Project 'BIN2GRID'

Turning unexploited food waste into biomethane supplied through local filling stations network
Grant agreement No: 646560

Report on concept of satellite local filling stations network

WP 6 – Task 1 / D 6.2

June 2016

Author: Philipp Novakovits, Güssing Energy Technologies GmbH, Austria

Reviewers: All consortium partners

Contact: Güssing Energy Technologies GmbH
Philipp Novakovits
Email: p.novakovits@get.ac.at
Tel: +43 3322 42606-321
Wiener Strasse 49
7540 Güssing
Austria
www.get.ac.at

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 646560.

Any communication activity related to the action must indicate that it reflects only the author's view and that the Commission is not responsible for any use that may be made of the information it contains.

Bin2Grid website: www.bin2grid.eu

Contents

1 Introduction

Today, the majority of biogas produced in Europe is utilized in cogeneration plants, where electricity and heat are produced. Thus, the profitability of these plants is directly dependent on a constant disposal of the heat produced. Biogas is on the other hand regarded as an essential source of energy in a future energy system. The injection of biogas into existing gas networks opens up the possibility of using biogas to a greater extent, since the usage can take place with a high degree of utilization and efficiency even if no heat consumer is available.

Especially with the usage of waste as input substrate for the biogas production, the process chain of biomethane production can be designed highly efficient and integrated in existing infrastructural systems. Figure 1 illustrates the value-added chain of biomethane beginning from the acquisition of substrate to various ways of utilizing the upgraded energy carrier.

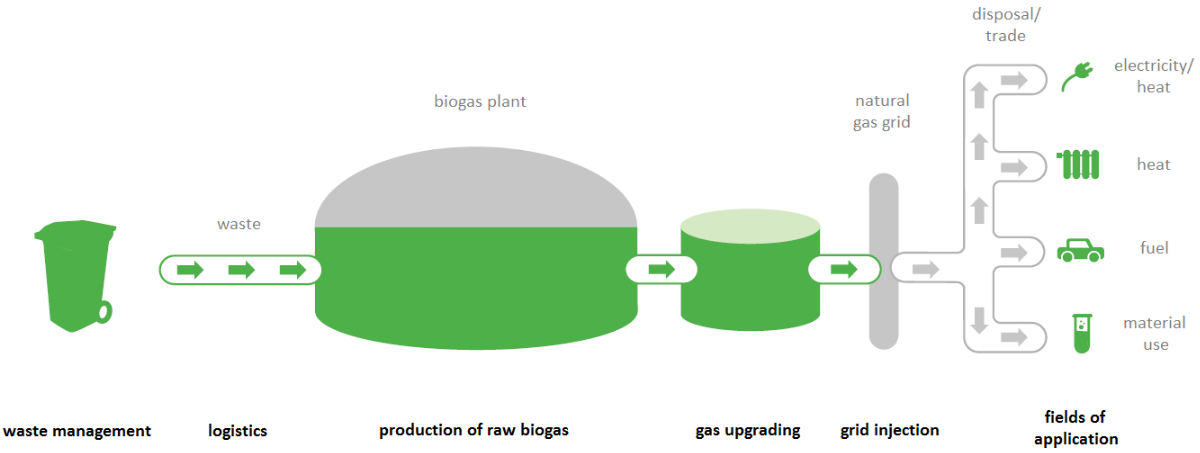


Figure 1: value-added chain of biomethane (modified after Deutsche Energie-Agentur GmbH, 2015)

This graphical description shows different areas (waste management, production of raw biogas, …) which have to be regarded in the process of biomethane production. While some of these fields (waste management, logistics, production of raw biogas, gas upgrading) are already analysed in other parts of the project, the aspects of grid injection and fields of application (most of all biomethane as fuel) are addressed in the present paper.

First of all, in paragraph 2, the waste-to-energy-cycle is described, beginning from biowaste acquisition and logistics to the utilization of upgraded biomethane. As some of these aspects have already been covered in other reports of this project, a reference is made in the respective passages leading to more detailed sources of information, which can be found on the project homepage (www.bin2grid.eu).

Subsequently, the concept of 'virtual biomethane' is illustrated and analysed (chapter 3), as this idea is essential for understanding the policy of distribution of biomethane through existing natural gas grids.

In chapter 4 technical boundary conditions for the injection of biomethane into a local natural gas grid as well as for the withdrawal of biomethane for its utilization are examined. These segment should answer the question to which technical aspects/facilities/devices have to be considered, when planning to injecting or withdrawing biomethane to/from an existing natural gas grid.

