets and institutional catering services. It generates about 4 million Nm$^3$ of biogas and 34,500 t of compost each year. In 2013, it processed about 69,000 t of bio-waste and 1,84 million Nm$^3$ of raw biogas was produced. About 10% of this is used to provide heat to the process. 835,000 Nm$^3$ of biomethane were injected into the grid, generating about 600,000 € of revenues.

About 430 buses are in use, among which 95% run on CNG.
Regarding costs, CNG buses are about 15% (e.g. +30 k€) more expensive than diesel buses, and savings are achieved due to the price of CNG compared to diesel. The running cost of CNG buses are estimated to 0.171 €/km vs. 0.477 €/km for diesel. No extra costs are reported for maintenance. Infrastructure investments are estimated to 1.6-1.8 M€ for a filling station for 150 buses. (Source: ADEME, Panorama et évaluation des différentes filières d’autobus urbains, 2015). The cost of the gas is 0.29 €/m³. (ATEE – Club Biogaz, Le bioGNV, un carburant propre et renouvelable pour nos villes, 2013).

The use of CNG for vehicles in France

In 2014, the number of vehicles running on CNG in France amounts to about 13,000, with the following distribution:

<table>
<thead>
<tr>
<th>General category</th>
<th>Type of vehicle</th>
<th>Number of vehicles in 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public transportation</td>
<td>Bus</td>
<td>2649</td>
</tr>
<tr>
<td>Heavy vehicles</td>
<td>Lorries</td>
<td>249</td>
</tr>
<tr>
<td></td>
<td>Waste lorries</td>
<td>962</td>
</tr>
<tr>
<td>Cars</td>
<td>Personal cars</td>
<td>2376</td>
</tr>
<tr>
<td></td>
<td>Commercial cars</td>
<td>6882</td>
</tr>
</tbody>
</table>

Table 1: number of CNG vehicles in France, 2014 (AFGNV)
(Source: AFGNV, 2015)
A list of filling stations for CNG available in France is updated by the “Club Biogaz” and made available here: http://atee.fr/biogaz/carte-des-stations-gnv-et-biognv

A short video of the bin2grid study tour at Lille Métropole is available here: https://youtu.be/3zpI9B1cewQ

1.7 Madrid (Spain)

Madrid is the capital and largest city of Spain. It is in the middle of Spain, in the Community of Madrid. The Community is a large area that includes the city as well as small towns and villages outside the city. 7 million people live in the Community. More than 3 million live in the city itself.

Madrid is one of the leading cities in Spain in the use of CNG for transport. Its municipal transport company (EMT) and the MSW management company, used vehicles powered by CNG.

There are other initiatives for promoting CNG for transport as a pilot project through which a small fleet of 10 taxis powered by CNG will travel for the region to demonstrate the environmental benefits of such fuels.

It is highlighting that both municipally services as transport (buses) and MSW collection have opted for VNG for their vehicles. This option was based on advantages of CNG as:

- Emissions Reduction (HC, PM NOx, CO and CO2)
- Increasing the quality of life of citizens by reducing noise and vibration
- Compatibly with diesel technology
- It is an alternative to oil
- Secured its regular supply and stable price
- Technology developed and established

Municipal Transport Company (EMT)

The Madrid Municipal Transport Company (EMT) founded in 1947, is the public organization that operates the urban buses in the city of Madrid.

The city of Madrid has an excellent urban buses network, consisting of 203 lines covering a total length of 3,562 km and more than 10,172 bus stops-line, operating more than 1.5 million trips a day.

According with the information shown in the Municipal Transport Consortium of Madrid website (2015), the 1,903-vehicle fleet has an average age of 6.6 years. All fleet buses are accessible, with low floor, unfolding ramp and lateral tilt system to facilitate access to people with reduced mobility and wheelchairs users. It is currently replacing older models with cleaner, more energy efficient buses to work towards its ambition of reducing harmful emissions. Furthermore, the fleet consists of 791 buses powered by compressed natural gas (CNG), and 20 propelled by electric motors. The remaining 1,092 buses run on biodiesel.

When EMT started with the procedure of changing traditional buses for others with low environmental impact, it was stipulated that all vehicles should be powered by either electricity or CNG. Buses using CNG as a fuel could be either CNG-electric hybrid or traditional mechanical CNG models.
Figure 8: Transport zones operated in Madrid region (EMT)

A major advantage of using CNG over traditional (pre Euro VI) diesel buses, however, is the reduction of harmful tailpipe emissions including particulates, which are negligible, and NOx emissions, which are substantially lower. The new CNG buses acquired by EMT under this contract produce between just 30 - 50% NOx emissions compared to equivalent buses run on diesel fuel.

Figure 9: 8 m long Bredamenarini Vivacity GNC bus (EMT)

EMT decided that it was needed a new center to ensure the daily performance of those new vehicles. This new facility is called Sanchinarro Operation Center (O.C.) and it is located in northern Madrid.

In Sanchinarro O.C. there is a CNG refuelling station. It was Inaugurated on November 17, 2010, this refuelling area covers about 5,500 square meters (sqm), divided into nine streets with refuelling capacity to supply a total of 150 to 180 buses per hour. Therefore, the 400 buses, which it was conceived for, can fill their tanks in less than three and a half hours. Due to its refuelling speed, Sanchinarro is considered the fastest CNG station worldwide.
It is worth highlighting that the CNG refuelling station is part of an operation center which occupies an area of 59,000 sqm and serves nearly one-fifth of the EMT bus fleets. The Operational Center has an operation concept: buses are identified automatically upon arrival at the service station; quickly and efficiently, all the services such as fuelling, lubricating, adjusting tire pressure, and cleaning are provided for optimal functioning. Sanchinarro intends to be an example of sustainability. Apart from the benefits of its CNG station, it features a photovoltaic plant for the production of hot clean water and a recycling plant for its own waste. It also has sound barriers and 3,000 plant species that minimize impact on urban environment. The construction of this operation center required an investment of 47 million euros.

Each of its nine refuelling streets is equipped with a CNG Microcore® packaged compressor to provide a total compression capacity of 25,000 normal cubic meters per hour (Nm3/h). Thanks to the unique Common Manifold® direct refuelling technology, this compression capacity results in the simultaneous operation of nine EMB® Suppliers of ultrafast flow (EMT Sanchinarro, 2015). This structure enables an average filling time of approximately 3 minutes per bus or fuel tank of 6,180 standard cubic meters (sm3), in addition to longer vehicle autonomy.

Refuelled buses cover a large area of the city, including the districts of Barajas, Hortaleza, Fuencarral, Chamartín, Centro, Salamanca, Ciudad Lineal and San Blas.

This CNG station has 5 points to refuel external vehicles (not owned by EMT) as taxis, private cars, etc.
MSW collection fuelled entirely by Natural gas

Madrid's whole fleet of currently 468 waste trucks is running on Natural gas. The company in charge of the city's garbage collection, Fomento de Construcciones y Contratas (FCC), started to introduce CNG trucks back in 1993. Supported strongly by the Spanish Administration, this development is the result of cooperation between FCC, Gas Natural Fenosa (the biggest Spanish gas provider), and Iveco (trucks manufacturer).

In a joint effort that started in 1993, the IVECO 240E26 6x2 RSU CNG (EEV), an innovative 3 axle truck with CNG engine, was developed. After a four year period of intensive testing with two prototypes - not only of the vehicle itself but also regarding the filling station, driver acceptance, maintenance and mechanics training - in 1997 the decision was made to include a significant number of the new truck model. The year 1998 saw the introduction of 85 units and after successfully operating on a large scale, in 2003 FCC purchased 266 new ones as part of its fleet renewal, thereby completely switching the fleet to Natural gas. Today the company operates 468 CNG-fuelled units.

Residents of the Spanish capital benefit from cleaner air and reduced noise levels ever since. The used trucks enables to save emission of 1.5t of NOx and some 2t of CO2 per year, when compared to Euro 3 diesel trucks and their respective emission levels at the time the gas trucks started operating. Furthermore, the utilisation of gas-powered vehicles produces significant savings in fuel cost.

Figure 12: Madrid fleet of gas-powered refuse trucks and three of the 790 CNG busses circulating in the city

Year 1994

The first 2 trucks were completed and put in service in 1994. They were the first ever CNG trucks running in Spain. These trucks introduced a number of configuration and functional innovations such as:

- Axle configuration with reduced wheelbase. The achievement was to have a bigger capacity truck than the older 2 axle, with a much better manoeuvrability.
- 3rd steering axle commanded. This configuration was first in Europe for this kind of application.
- Full pneumatic suspension for 2nd and 3rd axles.
- Frontal high performance Power Take Off.
- The CNG engine IVECO 8469G, giving 260 HP, belonging to the first generation of IVECO CNG engines, emitted only 1 g/kWh of NOx when the European Legislation in force was Euro 1 allowing up to 8 g/kWh, then offering, a reduction of 88% of the legal limit. Moreover, in that year they were considered ecological vehicles responding to the Euro 3 limits (to come into force in 2001), with a NOx level of 5 g/kWh.
Year 2000

✓ After a 4 year period of intensive tests with the two prototypes, not only of the vehicle itself but as well as the filling station, driver acceptance, maintenance learning and mechanics training, the conclusion of FCC and the Municipality of Madrid was perfectly clear and positive towards the new CNG technology trucks. As a consequence, in 1998 the decision was taken to include a significant number of CNG trucks to be specified in the next Municipal tender for garbage trucks renewal.

✓ In the year 2000, a total of 40 CNG trucks were put in service, together with the dedication of one of the FCC fleet depots that had been converted with a CNG filling station and workshop adaptation for the new trucks

Year 2003

✓ The experience of the 40 units running from 2000 was mainly to demonstrate that their performance regarding operational times, driver interchange ability, serviceability and maintenance downtimes were perfectly equivalent to the diesel units with the same mechanical configuration.

✓ On the other hand, the total absence of black smoke, much lower gaseous emissions and reduced noise levels were highly appreciated by the neighbourhood of the areas were these CNG trucks operated.

✓ Other major advantage, achieved with this first 40 truck fleet, was the fuel cost comparison with diesel, observing a significant saving that paid back in a few years the extra cost of acquisition of the CNG truck.

✓ Again the conclusion was clear and the decision from both, Madrid Municipality and FCC, was that in the next tender the whole fleet would be renewed with CNG trucks.

✓ In 2003 FCC bought 337 new IVECO CNG trucks.