As administrative and legal conditions for the purchase and disposal of biomethane through a local gas grid are still strongly dependent on national regulations and are not regulated in a uniform way in all EU member states, these aspects are only covered sketchy in an overview in chapter 5. What's more, existing non-technical barriers are analysed to outline possible problematic issues for planners in an early stage of project development.

Finally, in paragraph 6, the economic boundary conditions for the injection and the utilization of biomethane at CNG filling stations are analysed. For this purpose, on the one hand useful already existing economic models are illustrated and on the other hand a newly developed economic tool is described. The latter was generated in the course of this report to cover a wide range of questions and issues project planners in these fields are confronted with. The economic success of biomethane production is dependent on the technical and economic boundary conditions of many fields:

- substrate acquisition - quality and quantity
- biogas production - investment and operating costs
- gas upgrading - technology used, efficiency, investment and operating costs
- grid injection - investment and operating costs
- biomethane utilization - way of utilization, particular economic boundary conditions

This Excel-based tool is already freely available on the project homepage. Thus, economic boundary conditions evaluated in this paragraph can be examined in detail in the respective tool, where sensitivity analysis can give the user a good feeling for the economic boundary conditions on respective projects or fields of applications.

2 Waste-to-energy-cycle

There are many possibilities to use waste fractions for energy production. The way of acquisition, utilization and requirements for (pre)treatment are pretty much defined through the particular material you have to deal with – quantity, quality, physical structure, etc. In this paper the focus is solely on biowaste. As there are numerous biological waste fractions, the term 'biowaste' is defined in paragraph 2.1 to clarify what is meant when speaking about biowaste. The basic idea of the waste-to-energy-cycle is shown in Figure 2.

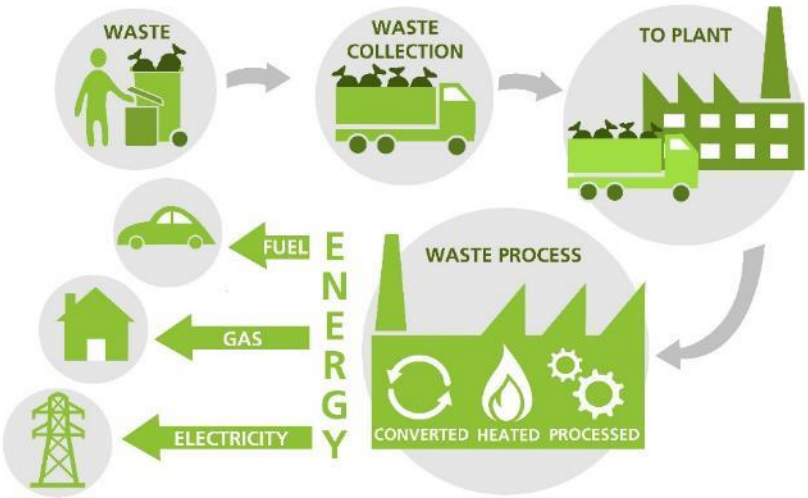


Figure 2: diagram of the waste-to-energy-cycle (Okello, 2016)

A common aspect the majority of biological waste fractions share is the need for pre-treatment of the material. Only a few of these biological waste fractions can be directly used for energy production. For example, raw wood material from the upkeep of gardens or parks in urban regions can be incinerated. Other waste fractions have to be treated in some way or another to get an energy carrier with specific properties appropriate for the existing infrastructure. Treatment methods can be distinguished in three sections: thermo-chemical conversion (e.g. carbonization, pyrolysis), physical-chemical conversion (e.g. esterification) or biochemical conversion (e.g. alcoholic fermentation, anaerobic digestion) (Kaltschmitt, Hartmann, & Hofbauer, 2009).

Here, the biochemical conversion of biowaste into biogas, the upgrading of biogas into biomethane and various ways of utilization of this energy carrier are analysed. As some of these aspects are explicitly addressed in other parts of the project, references are made to the respective passages/reports, where these topics are covered more in detail.

2.1 Biowaste

Biowaste is defined as 'biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. It does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood. It also excludes those by-products of food production that never become waste' (European Comission, 2016). A detailed list of biodegradable waste fractions can be found in the European Waste Catalogue where the mentioned categories are broken down in more detailed fractions.