Figure 13: Evolution of Waste Collection fleet operated with CNG (Iveco España S.L. Case of Study-2009)

CNG stations in Madrid (public used)

There are two CNG stations for waste-collection service vehicles in Madrid: in Vallecas and Manoteras neighbourhoods.
There is also a network of CNG station for public service. These stations are:

In used (black points in following figure):
- GNF EMT Sanchinarro exterior: Av. Francisco Pi y Margall, 5 / 28050 / Madrid / MADRID
- GNF CTM: Av. Eje Central, 7. Centro Transportes Madrid / Madrid / MADRID
- GNF SERPARLA: M-408 c/Pinto. Centro Comercial el Ferial / Parla / MADRID
- GNF SAN BLAS: C/San Romualdo, 13 / Madrid / MADRID
- GNF ARAVACA: C/ Rafael Boti 5 / Madrid / MADRID
- GNF VILLAVERDE: C/ Piñuecar, 53 / Madrid / MADRID
- GNF Megino: C/ Ebanistas 2, Polígono Industrial Urtinsa / Alcorcón / MADRID
- GNF VICALVARO: C/ Rivas, 14 / Madrid / Madrid

Upcoming openings (red points in following figure):
- MADRILEÑA - PORTOMARIN: C/ Portomarín / Madrid / Madrid
- DEMOCRACIA: Av. Democracia 7 / Madrid / Madrid
- MADRILEÑA - AV. CORDOBA: Av. Córdoba 49 / Madrid / Madrid
- MADRILEÑA - POBLADOS: Av. De los Poblados 128 / Madrid / Madrid
- MADRILEÑA - FUENTE DE LIMA: C/ Fuente de Lima 22 / Madrid / Madrid
- GNF- FUENBELLIDA: C/ Fuenbellida 3 / Madrid / Madrid

Figure 14: Public CNG stations in Madrid region (Gas Natural Fenosa)
1.8 Sevilla (Spain)

Seville is located southwest of the Iberian Peninsula, in the Region of Andalusia. It is the capital of Andalusia and the fourth largest city in Spain in terms of number of inhabitants, around 700,000 in the municipality. The total population of the capital and 105 villages in the province is spread over an area of 14,042 square kilometres.

Public transport in Seville is in charge of Transportes Urbanos de Sevilla (TUSSAM). It was established as a Public company by the Municipality of Seville in 1975. Its purpose is the operation and management of public transport in the city of Seville, covering a population more than 700,000 inhabitants, distributed over an area of 142 km², through a network of 43 day lines, besides 9 night lines. The total length of the transport network exceeds of 630 km. TUSSAM fleet consists of 385 buses and four trolleys to which must be added another 16 vehicles of contracted lines.

![Airbus CNG bus (TUSSAM)](image)

TUSSAM started to use CNG buses in 2006 due to its environmental benefits over the use of traditional fuels, highlighting such as reducing CO\(_2\) emissions, the zero emission of solid particles and SO\(_2\), the significant reduction of emissions NO\(_x\) and CO. With this reduction in emissions, quality of the urban environment is improved, the greenhouse effect is attenuated and it contributes to the conservation of the historic city.

In 2006, a CNG refuelling station was built at Headquarter of TUSSAM. It was able, initially, to refuel 40 vehicles overnight. Moreover, in March 2006, 18 CNG buses of 12 meters started to work in Seville. At the end of 2006, 18 vehicles with the same characteristics were received.

Due to the good result obtained, a fast-charging station was constructed in three phases (starting in 2007 and finishing in 2009). Between May and July 2007, another 50 CNG buses was joined to the fleet, for that, a total of 86 buses were powered by CNG, of the total of 380 buses in the fleet (22%). The operation of these 86 buses has allowed a reduction of the annual fuel consumption of 2.2 million litres and 1,193 tons of CO\(_2\) were given up to emit into the atmosphere.

50 new CNG buses were bought in 2008, reaching a percentage of 35% (136 CNG vehicles in total) and another 20 in 2010.

It is planning that 40 more CNG buses are going to be added in 2015. With this addition it is expected to get a further reduction of CO\(_2\) emissions into the atmosphere by 29.1 tons/year.
To carry out this ambitious initiative, Municipality of Seville has had a major investment effort with the help of grants awarded by the Andalusian Energy Agency in the construction of the CNG charging station and overpricing of Natural Gas vehicles. These grants have exceeded two million euros.

![Figure 16: CNG filling posts at the parking of TUSSAM (TUSSAM)](image)

### 1.9 Croatia, Switzerland, UK and Sweden

In **Croatia**, example of use of CNG for public transport comes from ZET, public transport company which is a part of Zagrebacki Holding group.

The bus transport fleet, which in 2008 consisted of 328 vehicles, includes MAN and Mercedes-Benz vehicles. Buses are located in three garages: Podsused, Dubrava and Velika Gorica. The buses are mostly low-floor and for that reason accessible by different categories of the population. Twenty buses have been running on biodiesel on the territory of the City since 2007. After a study on the justifiability of the use of natural gas in public transportation vehicles was done in 2006, ZET has begun the acquisition of vehicles which run on compressed natural gas.

An analysis of existing bus lines was conducted and lines where it is expected that the use of gas would express its full economic, environmental and advertising efficiency were defined.

When selecting candidate lines, the following criteria were used:

- The daily travelled distance limited to 300-330 km (in order to optimize the required number of compressed natural gas containers)
- The advantage given to the lines that operate in those parts of town where the promotional impact is greater.
- The advantage to higher occupancy lines
- Mountain lines are omitted from the first phase
- Advantage to buses that come into the garage early in the evening, or set off from the garage later in the morning.
- The advantage is, where possible, given to the lines operating within urban centres.

Based on the above criteria, about 25 lines were selected as potentially attractive for the switch to compressed natural gas, which powers a total of about 90 buses. Total annual consumption of natural gas per bus would amount to approximately 62 000 m³ per year (Bošnjak et.al, 2013).
Based on the above mentioned results, the total of sixty buses run by natural gas was purchased in 2009 (40 joint and 20 classic) in the first phase.

ZET has received funds from European funds (Civitas Elan Programmes) for the construction of infrastructure for natural gas vehicles usage: for construction of a compressed natural gas filling plant, reconstruction of maintenance garages for the maintenance of buses running on gas, and installation of gas alarm system in natural gas powered buses related to infrastructure (Krznarić et.al, 2011).

Currently, a new CNG filling station in ZET’s garage in Podsused is under construction, because the existing Zagreb City Gasworks filling station does not meet ZET’s demand.

Figure 17: ZET bus driving on CNG (ZET)

CNG filling station will be used primarily as an internal ZET filling station for a total of 60 buses, of which 40 are joint with engine power of 228 kW and 20 classic "solo" buses with engine power of 200 kW. Daily consumption should be covered by a single tank (Bošnjak et.al, 2013).

<table>
<thead>
<tr>
<th>Table 2 Technical data on ZET CNG buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLASSIC &quot;SOLO&quot; BUSES</td>
</tr>
<tr>
<td>Tank volume (l)</td>
</tr>
<tr>
<td>Pressure in the tanks (bar)</td>
</tr>
<tr>
<td>Total tank capacity (kg)</td>
</tr>
<tr>
<td>Tank capacity effectively (kg)</td>
</tr>
<tr>
<td>JOINT BUSES</td>
</tr>
<tr>
<td>Tank volume (l)</td>
</tr>
<tr>
<td>Pressure in the tanks (bar)</td>
</tr>
<tr>
<td>Total tank capacity (kg)</td>
</tr>
<tr>
<td>Tank capacity effectively (kg)</td>
</tr>
</tbody>
</table>

Biogas as a transport fuel is also well established in Switzerland. In Zurich alone, five plants ferment organic scraps from homes and restaurants to produce fuel for 1200 cars and trucks. Cities that developed viable biogas fleets more then ten years ago include Lille (124 vehicles), Reykjavík (44 vehicles) and Rome (12 vehicles) (Biogas as a Vehicle Fuel, A European Overview, 2003).

In the United Kingdom in 2008 a group of companies (SITA in collaboration with GasRec, BOC and the Linde Group) produced liquid biomethane (LBM) from landfill gas at its landfill site in Albury, Surrey. In 2010 SITA trialled the performance of LBM dual fuel vehicles against diesel counterparts of a similar age. Dennis Twin Pack vehicles were used for the trial, which showed the dual-fuel vehicles to be 12 -18% more efficient than diesel vehicles. The dual-fuel vehicles were also found to emit between 25% and 37% less CO2. A year long test by Leeds City Council found that powering refuse collection vehicles using biomethane can deliver both greatly reduced GHG emissions and cost savings for UK local authorities.
The trial vehicle, a Mercedes-Benz Econic LLG with a spark ignition engine running solely on biomethane gas, is estimated to have achieved a 49% saving in well-to-wheel GHG emissions, compared to the diesel Econics in the council’s fleet. This was achieved using a temporary filling station – a more efficient permanent station raises the GHG saving to 64%, with possible 78% savings estimated if gas was generated on-site.

Greenwich Council have been in the recent years testing CNG as an alternative to diesel in waste collection vehicles. Greenwich Council are also planning to build an AD plant treating biodegradable municipal waste and commercial food waste by 2014, with the intention of upgrading the biogas for use in their refuse collection (Mercedes Econic) and disabled-access minibus (Mercedes Sprinter 516) fleets. In 2010 the North East Regional Improvement and Efficiency Programme (NE RIEP) funded a Feasibility Study investigating the possibility of anaerobically digesting the regions food waste. The study revealed that the 30,000 tpa of food waste collected annually in Teesside (Hartlepool, Middlesbrough and Stockton local authority areas) has the potential to produce biomethane equivalent to 4.25 million litres of diesel or petrol. As Hartlepool, Middlesbrough and Stockton councils consume 2 million liters of diesel between them, the AD of municipal food wastes would produce more than enough fuel for their needs, as well as diverting food wastes from landfill (RENEW, 2010).

Elsewhere, Veolia have introduced 10 CNG waste collection vehicles to Sheffield. It is intended that these CNG vehicles will eventually be run on bio-methane. Tesco is also commissioning 25 Iveco EcoDaily light commercial vehicles fuelled by sustainable liquid biogas for its online retail and delivery service (Biofuels TP Website, Accessed July 2011), and private haulier Tenens has also invested in CNG HGVs, and intends to convert to biogas eventually. Lincolnshire County Council are also currently investigating biomethane fuelled public transport. There are many other examples of UK municipalities and companies currently investigating CNG/biogas vehicles and infrastructure, including Geneco, a spin off from Wessex Water, who have converted a VW Beetle to run off biomethane from sewage sludge digesters.

Figure 18: Geneco’s ‘Dung Beetle’
In terms of price, CNG/biogas vehicles are currently more expensive than their diesel counterparts by 10% - 20%, but are estimated to be up to 40% cheaper to run (Sustainable Transport Solutions Ltd., 2006).

At present **Sweden** leads the world in terms of the use of biogas as a transport fuel. Over 100 GWh/a (10 million m³) of biogas is upgraded in one of 22 biogas upgrading plants and used as vehicle fuel, representing around 2% of the country's total transport fuel demand. Based on experiences gained from projects with municipal fleets of buses and taxis, the Swedish program now aims for commercial expansion of vehicle fleets and infrastructure for (upgraded) biogas refuelling stations. Currently there are some 14 local fleets (including those in the cities of Linköping, Vasteras, Uppsala, Kristianstad, Gothenburg and Stockholm) where the major part of the urban public transport systems is operated on biogas (NSCA, 2006). Several of these cities also run waste collection fleets on biogas. In all cases biogas is from the anaerobic digestion (AD) of sewage sludge, biodegradable municipal wastes, commercial and industrial organic wastes and energy crops. Biogas from the Växktraft AD plant 8km outside Vasteras is combined with biogas from the sewage treatment plant, upgraded, piped into the city centre, compressed, stored and used as a vehicle fuel. The AD plant treats source separated kitchen waste, grease trap removal sludge and specially grown energy crops. The location of the plant in relation to the sewage treatment works (from which biogas is also collected and upgraded), and the bus depot is shown in Figure below.

![Figure 19: Organisation of biogas use for transport in Vasteras, Sweden](image)

Biogas from the centrally located sewage treatment works is piped to the out of town plant, where it is added to the biogas produced from the Växktraft plant and upgraded.
The upgraded biogas is the piped (under a 4 bar pressure) back to the centrally located bus depot, where it is compressed to 330 bar and stored, before being used to re-fuel the city’s bus fleet. At 330 bar, 6000 m$^3$ (at atmospheric pressure) of upgraded biogas can be stored in a volume of 32 m$^3$, in long gas storage tanks in a ventilated gas storage building.

In total, biogas from the two plants substitutes the equivalent of 2.3 million litres of petrol per year, which is sufficient to supply all of the city buses (at least 40 buses), 10 refuse collection vehicles and approximately 500 cars and other light transport vehicles.
CNG is stored on-site as a back-up, so that the public transport system is unaffected if for any reason the biogas from the biowastes treatment plant slows down or stops. The stations shown in Figure 7 are overnight docking and re-fuelling stations to which the buses are connected at night. After overnight refuelling, buses are operational all day and do not need refuelling before returning to the depot at the end of their daily run.
The biogas buses in Västerås are made by Volvo, and the ‘bendy-buses’ are made by MAN, a German based manufacturer of buses and heavy goods vehicles.

1.10 Linkoping, Sweden

After several traffic reduction schemes in the 1980’s failed to improve air quality, the Linkoping municipality decided to experiment with alternative fuels for its municipal fleets. Between 1989 and 1993, five biogas buses manufactured by Scania were trialled. The success of these vehicles led to a further 20 buses being replaced by biogas vehicles in 1998, and at present the entire bus fleet (at least 64 buses), the entire municipal refuse fleet, and at least 125 other vehicles including many taxis are fuelled by biogas. In Linkoping, each bus running on biogas fuel contributes to reducing NOx emissions by 1.2 tonnes and CO2 by 90 tonnes per year (Energy Cities website, 2006). With regards to the original driver, to improve the air quality in the city centre, the conversion of the bus fleet from diesel to biogas has led to ‘big air quality improvements’ (Svensk Biogas, Personal Communication). Biogas buses are also quieter than their diesel predecessors, which is important for a city centre. After upgrading, the biogas is compressed to 4 bar, to enable it to be transferred by underground gas grid to the bus station, around 2km away.

Five public biogas filling stations are also connected to the grid, and there are at least 7 other biogas filling stations in the Linkoping region, all of which are run by Svensk Biogas.

As the fuel is gaseous rather than liquid, the re-fuelling nozzles and connections must be gas tight and standardised. The nozzle at the filling station and the petrol tank connection on biogas vehicles are shown below.

![Figure 24: Public biogas filling station at Simsholmen (Jonkoping, Sweden)](image)

At the bus station, biogas is compressed to 200 bar and stored. Buses are filled up automatically at night. Forty five buses can be filled up simultaneously, although there are also quick filling stations available. All new taxis given licences in the city must run on a renewable fuel (either bio-ethanol or biogas), and other municipal vehicles are replaced with biogas vehicles when the old vehicles reach the end of their lifespan. Some biogas is compressed to 230 bars and stored in moveable containers, allowing the replenishing of public biogas filling stations in the area that are not connected to the localised biogas grid. Gas cylinders are also sent nightly to the biogas train which has run between Linkoping and Vastervik daily, since 2005 (Monson, 2013), (Cenex, 2015).
2 Biomethane and CNG vehicles

The strategic importance of CNG on the fuel market also highlights the adopted October 2014 EU directive on the construction of infrastructure for alternative fuels. The main driving force of the directive was the finding that the market development of clean fuel alternatives won’t work without state intervention. The Directive requires Member States systematic steps towards implementing alternative fuels on the market.

Biomethane will be here a chance to provide CNG vehicles with a renewable fuel. In Germany in 2014 more than 36% of all CNG filling stations offered biomethane pure or as a mixture with natural gas. (Peters et.al, 2015)

2.1 Market

The market for biomethane is growing, because the standard CNG vehicles can be used for operation. Three good practice examples of the market of biomethane and CNG vehicles are shown below as representative examples to implement all over Europe.

Italy

From 2005 to 2011, the population has doubled to 785,000 vehicles by 2014 and to more than 900,000 developed vehicles. For 2015, can be expected with the achievement of one million natural gas vehicles. The total vehicle market natural gas in new registrations reached a share of 2.5 percent. 2013, the share of natural gas vehicles rose to new registrations by 25 percent, in 2014 at 5 percent of the total market.

The European network for natural gas filling stations in Italy is the most densely. For 2014 974 reference points have been reported. Here regional differences have to be considered: On the densest is the "metano" network in northern Italy and on the Adriatic coast, while there is almost no infrastructure in other parts. (Peters et.al, 2015)

Netherlands

In the Netherlands, natural gas is growing steadily as fuel in importance. Although with 7,500 vehicles (September 2014) driven only 0.09 percent of the stock of natural gas and thus a
significantly lower proportion than in Germany. However, a second look at the numbers shows the success story of natural gas as fuel in the Netherlands:

With over 14 percent of buses and commercial vehicles have a significant share of the natural gas fleet, so that a disproportionately high natural gas sales with a correspondingly positive impact on the profitability of the 140 service stations is achieved. In addition, the growth is still high. So took the stock of natural gas vehicles in 2014 to the previous year by approximately 12 percent, compared to 2010, the stock has even doubled. Also noteworthy is with 65 percent of the high proportion of biomethane in the remote at gas stations methane.

An important factor for the market development of natural gas as fuel in the Netherlands is negotiated between government and industry "Green Deal" and its political support. (Peters et.al, 2015)

China

China is under great pressure to get his due the rapid growth environmental impacts in the transport sector in the handle. Part of the action plan is a targeted promotion of natural gas as fuel. The Chinese leadership is based on the incentive for the acquisition of natural gas vehicles and the creation of infrastructure.

Particularly noteworthy is the speed with which the development of the market for natural gas has taken place as a fuel. In mid-2011, the number of reported natural gas vehicles currently at 550,000 units, natural gas could be at 1,700 locations, especially along the main pipelines for natural gas, refer.

2014 (CNG and LNG) were already 3.3 million natural gas vehicles, of which 890,000 buses and trucks 217,000, and 5,730 natural gas stations reported. The share of the vehicle fleet in China amounted to 2.1 percent (from approximately 154 million vehicles) at ten times the proportion in Germany.

China thus has taken third place in the global natural gas vehicle statistics and is expected this statistic cited the end of 2015 if present trends continue. The Chinese economy benefited from this development: 80 to 100 per cent of all components for retrofit or new construction of vehicles so far produced in the domestic market, more than 60 manufacturers of vehicles and components are active here. This natural gas mobility has become an important factor in the value chain in the country, including and thus also with regard to the financial implications, as well as the considerable impact on the trade balance of the energy-hungry country. (Peters et.al, 2015)

2.2 Emissions

CNG vehicles can get real ecologists by using biomethane. Compared to gasoline, GHG emissions decline at a 20 percent admixture by up to 35 percent and the use of pure biomethane residue on base according to JEC even in negative territory. In the production of biogas on the basis of manure or sewage sludge are climate-damaging releases from Methane and nitrous oxide is avoided. Using the substitution procedure can be "credited" those avoided GHG emissions. For a vehicle drive based on biomethane, produced on the basis of manure, may be by this method, a maximum value of minus 178 percent compared to the reference gasoline yield. Even if the methane and nitrous oxide emissions are not considered, the GHG emissions of biomethane mobility are almost at the level of electro-mobility with renewable Electricity. Of particular interest for the economy are the low additional costs compared to the established mobility with conventional fuels.

(Peters et.al, 2015)
### Biomethane and Natural Gas Emissions

<table>
<thead>
<tr>
<th>[g/kWh]</th>
<th>THP</th>
<th>CO2</th>
<th>CH4</th>
<th>N2O</th>
<th>VP SO2-Äq</th>
<th>SO2</th>
<th>NOx</th>
<th>Dust</th>
<th>CO</th>
<th>NMVOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomethane</td>
<td>81,7</td>
<td>53,9</td>
<td>0,980</td>
<td>0,003</td>
<td>0,091</td>
<td>0,029</td>
<td>0,089</td>
<td>0,005</td>
<td>0,063</td>
<td>0,006</td>
</tr>
</tbody>
</table>

(Emissionsbilanz, 2013)

<table>
<thead>
<tr>
<th>[g/kWh]</th>
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<th>CO2</th>
<th>CH4</th>
<th>N2O</th>
<th>VP SO2-Äq</th>
<th>SO2</th>
<th>NOx</th>
<th>Dust</th>
<th>CO</th>
<th>NMVOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>251,1</td>
<td>227,5</td>
<td>0,845</td>
<td>0,001</td>
<td>0,076</td>
<td>0,006</td>
<td>0,100</td>
<td>0,004</td>
<td>0,063</td>
<td>0,011</td>
</tr>
</tbody>
</table>

(Emissionsbilanz, 2013)

### Types of Engine

Biomethane and synthetic methane gas can entirely substitute fossil fuel. Adjustments to the engine are not required. "Blend walls" (Blending limits) as with liquid fuel does not exist. The renewable share is freely variable and not as with gasoline or diesel to 10 to 7 per cent limited.

The biomethane used in the transport sector is 90 per cent of residual and waste materials won. As a result, competing uses for food or feed production avoided and, as already described, a very high greenhouse gas reduction be achieved. Through advances in research, the bandwidth expanded the usable for biomethane production residues constantly. (Peters et.al, 2015)

### NoVA

The NoVA is a one-time charge that depends on the CO2 emissions or the cubic capacity and is calculated as a percentage of the vehicle value (net). For cars moreover applies a CO2 pricing system and deduct a fixed amount depending on the type of drive.

It includes a new car, station wagon (including motorhome) or a new motorcycle in Austria is delivered to the customer, or a vehicle is registered for the first time for transport in Austria.

Trucks are not included in the NoVA. For CNG/biomethane vehicles there is a tax rebate in the amount of 600 €. (ÖAMTC, 2015)
There are two different types of biomethane vehicles. On the one hand biomethane only is used as fuel that means that a pure gas engine is required, on the other hand the gasoline/diesel engine can be modified and a mixture of gasoline/diesel and biomethane is utilized. There is also a little difference between using diesel or gasoline.

### 2.4.1 Usage of biomethane in CNG vehicles

Biomethane needs to have the same substances of content compared to natural gas. There are national regulations for natural gas compositions. Biomethane needs to meet this level. For example the Austrian regulation ÖVGW G31 determine the content of natural gas (ÖVGW, 2001):

- Caloric value: 10,7 to 12,8 kWh/m³
- Oxygen: <0,5%
- Carbondioxide: <2%
- Nitrogen: <5%
- Hydrogen: <4%
- Mean total sulphur: <10 mg/m³
- Halogen compound: 0 mg/m³
- Free of ammoniac, solid- and liquid elements

Most of the CNG vehicle producers do not have a separate guideline or regulation on using biomethane in their vehicles. That’s why biomethane can also be used in CNG vehicles. Limitations of usage of biomethane could be mentioned in the manuals of the vehicles.