Generally, there are four possible treatments for biowaste – anaerobic digestion, composting, incineration or disposal. Depending on the particular physical structure of the material, some biowaste fractions are more suitable for a treatment than for another method. In principal, a significant part of biowaste fractions is suitable for anaerobic digestion. However, a major aspect which has to be considered is the content of lignin, which has to be taken into account especially with wooden materials. As lignin is not (or rather bad) degradable by the microorganism in the digester of a biogas plant, waste fractions with a high lignin content can lead to procedural problems alongside with a low biogas yield (Kaltschmitt, Hartmann, & Hofbauer, 2009).

Another issue which has especially to be regarded in the energetic utilization of biowaste is the acquisition of the material. As there is usually not one source of origin but numerous, a special focus has to be on the logistics. This is especially difficult if there is a lack of logistical infrastructure, poor waste management or bad waste separation in the target area of a respective project.

For more detailed information about potential sources of biowaste, biogas yields, waste management procedures, acquisition or obstacles and limits for anaerobic digestion it is referenced to other reports of this project: ‘Guidelines for the anaerobic digestion of food and beverage industry waste’ (Bel, et al., 2016), ‘Food waste from food and beverage industry’ (Bel, Food waste from food and beverage industry, 2015), ‘Catalogue of food waste types and energy potential’ (Ribic, 2015) or the report about ‘Good practice on segregated collection of food waste’ (Morales, et al., 2015).

2.2 Biogas plant

In biogas plants biowaste is degraded under anaerobic conditions. Various microorganism break up the physical structure of the material and convert the macronutrients (carbohydrates, proteins, lipids) in several steps into smaller fractions, like fatty acids, saccharides, amino acids, alcohols, acetate, etc. Each intermediate product serves as food for particular microorganism. A by-product of this process is biogas, a mixture of methane, carbon dioxide and some trace elements. The methane content of the biogas, which defines the energy content of the gas, depends mostly on the substrate and the boundary conditions of the process, like temperature and duration. The anaerobic digestion takes place in one or more digesters. Other infrastructural equipment necessary for the process - depending on the particular process - are:

- Pre-treatment facilities
- Devices for the input of the material in the digesters
- Tank for digested residues
- Gas storage
- Gas treatment facilities
- Gas utilization infrastructure (e.g. cogeneration unit)
- Infrastructure for the utilization of waste heat

Figure 3 illustrates the functioning principle of a biogas production process.

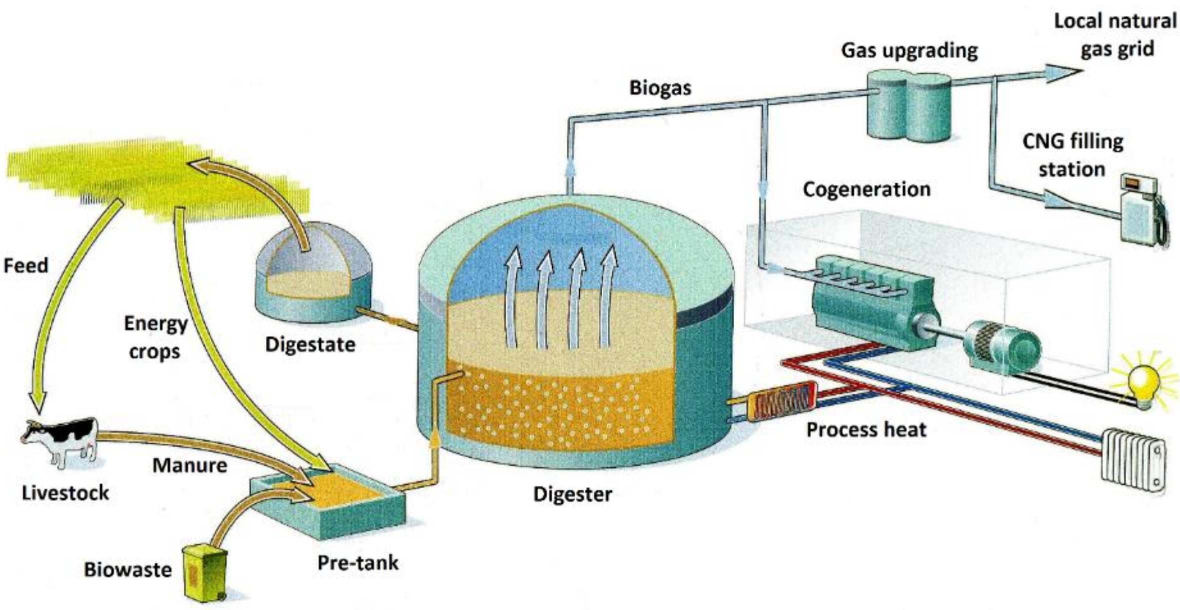


Figure 3: functioning principle of a biogas plant (modified after PlanET Biogastechnik GmbH, 2016)

A detailed description of the functioning principle, components, etc. are given in another report of this project, namely 'Factsheets on current biogas/biomethane handling practices' (Puksec, 2016).

Generally, the technology used for biogas production is pretty much the same for the most biogas plants. However, one aspect is especially important, which has to be considered when using waste for biogas production, namely the purity of the substrate.

To be suitable for recycling waste fractions as feedstock for anaerobic digestion, these wastes must have high purity. Amon and Boxberger (1999) show that low-purity waste, due to the presence of foreign materials, can cause technical malfunctions of the biogas plant, be a source of pollutants and can have a negative impact on the utilization of digestate as fertilizer. For this reason, the authors indicate that the content of foreign materials in organic wastes may not exceed 0.1% (Amon & Boxberger, 1999). Effectively, this is only possible if organic wastes are collected separately, according to their composition materials, at their place of production or utilization. Separate collection is an integrated part of the overall waste management system and may enable a high quality and purity necessary for the optimal use as feedstock for anaerobic digestion (Wellinger, Murphy, & Baxter, 2013).

Compared with source separation, mixed collection followed by a central separation implies higher costs and considerable losses of organic matter as well as high contamination risk (Favoino, 2002). For this reason, the application of digestate from mixed-waste collection onto agricultural land is not allowed in some countries (Wellinger, Murphy, & Baxter, 2013).

The content of foreign materials depends to a very large extent on the human factor, that is, the awareness and motivation of the population involved in collection systems (Favoino, 2002). Favoino (2002) indicates that, even if purities higher than 90% are achieved, organic household wastes can contain significant amounts of disturbing compounds such as metal, glass, plastic and sand.

2.3 *Biomethane upgrading*

Biomethane is a renewable natural gas. It is made by upgrading biogas that is produced by the controlled decomposition of biodegradable waste products or other substrates. It can serve as a substitute for natural gas in transportation, heating, cooling, and power generation.

The upgrading is in fact only a separation or concentration process. Carbon dioxide and smaller fractions of trace elements in raw biogas are separated from methane, as shown in Figure 4.

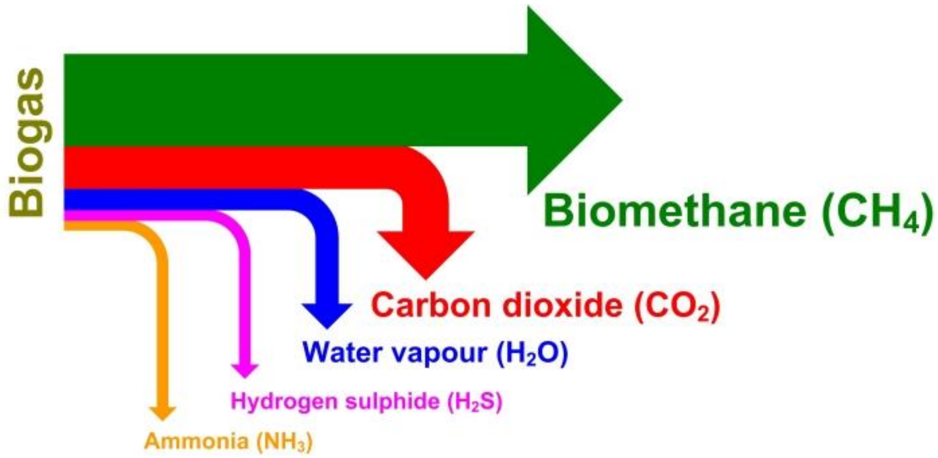


Figure 4: process of biogas upgrading (Harasek, 2016).

The resulting gas, mainly methane, is a fuel with a high energy volume and with properties similar to natural gas. The latter aspect is the reason for the additional effort of the upgrading process. Raw biogas is also suited for combustion and energy production, but the upgrading to biomethane brings a crucial advantage, namely an energy carrier with properties that allow a utilization in an existing infrastructure of power supply – transportation in natural gas grids, storage in conventional gas stores, utilization in gas engines, boilers, vehicles, etc.