### 2.4.2 Dedicated gas engine

CNG/biomethane is used in traditional gasoline/internal combustion engine automobiles.

![Figure 26: Dedicated gas engine (TSTC forecasting, 2015)](image)

### 2.4.3 Diesel-biomethane engine

Because biomethane can’t fire itself like diesel, a little amount of diesel is add to the gas in order to create a spark which fires the biomethane. The most common usage of this system is in trucks. Therefore the usual ratio is 40% diesel and 60%biomethane.
By using the HPDI Technology (high-pressure direct injection) not previously possible with natural gas engines self-ignition in the cylinder can be brought about. For this purpose, a small amount of diesel is injected into the chamber, followed by natural gas as the main fuel. Thus, a diesel substitution rate of over 90 percent can be achieved. (Peters et.al, 2015)

2.4.4 Gasoline-biomethane engine

Here no gasoline is required for firing because spark plugs are used either for lighting gasoline and biomethane. So it is possible to use these separately via pushing a button and if one fuel is used up it is automatically switched to the other. This engine is commonly used for cars or taxis.

According to the Austrian companies Hödlmayr and LuPower, which are modifying vehicles to a bivalent system (mixture of gasoline/diesel and CNG/biomethane), the costs for this modifying depending on the scope and number of cylinders are between 5,000 and 9,000 €. (Hödlmayr and LuPower, 2015)
2.4.5 Storing options

This is the most difficult part, because the tank needs enough space. Here are a few solutions for storing the gas:

Figure 29: Underfloor solution (erdgas-mobil, 2015)
2.4.6 Common CNG vehicle producers

Passenger Cars

Based on the MQB platform of the VW Group has significantly improved in 2014 in all volume brands, the supply of natural gas vehicles in the compact class.

Unifying element of the model offensive is a powerful yet more efficient 1.4-liter turbo engine with 81 kW (110 hp), which with two transmission options (6-speed DSG automatic transmission, 6-speed manual transmission) is offered. In natural gas mode the consumption is estimated at 3.4 to 3.5 kg / 100 km, with CO2 emissions of 88 to 97 gCO2 / km decreases. The emission of biomethane content in fuel is not yet considered. The ranges of the models are provided with natural gas operation 440 and 400 kilometers between. By activating the additional existing fuel tanks a total range from 1,300 to 1,440 kilometers, will achieve.

At the beginning of the VW Golf BlueMotion TGI was introduced into the market, followed in the autumn by the Combi version. Skoda Octavia 1.4 brought with the G-Tec another model in the compact car class on the market. The vehicle is provided with an attractive features, including the start-stop system and braking energy recovery. With the sporty Leon TGI Seat has brought another low-emission natural gas model on the market. Also of Leon is available in the ST estate version.

Daimler launched the new E- and B-Class, which will anchor the natural gas mobility firmly back in the taxi market. The models carry the abbreviation for NGT Natural Gas Technology and are also designed as a bivalent concepts, so have natural gas and fuel tank. The gas tank of the E 200 NGT summarizes 18 kg - thus reached the car with the gas tank can be ordered in two sizes 1,000 to 1,200 kilometer range. The B-Class 180 NGT achieved with the 16 kg capacity tank has a range of up to 300 kilometers in natural gas operation. Daimler is a NEDC combined consumption of 7.3 l premium gasoline and 4.9 kg of natural gas per 100 km.

With the A3 Sportback g-tron Audi offers its customers a sporty compact car for use with natural gas. Buyer optionally have the ability to generated from wind power synthetic methane - sold under the brand name Audi e-gas - to relate. A special accounting system guarantees that each fueled by the customer kilogram of natural gas is fed as renewable.
methane in the natural gas grid. Owner of g-tron models - the launch of the A4 g-tron is announced - can thus CO2 neutral mobile. (Peters et.al, 2015)

Commercial Vehicles

In the commercial vehicle segment was the 2014 introduction of the Euro VI emission standard is the dominant theme: January 1, 2014 only new vehicles may be authorized which meet this standard. The focus of the development departments was first on getting the diesel vehicles in Euro VI. Natural gas commercial vehicles meet Euro VI with significantly less effort. Since 2015, there are many new releases too.

The Iveco Stralis is available with a combination of CNG and LNG tank. Due to the conformity of the LNG tanks with Directive ECE 110, the vehicle is homologated after WVTA (Whole Vehicle Type Approval) and can be easily approved. In addition, Iveco truck series, which are especially suitable for the disposal within the municipal areas of application, more user-oriented CNG variants can be achieved.

For commercial vehicles up to 12 tons in 2014, the new Iveco Daily has been presented to the public (3.5 to 7.2 t). In this series, the "Natural Power" version was presented simultaneously with the diesel variant - with a positive impact on the reach of the message. The new Daily, named "International Van of the Year 2015" is available with natural gas drive for all constructions (box and flatbed) and also as a minibus. (Peters et.al, 2015)

There are also some companies on the market which convert existing Diesel vehicles to Biomethane vehicles. The vehicle in the following figure was converted to a Diesel-Gas engine. The gas tank with 90 kg of natural gas is enough for about 1000 km, the incorporation rate is about 35%. The system pays for itself, depending on the mileage within 1.5 to 3 years. (infinite.at, 2015)

![Converted Diesel-Gas vehicle](www.infinity.at, 2015)
CNG Busses
There are also some CNG vehicle producers for busses (type):
Iveco Bus: Daily, Urbanway CNG
MAN: Lion’s City
Mercedes-Benz: (EvoBus) Citaro
Otokar: Kent CNG
Scania: Citywide LF/LE
Solaris: Urbino 12/18
Solbus: Solcity 12
Van Hool: A330 CNG, A360 CNG, Exqui.City
Volvo: 7700/7900

Under the name Exqui.City in cooperation Scania and Van Hool created an adaptable to customer requirements innovative vehicle concept. This combines the flexibility of buses with the efficiency of trams. The power transmission to the wheels works only via electric motors. Methane combined powered this Trambus takes a high passenger capacity which is environmentally friendly. (Peters et.al, 2015)

2.5 Production of 1 kg Biomethane
From 1000kg food waste you win about 39 to 390 kg biogas. Thus 1kg biomethane needs about 4.8 kg to 48 kg food waste. (Fachagentur Nachwachsende Rohstoffe, 2009)
The most important components of the substrates for the biomethane production are fat, proteins and carbohydrates. Here is the biogas output of each component:

<table>
<thead>
<tr>
<th></th>
<th>Gasoutput theoretical (l/kg oDM)</th>
<th>Gasoutput practical (l/kg oDM)</th>
<th>Methane content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>1400</td>
<td>1000 - 1250</td>
<td>68 - 71</td>
</tr>
<tr>
<td>Protein</td>
<td>900</td>
<td>600 - 700</td>
<td></td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>830 - 960</td>
<td>700 - 800</td>
<td>50</td>
</tr>
</tbody>
</table>

(Renewable energy concept, 2015)
2.6 Filling stations equipment

To get the biomethane from the gas grid into the vehicles, some important equipment is needed. The size of the filling station depends on the needed gas flow and storage. The filling station normally covers compression, flow meter, storage and dispenser.

Figure 32: Filling station for biomethane (GET)

There are some manufacturers on the EU market offering filling stations. Here are some of them listed:

- Bauer-Poseidon Kompressoren
- Bohlen & Doyen GmbH
- C.A.M. s.r.l.
- Europump Italia SRL
- Fornovo Gas S.R.L.
- Graf S.p.A.
- Leobersdorfer Maschinenfabrik GmbH
- SAFE S.p.A.
- Schmack Carbotech GmbH
- SK GAS engineering
- Tokheim Service GmbH & Co. KG
- Wayne Fueling Systems
2.6.1 Compressor
A compressor is needed to compress the biomethane from the pressure in the gas grid to about 250 bar.

![Compressor of a filling station](image33)

Figure 33: Compressor of a filling station (GET)

2.6.2 Storage
A storage higher the operating cycle time of the compressor and helps at peak loads of the customers.

![CNG storage for Biomethane in gas bottles](image34)

Figure 34: CNG storage for Biomethane in gas bottles (GET)
2.6.3 Dispenser

Dispensers are needed to fill CNG vehicles. There are several types of solutions and options, e.g.

- Single, double or four hose configuration
- Mass flow meter with a high precision
- High flow rates, e.g. 100 kg/min
- Interface for remote sales data storage

And for safety there are also several solutions and options, e.g.

- Inlet filter
- Pressure transducer
- Break-away valves
- Shutoff manual valves
- Operating status indicator lights
- Pressure indicator
- Self-diagnostics
- Emergency shutdown button
- Temperature compensation system

Figure 35: CNG dispenser (safe-ita.com, 2015)

Private stations

There are certain civil or industrial organizations (municipalities, waste collection companies, logistic and material handling centres or even simple private companies) that, based on the number of the owned vehicles and yearly mileage, have high convenience to purchase CNG
vehicles. Private CNG refuelling plants for civil and industrial users would be a solution. They can convert their vehicles fleet to use this type of fuel, in order to minimize their management costs.

They can have their own disposal CNG refuelling plants inside their company, in order not to be dependent on public refuelling stations that impose opening hours, distances and refuelling times often not compatible with the economical management of personnel and fleet.

Fleet fueling stations can be conveniently located on-site, using either the "fast-fill" or "time-fill" method of fueling.

- Fast-fill refueling is similar to using a gasoline or diesel pump and takes minutes to refuel.
- Time-fill refueling is usually done overnight, in about five to eight hours. A refueling station can be installed wherever natural gas is available.

(socalgas.com, 2015)

3 Good practice of biomethane injection into the natural gas grid

A basic requirement for the use of biomethane at gas stations is the production of biomethane, which is usually produced from biogas plants through an upgrading facility. The produced biomethane can then fill up vehicles directly at the plant, or be fed into the natural gas grid (injection). The biomethane can then be used at local filling stations. Below some examples of good practice are presented for the production of biomethane and biomethane injection into the natural gas grid.

3.1 Margarethen am Moos (Austria)

The biogas plant in Margarethen am Moos, nearby the Vienna airport, has been founded by farmers in 2005. The plant was designed for electricity and heat production and furthermore a public heating grid for the town has been implemented as well as the first biomethane fuel station based on membrane upgrading technology is operational since 2007. In 2011 MethaPOWER has taken the biogas plant in Margarethen am Moos while still keeping the participation of the initial founding farmers involved and has increased the biogas production. Thereby the production capacity of the plant has been increased to more than 3 MW.

The unique aspects about the plant are the innovative inlay material cracking technology as developed in-house and the state of the art substrate management. The plant only process agricultural residues, harvest waste fractions and different stable wastes. Further unique feature is the innovative membrane technology for the upgrading of the produced biogas to biomethane that ensures an economically and technically effective purification process.