Today, different upgrading technologies are used for the gas upgrading process, each with different advantages and disadvantages. In another report of this project, 'Factsheets on current biogas/biomethane handling practices' (Puksec, 2016), detailed depictions of the upgrading process, different technologies and technical and economical boundary conditions are given.

2.4 Utilization

The properties of combustion of biomethane make utilization in a wide range of applications possible. Regarding only the technical boundary conditions, biomethane is able to serve as a complete substitute for natural gas. Here, the report does not go into detail about the utilization of biomethane for final energy consumption (e.g. biomethane for cooking, domestic heating, etc.), as these technical processes are the same with natural gas. The focus is on two paths of utilization at a higher level, on which the operator of a biogas upgrading plant has to decide:

- Injection into a local gas grid

  After upgrading the biomethane can be injected into a local natural gas grid. In this case, the biomethane is mixed and it is not possible to distinguish between biomethane and natural gas anymore. Therefore, we talk about 'virtual biomethane' (see paragraph 3).

- Utilization at a CNG filling station

  Generally, there are two ways for this option – direct utilization of biomethane at a local CNG filling station or injection of biomethane into natural gas grid at first and withdrawal and utilization at a conventional CNG filling station in a second step.

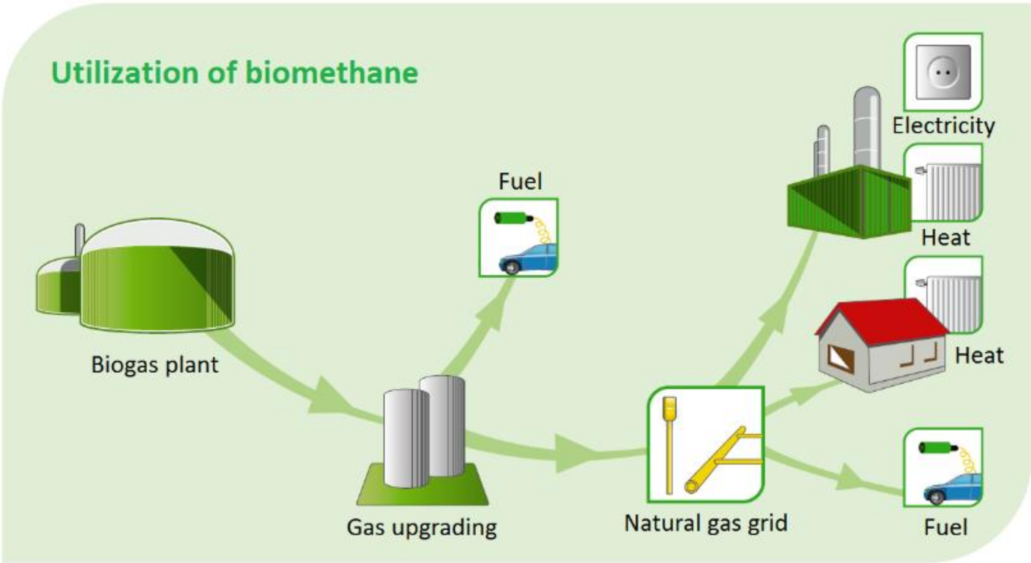


Figure 5: Most important ways of utilization of biomethane (modified after Urban, 2013)

2.4.1 Concept of satellite local filling stations network

When utilizing biomethane as a fuel for vehicles, the applications already implemented today are mostly bound to a certain location. Raw biogas is produced in a biogas plant and an upgrading facility is right next to the plant bringing out biomethane. Today, in many cases in Europe, the biomethane is directly injected into the natural gas grid, as shown in Figure 6. In this table you can also see the number of biomethane or CNG filling stations in the respective countries in the year 2015. Only Finland, Germany and the Netherlands have a significant number of biomethane filling stations, distributing pure biomethane, in operation. Sweden and Switzerland on the other hand have no biomethane filling station whatsoever, but offer biomethane on every standard CNG filling station as a blend with natural gas. That means, that there is a certain amount of biomethane in every quantity withdrawn from fuel dispensers at CNG filling stations, e.g. 80% natural gas and 20% biomethane.

Country	Biomethane plants	Raw biogas upgrading capacity [Nm^3/h]	Produced biomethane [GWh]	Plants feeding into grid	Biomethane used in transport	Number of biomethane filling stations	Number of CNG filling stations*	Tariff (FiT) or premium (P) for biomethane [€/MWh]
Austria	14	5 160	70	11	n/a	3^p	180	8 (FiT)
Denmark	6	8 650	n/a	n/a	n/a	n/a	7	18.8 (P)
Finland	9	2 731	40	3	43%	24^p	25	n/a
France	8	2 610	41	6	n/a	n/a	310	129.7 (FiT)
Germany	178	204 082	9 140	165	3%	$165^p + 143^b$	920	n/a
Hungary	2	625	4	1	n/a	1^p	19	n/a
Italy	5	500	n/a	n/a	n/a	n/a	1 040	150 (FiT)
Luxembourg	3	850	26	n/a	n/a	n/a	7	n/a
Netherlands	21	16 720	683	n/a	n/a	60^p	141	1.03 €/Nm^3
Spain	1	4 000	n/a	n/a	n/a	n/a	69	n/a
Sweden	59	38 858	1 303	13	78%	218^b	218	n/a
Switzerland	24	6 310	166	22	33%	137^b	137	n/a
UK	37	18 957	700	34	n/a	n/a	8	70 (FiT)
TOTAL	367	310 053	12 173	255		$253^p + 498^b$	2041	

^{b} blend
^{p} pure (100%) biomethane
**NGVA Europe*

Figure 6: biomethane production and infrastructure in Europe (European Biogas Association, 2016)

The figures shown in this table suggest that there is a lot of potential for increasing the amount of biomethane in the transport sector in this sense. If you take the situation in Austria for example, there are three biomethane filling stations offering pure biomethane and 180 CNG filling stations offering only natural gas. The same example can be made for other countries, like Hungary, Italy, France, Spain, etc. Although there's not always data about the biomethane filling stations available, you can see - based on the number of CNG filling stations - that there is a huge potential for biomethane being delivered through already existing infrastructure.

This is the idea of **satellite local filling stations** – to use existing infrastructure (natural gas grid, standard CNG filling stations), thus minimizing investment costs and enabling a wider utilization of biomethane.

The concept of the satellite local filling stations network, in the context of the waste-to-energy-cycle, is also shown in Figure 7.

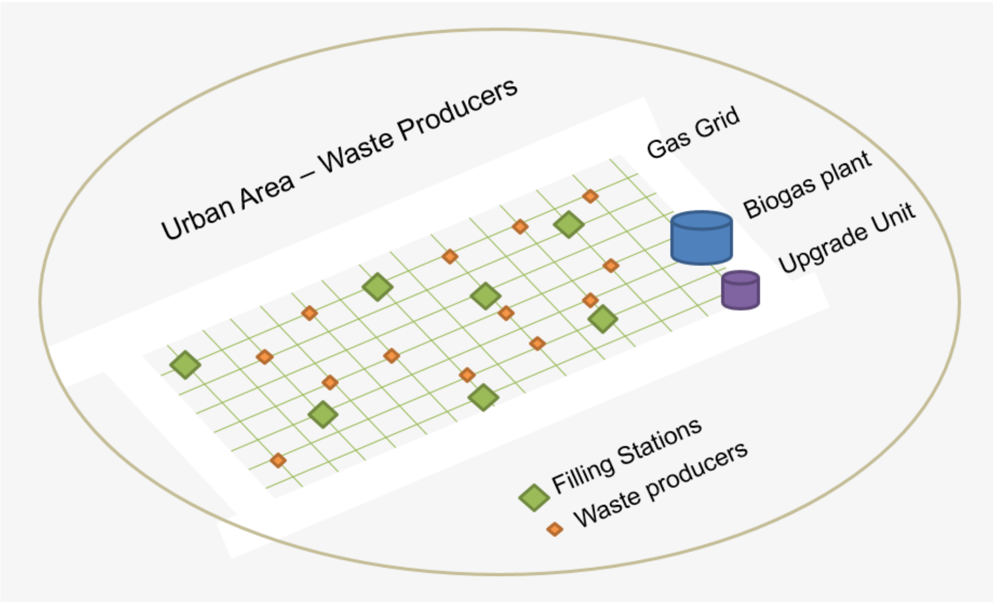


Figure 7: concept of satellite local filling stations network

In this illustration an urban area is schematically depicted. In this urban area there are a lot of waste producers – smaller ones (regular consumers, small shops and retailers, etc.) are distributed all over the area and bigger ones (gastronomy, large kitchens and canteens, etc.) are located on certain spots (orange dots in the graphic), depending on the particular urban structure. A progressive waste management ensures that a high percentage of all waste fractions is (separately) collected. Depending on the particular waste fraction, the quantity and quality of the wastes, there are specific ways of waste treatment and utilization. In this case, biowaste is used to produce biogas, which is upgraded to biomethane. Biomethane is injected into the natural gas grid and – in that way – is available for every consumer in the area and can be directly used through the existing infrastructure of CNG filling stations as a fuel for vehicles – private cars, trucks or even fleets from transport or waste management organisations.