3.2 Vienna (Austria)

The first biogas upgrading plant of Vienna Municipal Department 48 has started operation. A special process upgrades biogas produced from kitchen waste in the biogas plant in Vienna-Simmering in the new upgrading plant to biomethane. So it can be fed into the Vienna gas grid. The plant produces about 22,000 tons biogenic kitchen waste over a million cubic meters of CO2-neutral biomethane annually. 900 Viennese households are thus supplied with environmentally friendly biomethane. This saves 3,000 tons of CO2 annually.

The input material is the in the biogas plant produced and desulfurized biogas. For upgrading, a modern membrane separation process is used. This ensures that the biogas with a methane content of 64 percent is now nearly pure biomethane with a methane content of 99 percent. After quality control, the biomethane is compressed to the grid pressure of up to 70 bar and then arrives at the Wien Energie customers.

The upgrading of biogas to biomethane has won in recent years clearly more relevant and offers many advantages. Biomethane is a complete replacement for natural gas, so that the entire spectrum of use of natural gas is covered. Wien Energie customers are supplied immediately with CO2-free gas which is used for gas water heaters, gas stove and the fueling of vehicles. This represents a further step towards increasing the share of renewable energy sources and reduction of gas imports for the City of Vienna. More information can be retrieved from their website: http://www.wku.at/Biogas-Wien.12.0.html (WKU, 2015)
3.3 Utzendorf (Switzerland)

In the Kompogas plants operated today the daily delivered biogenic waste is recycled with an optimal energy utilization. The biogas obtained in the fermentation process is converted into electrical energy and heat. Alternatively or in combination, the biogas can be upgraded for the neutral operation of vehicles to natural gas quality and fed into the gas grid. Depending on the composition of biogenic waste, between 105 to 130 m³ of biogas per ton, equivalent to 70 - 90 liters of gasoline are produced. Kompogas (biomethane), which can be used as fuel for vehicles or for combined heat and power to generate electricity, is today considered one of the most environmentally-friendly, accessible to a broad population, neutral energy. (Kompogas Utzendorf, status 2015)

3.4 Norrköping (Sweden)

The filling station for buses has 22 slow-fill fuel posts and provides 16 buses with gas. The annual turnover of gas is approximately 700,000 Nm³. The public filling station has some 20 customers per day; including cars of the E.ON company and local authority vehicles, taxis and a number of private cars. The yearly consumption of gas is 70,000 Nm³. In the wastewater treatment plant, biogas production is naturally decreased during the summer months, when the bus schedule is less frequent. However, in August when the bus system increases the frequency of their routes, there may be a gap between biomethane production and consumption. Previously, an occasional gas deficit was relieved by lorry transports from another part of Sweden. Today, the E.ON filling station is connected to the same gas grid as another biomethane filling station in Norrköping owned by Svensk Biogas. This second filling station receives biomethane from another production plant in town. Consequently, lack of gas is rare. Now that the supply of gas is secure, E.ON will try to increase the number of customers. (Biogas East, 2008)
3.5 Madrid (Spain)

Valdemingómez Technology Park concentrates since 1978 all treatment facilities for urban waste of Madrid, which reach more than four thousand tons generated daily in the city.

The design of the Technology Park Valdemingómez and development were designed nine years before of European Directive 2008/98 / EC of 19 November was set, which requires recover all the materials and energy contained in waste.

Its essential purpose is to process waste for taking advantage of all that can be recovered from it and deposit the unrecoverable waste safely in the landfill.

To meet this objective, the Technological Park has a wide range of facilities with different functions. These centers are Las Lomas, La Paloma, Las Dehesas and La Galiana, a biomethanisation complex also the Visitor Center and five educational facilities.

Biomethanisation centers and biogas treatment available to the Park are as follows:

- Biomethanisation plant of Las Dehesas (pre-treatment, biomethanisation and deodorisation systems)
  
  Average operating capacity: 161,000 t / year.  
  Digesters: 5  
  Products obtained: biogas and compost (low quality).  
  Destination biogas: biogas treatment plant.

- Biomethanisation plant of La Paloma (pre-treatment, biomethanisation and deodorisation systems)
  
  Average operating capacity: 108,000 t / year.  
  Digesters: 4  
  Products obtained: biogas and compost (low quality).  
  Destination biogas: biogas treatment plant.

- Biogas from biomethanisation treatment plant.
  
  Operating capacity: 4,000 Nm³ / h.  
  Processes: desulfurization, methane concentration, drying, compression and odorisation.
  
  Desulfurization and purification system: counter pressure washing with water.
  Drying system: PSA / TSA adsorption pressures and fluctuating temperatures.
  Destination biogas treated: use as a biofuel and electricity production.
The biomethane is injected into the CNG Network. In 2014 biomethane injected into the network it was equivalent to the energy needed for 190 buses of the EMT (municipally transport company of Madrid).

Association of Biogas in Spain

AEBIG was founded in 2009 by initiative of a group of companies dedicated to agro-industrial biogas in all its applications: electrical, thermal, biomethane, etc.. It was created due to the concern about the future of the sector. The main mission of the association is to represent the interests of its members with the Public Administrations and other organizations to further disseminate and promote biogas development in society (http://www.aebig.org/).

3.6 Biomethane injection in France

There are some good practice examples in France for injection of biomethane. In 2015, 14 sites injecting biomethane in the gas grid were registered by GrDF (source: GrDF website, http://www.grdf.fr/dossiers/biomethane-biogaz/unites-injection-gaz-vert-biomethane-reseau):
<table>
<thead>
<tr>
<th>Units injecting biomethane</th>
<th>Description</th>
<th>Production in GWh/yr</th>
<th>More info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lille-Séquedin (Nord)</td>
<td>AD plant for household bio-waste</td>
<td>18</td>
<td>Link</td>
</tr>
<tr>
<td>Méthavaler (Moselle)</td>
<td>AD plant for household bio-waste</td>
<td>5</td>
<td>Link</td>
</tr>
<tr>
<td>Bioénergie de la Brie (Seine-et-Marne)</td>
<td>AD plant in a farm (livestock effluent, whey, beet pulp)</td>
<td>13</td>
<td>Link</td>
</tr>
<tr>
<td>AgriBioMéthane (Vendée)</td>
<td>AD plant in a farm (manure, slaughterhouse fat waste from biscuit factory)</td>
<td>8</td>
<td>Link</td>
</tr>
<tr>
<td>Létang Biogaz (Seine-et-Marne)</td>
<td>AD plant in a farm (energy crop, discarded potatoes)</td>
<td>13</td>
<td>Link</td>
</tr>
<tr>
<td>O Terres Energies (Seine-et-Marne)</td>
<td>AD plant in a farm</td>
<td>13</td>
<td>-</td>
</tr>
<tr>
<td>Wannehain (Nord)</td>
<td>AD plant in a farm (manure, waste from vegetables and cereals)</td>
<td>8</td>
<td>Link</td>
</tr>
<tr>
<td>Bio'Seine (Aube)</td>
<td>AD plant in a farm</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>Panais Energie (Aube)</td>
<td>AD plant in a farm</td>
<td>13</td>
<td>-</td>
</tr>
<tr>
<td>Sioule Biogaz (Allier)</td>
<td>AD plant in a farm (manure, cereal residues)</td>
<td>3</td>
<td>Link</td>
</tr>
<tr>
<td>Pré Saint-Loup (Pas-de-Calais)</td>
<td>AD plant in a farm (manure)</td>
<td>12</td>
<td>Link</td>
</tr>
<tr>
<td>Andelnans (Territoire de Belfort)</td>
<td>AD plant in a farm (manure)</td>
<td>5</td>
<td>Link</td>
</tr>
<tr>
<td>Champs Fleuris (Ille-et-Vilaine)</td>
<td>AD plant in a farm (manure, vegetable waste, cereal waste)</td>
<td>5</td>
<td>Link</td>
</tr>
<tr>
<td>Hénin-Beaumont (Pas-de-Calais)</td>
<td>AD plant after MBT sorting MSW</td>
<td>32</td>
<td>Link</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>163</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: List of plants injecting biomethane into the gas grid (GrDF, 2015)

### 4 Directives of biomethane and injection

In the EU there are some national directives to inject biomethane into the public natural gas grid. Most of these regulations on EU and national level can be found below.

#### 4.1 EU Directives & Standards

- **DIRECTIVE 2014/94/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 October 2014 on the deployment of alternative fuels infrastructure.** This Directive sets out minimum requirements for the building-up of alternative fuels infrastructure, including recharging points for electric vehicles and refuelling points for natural gas (LNG and CNG) and hydrogen, to be implemented by means of Member States’ national policy frameworks, as well as common technical specifications for such recharging and refuelling points, and user information requirements.

- Regulation No 115 of the Economic Commission for Europe of the United Nations (UN/ECE) Uniform provisions concerning the approval of: I. specific LPG (liquefied petroleum gases) retrofit systems to be installed in motor vehicles for the use of LPG
in their propulsion system; — II, specific CNG (compressed natural gas) retrofit systems to be installed in motor vehicles for the use of CNG in their propulsion system

- EURO VI: Standard regulating vehicle emissions
- prEN 16723-1 Natural gas and biomethane for use in transportation and biomethane for injection into the natural gas network. Part 1: Specifications for the injection of biomethane into the natural gas network
- PNE-prEN 16723-2: Natural gas and biomethane for use in transportation and biomethane for injection into the natural gas network. Part 2: Specifications for automotive fuel

4.2 Situation in Austria

The Austrian Gas Act (GWG) regulates the general framework conditions for the integration of biogas, and grants non-discriminatory, but not priority, grid access for biogenic gases. Distribution companies are obliged to establish General Distribution System Conditions which must be approved by the E-Control Commission. In the distribution system’s condition, the quality requirements and possible integration points relevant to the introduction and transport of biogenic gases must be determined. The distribution system operator charges the plant operator those expenses incurred through the initial establishment of the connection of the biogas plant to the distribution grid in the form of a grid access fee. These costs are entirely born by the biogas suppliers. This regulation combined with the current situation in terms of feed-in tariffs and the lack of preferential access to the grid does not provide sufficient basis for developing biomethane to grid projects.

The quality requirements specified in the General Distribution System Conditions are stated in Chapter 6 of the Technical Code of Other Market Rules. Biogas must fully respect the criteria of ÖVGW Directive G31, in order to be integrated into the grid. The quality requirements of the gas are defined in detail in ÖVGW Directive G31 that ensures safe transport within the Austrian gas network.

The quality criteria mentioned in the document focus strongly on the characteristics of imported natural gas. Additionally, the requirements of ÖVGW Directive G33 stipulating further gas quality criteria for the injection of biogas and the measures for quality control must be fulfilled.

The technical standard ÖVGW Directive G79 sets the requirements on odorization. If fed into a grid containing odorized gas, biomethane has to be odorized as well. The grid operator determines the kind of odorant and the minimum requirements for safe operation. However, landfill gas is rejected from the public grid due to concerns about harmful gas components affecting the infrastructure or gas end consumer, and due to concern about the limited availability of appropriate measurement equipment for all the impurities.

There is a uniform gas quality in the whole country (H-gas). Due to the corresponding high heating value, in some cases addition of LPG or propane may be required. Injecting upgraded gas with lower calorific value (off-spec gas) than the natural gas quality to the grid is not allowed.

To feed biogas into the gas grid following facilities are in addition to the upgrading plant necessary:
- compression (optional)
- buffer memory (optional as line buffers)
- transfer station
- filter
- quantity measurement and gas quality control
- odorisation
- safety devices
- Connection pipe

(Green Gas Grids, 2012)
4.3 Situation in Croatia

In Croatian legislation, biogas is explicitly mentioned in over 20 legal documents under the jurisdiction of various institutions. Most important legal documents in Croatia for the area of energy, environment protection and agriculture are:

- Act on Energy (NN 120/12, 14/14, 95/15, 102/15)
- Act on Sustainable Waste Management (NN 94/13)
- Directive 2009/28/EZ
- Strategy for Waste Management in the Republic of Croatia (130/05)
- Ordinance on sideproducts of animal origin not suitable for human use (NN 87/09)
- Strategy of Energy Development of the Republic of Croatia (NN 130/09)
- The Plan for Waste Management in the Republic of Croatia in the period 2007 – 2015 (NN 85/07)
- Gas Market Act (NN 28/13)
- Directive on landfills 1999/31/EZ
- Grid rules for Gas Distribution System (NN 50/09)
- General Conditions of Energy Supply of natural gas (NN 43/09, 87/12)
- Act on use of biofuels for transport (NN 65/09, 145/10, 26/11, 144/12)
- Ordinance on biofuel quality (NN 141/05)

Demands for gas quality for natural gas are defined in Grid rules for access to gas transport pipeline (NN 28/13,14/14) but there is no mention of requirements for the quality of biogas. Network operator prescribes the minimal requirements for the quality of biogas for safe operation. General terms for integration of biogas in the grid are determined, but there is no dedicated ordinance or priority approach for such category of gas.

Since relevant data are not yet available, in future projects the following requirements should be investigated:

- Sulphur
- Siloxanes
- Trace components that may (or can) have an effect on health
- Exposure models for these trace components
- Oxygen
- Hydrogen
- Methane number (parameter linked to the risk of knocking in engines, cf. octane number for liquid fuels). In the case of insecurity preliminary figures will be used in the standard that will subsequently be adapted. There is still dispute if these values will arbitrarily be set at a low value and weakened afterwards if possible or if they should be set at the upper limit of known band width and subsequently be reduced if necessary (Bošnjak et.al, 2013), (Hoffstede, 2014), (Rutz et.al, 2014).

In Croatia there is overarching legal framework for the production of biomethane from biogas and its injection into the natural gas network in compliance with applicable rules stemming from the Gas Market Act (NN 28/13). The rules established by the Act and the regulations issued there under are applicable to biogas, gas from biomass and other types of gas if these types of gases can be safely transported through the gas system. There are no legal barriers for biomethane injection in the grid system, neither through the origin of feedstock for biogas production, neither for the mixture of biogas outside of the prescribed specifications (purified, but with large concentration of CO₂) with natural gas in the grid, if the mixture satisfies the requirements prescribed for natural gas. For injection in the grid and use as a vehicle fuel there is no additional standards.
Network Gas Distribution System rules (NN 50/09) permit blending of the biogas, gas from biomass and other types of gas with natural gas, but only if these types of gases can be safely added to the flow, and if the resulting gas mixtures can technically and safely be distributed through the distribution system. Biogas or gas mixtures shall meet the standard quality natural gas from Appendix 1 of the General Conditions of Energy Supply of natural gas (NN 43/09, 87/12). Gas blending is approved by the Distribution System Operator.

Implementing regulations to provide a simple and transparent way to the consumer, such as biomethane technical requirements for biomethane injection, positive discrimination towards the use and/or injection of biomethane into the natural gas network, payment terminal, etc. are currently lacking.

By the end of 2012 in eleven European countries biogas was upgraded to biomethane. In nine countries thereof biomethane was injected into the grid. Sweden and Switzerland have the longest experience which started back in the early 90s. All of the biomethane countries developed standards for injection (plus some more countries not injecting biomethane yet). However, a lot of differences could be found in fundamental aspects such as parameters and/or concentrations of compounds other than methane, with variations even up to a factor of 100 (i.e. for mandated oxygen levels).

There is no legal trading register for biomethane in Croatia.

The price of gas transmission and injection into natural gas distribution network would, according to the simplified calculation (simple return of investment in 10 years) for the expected production of biogas, be 0.007-0.035 kn / kWh (depending on the production scenario and the distance of location from the gas network). (Bošnjak et.al, 2013), (Hoffstede, 2014), (Rutz et.al, 2014)

4.4 Situation in Germany

The Ordinance on Gas Network Access (Gasnetzzugangsverordnung / GasNZV) provides the framework for the access to the natural gas grid. It governs several important issues such as the following:

- Procedure regulation: how to apply for grid connection including time frames for the different steps,
- Responsibilities and cost split for grid connection,
- Maximum methane slip of 0.2 % from 30th of April 2012,
- Provision of bonus for avoided network tariffs of 0.7 €cent / kWh biomethane to reward not using the transmission pipeline system (in contrast to natural gas imports).

Basically, the Ordinance stipulates a cost split of 25 % / 75 % between grid connection applicant and the grid operator. If the distance between upgrading plant and the grid connection point is less than 1 km, the costs for biomethane producer will be capped at 250,000 €. If the distance between the upgrading plant and the grid connection point exceeds 10 km, biomethane producers will have to bear the total costs for the grid connection. The grid operator has ownership of the grid connection station and bears the operation costs for compression, odorization, gas measurements and adjustment of the heating value. Since the grid connection represents a bottle neck for biomethane injection and is of significant importance for the profitable operation of the entire plant, a minimum availability of the grid connection station of 96 % per year must to be guaranteed by the grid operator. The German Association for Gas and Water (Deutscher Verein des Gas- und Wasserfaches / DVGW) is in charge of providing technical standards. The gas quality requirements are stipulated in the technical standards DVGW G260 and G262. The rules offer the possibility of feeding biomethane as an additional gas, apart from feeding biomethane as a substitute for natural gas.

This implies that biomethane of different heating value (off-spec) can be fed into the grid as long as the resulting gas quality is in line with the specifications. This case can be observed
in Pliening, Bavaria where off-spec biomethane is fed into a large transmission pipeline. (Green Gas Grids, 2012)

4.5 **Situation in France**

There are many different regulations setting rules on the injection of biomethane in the gas grid:

- Decrees 2011-1594, 2011-1595, 2011-1596 and 2011-1597 on the conditions for the sale of biomethane to natural gas providers, guarantees on the origin of biomethane and contracts between biomethane producers and natural gas providers;

- Various decrees describing the possible inputs for the production of biomethane and defining the conditions of purchase of biomethane injected in the grid, as well as the possibility to identify “last resort” purchasers in case no natural gas provider could be identified;

- A decree (05/12/2012) designating the organisation in charge of managing a national register for the guarantees on the origin of the biomethane injected in the gas grid.

The gas grid can be managed either by GrDF (Gaz réseau distribution France, the main gas distribution company in France) or by a local distribution grid.

Injection of biomethane into a gas grid is only permitted under several conditions:

- The biomethane has been produced from municipal waste (either by anaerobic digestion or in landfills), from agricultural waste (manure, crop residues, energy crops), from food and beverage (FAB) waste (only for slaughterhouse waste, whey and discarded products from supermarkets) or from the anaerobic digestion of wastewater treatment plant (WWTP) sludge.

- The biomethane has to comply with technical requirements to ensure its proper combustion, safety for users and to preserve the grid. Its specification must be the same as “traditional” natural gas, meaning it has to undergo proper upgrading.

Different processes are available, yet the gas has to undergo at least 3 stages in its upgrading process: decarbonation, desulfurization, dehydration.

There are 2 types of gas available in France: “gas B”, whose heat of combustion is lower and is primarily used in the north of France, and “gas H” that presents a higher heat of combustion and is used in most parts of France, including the Paris Region.

Injected biomethane must have a methane content above 96.65%. The limit values for the various parameters of biomethane are presented in the table below:
Parameter | Specification
---|---
HHV* | 10.7 to 12.8 kWh/m³
Wobbe index | 13.64 to 15.70 kWh/m³
Density | between 0.555 and 0.70
Dew point - water | < -5°C at the maximum pressure downstream of the connection
Dew point - hydrocarbon | < -2°C from 1 to 70 bar
Total sulfide content | < 30 mgS/m³
Mercaptan sulphur content | < 6 mgS/m³
H₂S + COS | < 5 mgS/m³
CO₂ | < 3.5% (molar)
Tetrahydrothiophene content | Between 15 and 40 mg/m³
O₂ content | < 0.75% (molar)
Impurities | Gas that can be transported, stored and sold without further processes
Hg | < 1 µg/m³
Cl | < 1 mg/m³
F | < 10 mg/m³
H₂ | < 6%
NH₃ | < 3 mg/m³
CO | < 2%
Temperature of the biomethane | < 35 °C and > 5 °C

Table 4: requirements for the injection of biomethane * HHV: Higher Heating Value

To be injected into the grid, biomethane has to be sent to an injection station set up by the company operating the gas grid or the contractor in charge of the system. In this station, the gas is odorized, its characteristics are checked, its pressure is adjusted and the volume injected is monitored.

In order to inject biomethane into the grid, it is necessary to contact the company operating the grid and to provide details on the location and estimated quantities. The company then carries out a feasibility study in addition to a detailed study assessing the possibility of injection taking into account the current flows in the grid. The operator has to submit an application for the authorization of the system; if the application is validated, an update of the detailed study has to be done in case the situation has evolved.
The detailed study is used to make the project part of the “capacity register” acting as a database of reserved injection capacities, which is shared by all the operators working on the grid. The organization in charge of the register makes a “reservation” for the project based on the specifications of the study. It sets both a “reserved” capacity and an “allocable” capacity that refers to the capacity technically allocable to the project. The project enters a “waiting list” before its actual implementation. When the project is operational, it leaves the waiting list and is registered in the “allocation register”.

Once the authorization is obtained, the grid operator establishes 2 contracts: one for the connection detailing how the pipes between the injection station and the grid are set, and an injection contract detailing the relationship between the biomethane producer and the grid operator during the period of injection.

If the capacity of the distribution grid is not sufficient, it is possible to inject biomethane on the transportation grid.

4.6 Situation in Hungary

The Governmental Decree No 19/2009 on the provisions of the Hungarian Gas Law (Act XL 2008) assures the non-discriminatory access to the gas grid. Biomethane can be fed into the grid as long as its quality meets the requirements of the national standard MSZ 1648:2000. This standard focuses on natural gas and does not regulate the usage of different biogas feedstock or any method for adjusting the heating value. However the standard requires e. g. a strict limit for the oxygen content 0.2 % by volume and a continuous online measurement of the gas quality. (Green Gas Grids, 2012)

4.7 Situation in Italy

In March 2011, Italy introduced Decree No 28/2011 which allows biomethane injection into the gas grid. This law stipulates that the development of natural gas infrastructures is a national priority and the codification of biomethane to natural gas grid injection is also a priority of the Italian Authorities for Energy. The Decree allows biomethane to enter the grid, if it meets the necessary requirements. A related quality standard hasn’t been established so far, but is expected in near future. Italy implemented the Directive 98/30/EC with the Legislative Decree No 164/2000 which provides that grid access to the existing pipeline system cannot be refused for any reason for natural gas produced within Italy, in Italy waters or on the Italian continental shelf. Moreover, the act stipulates that in case of lack of connection capacity, the access cannot be refused. Moreover, with Resolution No. 108/06, the Authority for Electricity and Gas has approved its network code, the CRDG (Codice di Rete per il servizio di distribuzione gas). This particular act regulated the relationship between the companies that manage the natural gas distribution and the sales companies. Adoption of this instrument obliged the distribution companies to offer neutrally and non-discriminatory distribution services to companies and sales to wholesalers. The grid operator is obliged to ensure grid connection verifying the economic feasibility and conformance to the technical standards. The investment costs for grid connection are fully to be borne by the grid connection applicant as the Italian regulations don’t specify any cost split. (Green Gas Grids, 2012)

4.8 Situation in Netherlands

Upgraded biogas derived from all feedstocks is allowed to enter the grid. According to Agentschap NL, to ensure the injected gas is free of pathogenes a HEPA filter needs to be installed and related gas measurements are carried out twice a year. Due to the lower heating value in the major part of the grid there is less effort required for upgrading, to adjust biogas’ quality to match the natural gas requirements, reduced energy and operating costs for CO2 removal as well as reduced costs for augmentation of heating value by adding LPG or propane. Gas quality requirements are currently under discussion. The Netherlands gas grid (mainly constructed by using steel pipes) is considered to be more sensitive towards
corrosion compared to grids made from other materials, leading to discussion regarding biomethane quality parameters such as oxygen content. (Green Gas Grids, 2012)

4.9 Situation in Poland

The Act of 8th of January 2010 amends the Energy Act and also other acts (Journal of Laws No 21 item 104) making important provisions for biogas. The law defines non-discriminatory access to the grid. The operator of the gas distribution system is obliged to accept agricultural biogas when conforming to the gas quality parameters. The law is limited to biogas from agricultural sources, wastes from food industry and from forest biomass as substrates. Landfill gas and sewage gas are restricted from the grid. By all means, the biomethane producer is obliged to prove the hygienic harmlessness of the injected biomethane before the delivery of biomethane to the distribution network, and again when changing the applied technology.

The requirements for gas quality in the grid are laid down in Polish Standards PN-C04752:2011 and PN-C-04753:2011. There are two gas qualities in Poland, highmethane gas - with a minimal required calorific value of 34.0 MJ/m³ and nitrogenrich gas with a minimal required calorific value 18.0 MJ/m³. (Green Gas Grids, 2012)

4.10 Situation in Slovakia

The regulation of the Ministry of Economy of the Slovak Republic No. 337/2005 Coll. sets out the details of the technical conditions for access and connection to the electricity and gas system and the rules for operating them. Biomethane can enter the distribution grid if it meets the technical requirements. There are no restrictions on the feedstock the biomethane is derived from, but the producer is obliged to prove that the gas does not cause any hygienic risks for the distribution network. Augmentation with LPG or propane as well as the injection of upgraded biogas not fully in line with the specifications is allowed in principle as long as the resulting quality of the gas flow conforms to the requirements. (Green Gas Grids, 2012)

4.11 Situation in Spain

The main use of biogas in Spain is the production of electricity. In terms of electricity fed into the grid, the biogas from landfill and sewage accounts for approximately 90%, while the agro-biogas is around 9%. The situation and specification can be found in the tables below.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2007</td>
<td>2008</td>
<td>%</td>
<td>2007</td>
</tr>
<tr>
<td>Renewable special regime (mainland)</td>
<td>Biogas from agricultural waste or gardening</td>
<td>54.8</td>
<td>54.9</td>
<td>0.3</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>Biogas from sewage</td>
<td>38.3</td>
<td>35.7</td>
<td>-6.8</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Biogas from MSW (methanation units)</td>
<td>0.1</td>
<td>0.1</td>
<td>45.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Renewable special regime Canarias</td>
<td>Biogas landfill</td>
<td>3</td>
<td>0.0</td>
<td>100</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Total

603.3 585.1 100

Figure 41: Energy fed into the grid, data until May 31, 2009 (idea.es, 2011)
Regarding to biogas and other gases from unconventional sources:

In the case of biogas, biogas injection into the network is accepted with a $O_2$ content to 0.3 mol% provided that simultaneously following circumstances in the injection:

- The $CO_2$ content must not at any time exceed the 2% mol.
- The water dew point must not exceed at any moment the minus eight degrees Celsius (-8 °C)
- The injection volume of biogas in the main transport network never will exceed 5.000 m$^3$ / h (at reference conditions). For higher volumes and in any case for other entry points to the gas system, the maximum injection volume of biogas will be determined for each case depending on the quality and volume of transported gas from the network to which it connected by the owner and communicated to the Directorate General for Energy Policy and Mines, the GTS and the National Energy Commission.
Spanish Laws

- Directive 2009/33/EC, on the promotion of clean and energy efficient road transport vehicles;

- Royal Decree 919/2006 of 28 July, on the approval of the Technical Regulations of Distribution and use of gaseous fuels (ITC-IGC-05) (BOE number 211 of 4/9/2006). This Royal Decree sets that operation centers will provide mechanisms to control and maintain adequate margins within the parameters of quality of supply, which are at least pressure on the facilities and the concentration of odorant in the gas.

- LAW 22/2005, of 18 November, which are incorporated into Spanish law various community directives on taxation of energy products and electricity. This Law contemplates for the first time natural gas as vehicle fuel and it set a tax for it. What is remarkable is that CNG tax is substantially lower than that of diesel and gasoline.

- Resolution of 13 March 2006, the Directorate General for Energy Policy and Mines, establishing the detailed protocols for the Technical Management Rules established the Gas System & Resolution of 22 September 2011, the Directorate General of Policy Energy and Mines, the detailed protocol PD-01 'metering' of technical management standards for the gas system is modified. This document sets which requirements are there for biomethane or CNG as fuel (see following point) and the odorant conditions as:

  - Provide a distinctive and persistent odour.
  - Provide a specific odour not to be confused with other scents commonly found: odour of petroleum products, combustion gases, kitchens, perfumes, etc.
  - Easy to handle and add gas.
  - Non-toxic concentrations in the spiked gas.
  - Insoluble in water and soluble in gas phase.
  - Inert to the different types of materials used in pipes and poorly absorbed by residues that can be found inside the network.
  - Poorly absorbed by the ground.
  - Combustion without producing harmful products.
  - Chemical stability against gas components.

Spanish Standards


- UNE 60310:2015: Gas supply pipelines for maximum operating pressure above 5 bar and up to and including 16 bar.

- UNE 60311: 2015: Gas supply pipelines for maximum operating pressure up to and including 5 bar.


- UNE 60670-1:2014: Gas installations pipework supplied at maximum operating pressure (MOP) up to and including 5 bar. Part 1: General.
Andalucía Legislation

Law 2/2007 of 27 March, on promoting renewable energies and energy saving and efficiency in Andalusia.

4.12 Situation in Sweden

The Swedish Natural Gas Act (naturgaslag) provides the legal framework for grid injection and includes regulations for natural gas pipelines and natural gas storage facilities and, in certain cases, for trading in natural gas. According to the Act, tariffs, inter alia, for the transfer and storage of natural gas must be reasonable, objective and non-discriminatory. This also refers to biogas and gases from biomass in accordance with Chapter 1 Section 2 of the Natural Gas Act.

Sweden is one of the few countries in the world with a national standard for biogas as vehicle fuel. The standard Swedish Standard (SS) 155438 "Motor Fuels – Biogas as fuel for high-speed otto engines" was established in 1999, and is used ad hoc for grid injection cases. SS155438 states that the methane content must be higher than 95 % and also sets limits for dew point, sulphur content and some other minor constituents. Gas quality requirements for grid injection are under discussion at the moment on European level. It is likely that in the future more attention will be drawn to impurities of trace compounds such as heavy metals, siloxanes etc. and biomethane producers will face stricter requirements when feeding into the public grid. Simultaneously, on national level, a revision of SS155438 is on-going, aiming to launch a quality standard for all types of "fordonsgas" (i.e. vehicle gas), a generic term for biomethane and natural gas when it is used as a road transport fuel. When biomethane is injected into the Swedish gas grid, the addition of propane is allowed and even essential in order to reach the high calorific value of Danish gas. 7 % to 9 % of propane is often necessary for augmentation with significant costs for the biomethane producer. (Green Gas Grids, 2012)

4.13 Situation in Switzerland

The Swiss Gas Industry grants a non-discriminatory but not priority grid access for biogenic gases. There are no restrictions regarding the sources of biogenic gases apart from ecological points. The SVGW standard G13-09 determines the gas quality requirements in order to protect the pipeline system, the measuring devices and the gas customers from inappropriate gases entering the public grid. Moreover, the technical standards SVGW G11 on odorization and SVGW G209 on the technical realisation of the grid connection are of particular relevance for gas injection. In the Swiss public grid, propane or LPG can be used to augment the heating value of injected biomethane. In principal blending of biomethane containing a high CO2 levels is possible as long as the resulting gas stream meets the quality requirements. (Green Gas Grids, 2012)

4.14 Situation in the UK

The UK grants a non-discriminatory but not priority grid access for biogenic gases. There are no restrictions regarding the sources of biogenic gases meaning that biomethane derived from landfill or sewage gas is also allowed to be injected into the national grid. In the UK the typical gross calorific value is 39.0–39.5 MJ / m³ while the heating value of 100 % biomethane is about 37.7 MJ / m³. Due to the high heating value requirements, significant amounts of propane or LPG are needed to adjust the heating value of the injected biomethane.

For historic reasons (related to the fact that UKCS gas has no oxygen) an arbitrary 0.2 % specification for oxygen is in place. Work is underway to change this to 1 % and it is expected that this will be changed in the second half of 2012 to 1 %. (Green Gas Grids, 2012)
5 Economic, financial issues and models

5.1 Economic situation

The biomethane market is growing, that’s why countries start initiatives to support this market. Here are some initiatives in the countries (European Biogas Association, 2015):

- UK: Renewable Heat Incentive (RHI) + gas market value up to 11.0 €Cent/kWh
- FR: Fixed FIT 6.4 – 9.5 €Cent/kWh
- depending on capacity (350 m³/h – 50 m³/h) and substrates
- example: 150 m³/h, 50% manure + 50% org. waste > 9.38 €Cent/kWh
- DK: Guaranteed biomethane feed-in-bonus (FIB)
- IT: FIT set by law, 8.0 – 10.0 €Cent/kWh
- NL: SDE+ scheme, „biotickets“ for vehicle fuel use
- AT: „Technologiebonus“ at green electricity generation
- DE: Biofuel GHG emission reduction certificates
- SE: Complex support system, incl. tax relief
- FI: Tax relief, (high taxes for fossil vehicle fuels)
- NO: Tax relief till end 2015

The economic difference between commercial Diesel- and CNG vehicles is shown in the figure below.

![Economic comparison between Diesel and CNG vehicles (Westcott, 2014)](image)

5.1.1 Economic situation in Croatia

In Croatia, the benefits of injection of biomethane into the gas grid have not been systematically studied. Therefore, no financial support was dedicated in order to provide investors with stable ground for business plan creation.

The potential cost of biomethane at the connecting pipeline depends on the specific cost of waste collection and processing, production and purification of biogas to biomethane. Considering that the concept of waste disposal was created in scenarios, and for that reason
it was too complex to calculate the cost of biogas, the use specific prices from Germany increased by 30% (the impact of developing markets and lack of technology) were used. In this way, the calculated cost of biomethane would amount to 0.5 - 0.7 kn / kWh.

The estimated price for a pre-treatment plant would be 1.67 mil. € or 84 €/t (including engineering, electrical equipment, montage...). Investment in a biogas plant running on biowaste would be the same as in a biogas plant running on agricultural feedstock. Currently, there are 8 agricultural biogas plants in Croatia where 7 of them are of 1 MW\textsubscript{el} installed capacity. The average investment is 4,500 €/kW which is some 60% higher than its counterpart investment in Germany. This will lead to an investment of 6.2 mil. € for the AD installation. For the up-grading plant, the biogas yield from biowaste was taken (biogas yield in 2020) to which existing biogas production (~500 Nm\textsuperscript{3}/h) was added. The desired methane content in biomethane was set to 97%.

With an initial gate fee of 25 €/t, a price for biomethane starting with 0.27 €/m\textsuperscript{3} in 2015 and a pay-back period of 15 years it is obvious that this system is only profitable by a strong support of the local waste management and a national support for the production and use of biomethane regarding both tariff systems (gate fee and gas feed-in). Crucial is also the negotiation with the sewage treatment plant on the price of their biogas and respective escalation clauses. In this cashflow analysis the AD and the up-grading facility was built for the full capacity which – according to the studies of the Zagreb waste management – is true only from 2020 onward; meaning the AD and biomethane plants are operated with partial load only which reduces the profitability. Investments in 2 phases (2014 and 2017 e. g.) might relieve the financial burden.

For public transport, the expected investment for the construction of one natural gas filling station at Podsused for two locations amounts to approximately EUR 1 million for the first phase, and the total investment phase might be between 1.5 and 1.7 million. The cost of construction, operation and maintenance of the filling station, depending on capacity and level of utilization, is between 0.06 and 0.14 kn / kWh.

The price of gas distribution in the city of Zagreb is 0.039 kn/kWh. Based on the above-mentioned indicators, the total price of biomethane at the exit of the filling station would amount to between 0.61 and 0.91 kn/kWh, excluding VAT. The above price is in its smaller amount lower than the cost of diesel fuel or gasoline, but in its larger amount it is higher than the price of motor fuel. Price of CNG supplied by City Gasworks Zagreb – Supply Ltd. is 6 kn/kg plus VAT (7.5 kn/kg or 0.56 kn/kWh including VAT).

The Central WWTF has a biogas plant with an installed capacity of 2x1.5 MWe. It uses biogas in a CHP where a part of the heat is used internally and electricity is sold to the grid. The current Feed-in tariff (FiT) system does not support preferential price for electricity from landfill gas and the electricity is purchased at average production price (0.53 HRK/kWh or 0.07 €/kWh). This could motivate power plant management to consider entering the biomethane market by joining its existing biogas production with the new biowaste biogas (up-grading) facility. New Act on Renewable Energy Sources and High Efficient Cogeneration (NN 100/15) introduces Feed-in Premium (FiP) instead of FiT, but the ordinances that are to define the premium for biogas and biomethane use are not yet announced.

The biogas/biomethane plant on biowaste would be the first of its kind in Croatia and there is little information on the actual investment costs. However, using the average investment for plant of that type in developed waste-to-biogas market and adapting it to the national situation would provide a sufficient approximation to start from. (Bošnjak et.al, 2013), (Hoffstede, 2014), (Rutz et.al, 2014)
5.1.2 Economic situation in France

There are fixed **power purchase prices** systems for biomethane and electricity from biomethane.

The **fees for injection of biomethane** are established by Decree 23/11/2011. For the injection of biomethane into the gas grid by an anaerobic digestion plant, the fee is calculated by adding a baseline fee according to the size of the unit and an "input fee" based on the nature of the waste. The baseline fee is calculated by using the following table:

Table 5: calculation of the baseline fee for injection of biomethane in France

<table>
<thead>
<tr>
<th>Maximum production capacity of biomethane</th>
<th>Baseline fee (in ct €*/kWh HHV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 50 Nm³/hr</td>
<td>9.5</td>
</tr>
<tr>
<td>Between 50 and 100 Nm³/hr</td>
<td>Linear interpolation between 9.5 and 8.65</td>
</tr>
<tr>
<td>Between 100 and 150 Nm³/hr</td>
<td>Linear interpolation between 8.65 and 7.8</td>
</tr>
<tr>
<td>Between 150 and 200 Nm³/hr</td>
<td>Linear interpolation between 7.8 and 7.3</td>
</tr>
<tr>
<td>Between 200 and 250 Nm³/hr</td>
<td>Linear interpolation between 7.3 and 6.8</td>
</tr>
<tr>
<td>Between 250 and 300 Nm³/hr</td>
<td>Linear interpolation between 6.8 and 6.6</td>
</tr>
<tr>
<td>Between 300 and 350 Nm³/hr</td>
<td>Linear interpolation between 6.6 and 6.4</td>
</tr>
<tr>
<td>Above 350 Nm³/hr</td>
<td>6.4</td>
</tr>
</tbody>
</table>

*ct € = Eurocent

The bonus depending on the nature of the input ("prime à l'intrant", or PI) is calculated according to the following formula: PI = 0.5 x p₁ + PI₂ x p₂, where:
- p₁ is the proportion of municipal waste (either from the technical services or household and similar waste) or catering waste in the input material;
- p₂ is the proportion of energy crop or of waste from agriculture or FAB industries in the input material
- PI₂ is defined according to the following table:

Table 6: calculation of PI2 for the input fee - injection of biomethane

<table>
<thead>
<tr>
<th>Maximum production capacity of biomethane</th>
<th>PI₂ (in ct €/ kWh HHV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 50 Nm³/hr</td>
<td>3</td>
</tr>
<tr>
<td>Between 50 and 350 Nm³/hr</td>
<td>Linear interpolation between 3 and 2</td>
</tr>
<tr>
<td>Above 350 Nm³/hr</td>
<td>2</td>
</tr>
</tbody>
</table>

To ease the injection of biogas in the grid, ADEME and GrDF have co-elaborated a website providing guidance and useful resources: [www.injectionbiomethane.fr](http://www.injectionbiomethane.fr)
The gate fee for bio-waste to anaerobic digestion highly dependents on various parameters. Several data sources could be identified. For treatment only, costs ranged from 60 to 100 €/t. In 2015, the average price for CNG is about 1.26 €/kg.

### 5.2 Economic biomethane calculators

#### Biomethane calculator

To calculate the economic values for a biomethane (upgrading) plant with grid injection, on a prefeasibility level, there is a biomethane calculator shown in the figure below.

![Biomethane Calculator](image)

**Figure 45: Biomethane calculator for technical and economical assessment (Bull, 2014)**

This calculator was developed by the Technical University of Vienna within the EU-co-funded project “Bio-methane Regions” (IEE). The calculator can be downloaded here: [http://bio.methan.at/en/download_biomethane-calculator](http://bio.methan.at/en/download_biomethane-calculator)

#### Biowaste to Biomethane calculator

A biowaste to biomethane calculator based on Excel was developed within the Bin2Grid project. The calculator is easy to use and designed for prefeasibility level to calculate the technical and economic values. The tool also includes the distribution via mobile storage tanks to the filling stations, as well as injection into the natural gas grid and usage at CNG filling stations. The calculator can be found at the [http://www.Bin2Grid.eu](http://www.Bin2Grid.eu) website and is very useful for implementing biomethane.
5.3 **Financial models for biomethane**

There are different types of financial models to implement biomethane for usage at grid injection or at local filling stations.

**Loan**

One way of financing a biomethane project is the traditional financing concept. In this concept the credit worthiness of the company is very important. The company gets a loan and invests into the project and then gets equity.

**Project financing with many shareholders**

Another possibility to finance a biomethane project is the project financing concept. This concept is used if many shareholders want to invest in the same project. The project itself is a legal entity. The return and success of a project are very important facts which are hard to predict. The mentioned biowaste to biomethane calculator (5.2) will show the production costs. This criteria depend on the technology of the project, location of the project, contracts of electricity, availability, price of the substrate (biowaste, foodwaste,…), legislation, insurance and qualification and knowledge of the operator.

**Investment funds**

Investment funds are another solution for the financing problem. In this solution some smaller investors invest in the biomethane project. Costs and benefits are split even between investors depending on the amount they invested. Investors can also form a cooperative where they are able to invest in new biomethane projects.

**Contractor**

The cooperation with a contractor can also be a possibility for financing the biomethane project. Contractors are companies specialized in certain branches for example biomethane. Contractors have a big variety of cooperation possibilities.

**Leasing**

The possibility of leasing can only be applied for biomethane projects which include equipment or dedicated buildings. In this case the leasing company and the project manager have to set up a contract.

It is possible that these financing concepts are combined to get a proper contract for each possible scenario. (Henning H., 2010)
Furthermore there are additional possibilities to lower costs to be more economic:

- Subsidies (Investment or for m³ biomethane)
- Trading with injected biomethane (see 5.4)
- If production costs of biomethane are lower than the natural gas at the local filling station, the biomethane plant can be operated more economic, with higher profit
- Public participation: Citizen have the possibility to invest into the biomethane concept and get interest rates as a profit back
- Public participation and usage: Citizen have the possibility to invest into the biomethane concept and get biomethane (limited amount) for free for their biomethane vehicles
- Higher gate fees for food- and beverage waste

5.4 Trading with injected biomethane

When biomethane is injected into the natural gas grid it can´t be determined where it is going to. This is called virtual biomethane. There are already existing methods for trading with this virtual biomethane e.g. Biogasanregister Austria who uses certificates for trading. (Biogasanregister, 2015)

In France a register for biomethane has been established to manage the capacities of the grids and prevent their possible saturation. The organisation in charge of the register (GrDF) is responsible for reserving capacities to projects and allocating them when the injection station is operational. It ensures the procedures are homogeneous for all actors.

To distinguish biomethane from traditional gas, a system of guarantee on its origin has been established. For every MWh of biomethane injected in the grid, a guarantee of origin is delivered to the gas supplier, allowing to prove that the biogas is renewable. The register is available on a website (https://gobiomethane.grdf.fr/) to producers and suppliers of biomethane.

Producers of biomethane can receive different subsidies for designing and setting an anaerobic digestion plan (e.g. from ADEME, ERDF and Regions). The main advantage in France is the fixed price for injection into the gas grid.

The “Green Gas Certification Scheme” in the UK provides renewable gas guarantee of origin (RGGO) for grid injected biomethane. It tracks commercial transactions of biomethane through the supply chain. Unique identifiers ensure there is no double-counting or double-selling of green gas. Producers, suppliers and consumers can all participate on a voluntary basis. (greengas.org.uk, presentation at the UK Biomethane Day 2015)
Figure 47: Green Gas Certification Scheme (greengas.org.uk)

Figure 48: Certificate of the Green Gas (greengas.org.uk)
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