In this sense, biomethane could substantially contribute to the decarbonised transport sector of tomorrow. The technology is advancing year upon year, making the growing number of upgrading units more cost-efficient. Unlike the electric transport, the mature technology of gaseous transport does not require further big investments and innovation in order to be deployed (European Biogas Association, 2016).

Biomethane is a commercially viable fuel: it can rely on existing natural gas infrastructure and the upgrading technology is mature and proven. The green gas provides Europe with several advantages: it contributes to the European climate targets by reduced CO_2 emissions and improved air quality (while fossil fuels are replaced, particulate (< PM10) and NOx emissions are massively reduced), and it advances security of supply and European energy independency from (unstable) third countries. Furthermore, the use of digestate as a fertiliser closes the nutrient cycle in regional ecosystems and saves the CO_2 emissions that would be released by the production of mineral fertilisers. Biogas and biomethane production also generates green jobs through increased regional and agricultural employment. Biomethane is moreover the most energy efficient biofuel and already now the first broadly available second generation biofuel (European Biogas Association, s.a.).

2.4.2 Filling stations for waste management vehicles

CNG filling stations for waste management fleets using natural gas or rather biomethane is an idea showing promise because fleets can save money on fuel while taking advantage of other benefits, such as low criteria pollutant emissions, lower/no greenhouse gas emissions, and quieter operation.

Waste management fleet operators may choose CNG or biomethane as fuel to help meet corporate and municipal financial, environmental and energy sustainability goals. Depending on the prevailing economic boundary conditions, the cost advantage of CNG or even biomethane compared to diesel can be visible in short time. A study about three waste management fleets who switched from diesel to CNG showed that the fleets saved on average around 50% of fuel costs (Laughlin & Burnham, 2014).

In the following section two case studies regarding waste management fleets, biomethane and CNG filling stations are presented.

The first one (paragraph 2.4.2.1.1) is sort of an experience report about three waste management fleets who switched from diesel driven vehicles to CNG driven ones. This review visualises obstacles and chances of waste management fleets operated with CNG and shows some of the practical challenges one might not think of beforehand.

In 2.4.2.1.2, a success story of an integrated concept of the waste-to-energy-cycle (biowaste – biogas plant – biomethane upgrading – filling stations for waste management vehicles) is presented. This case study describes the functioning of this process chain at the Sobacken biogas plant in Borås, Sweden.

2.4.2.1 Case studies

2.4.2.1.1 Study by Laughlin & Burnham (2014)

Laughlin & Burnham (2014) investigated three waste management fleets who switched from diesel to CNG with interesting findings and recommendations, which are shortly illustrated in the following section.

The three fleets in this case study purchased a total of 70 natural gas vehicles. The fleets constructed three new public CNG stations and three new private CNG stations. They also upgraded the equipment for one additional private CNG station as part of these projects.

Training for drivers and technicians

The fleets conducted training for technicians and drivers to improve the level of success for the vehicle deployments. One waste management organisation started mechanics training and cylinder inspection certification training one month prior to the arrival of the first trucks. Another organisation trained its drivers using both hands-on and video resources about vehicle operation and safe filling practices.

Fleet acceptance and feedback

Drivers have received the trucks favourably and drivers from all three fleets singled out their quieter operation for particular praise. The CNG vehicles have produced significant labour cost savings. The overnight time-fill filling system allows drivers to spend less time filling the vehicles. They only need to return their vehicles, do a post-trip inspection, and clock out for the day. They no longer need to wait in a 15-minute line for filling as they did with diesel trucks.

Challenges

Some problematic aspects were the necessary modifications on the garages. The waste management organisations had to include additional ventilation systems in the garages to exhaust potential methane releases and visual/audible methane alarms. Audible methane alarms were added to supplement the visual alarms that could be overlooked by technicians who were working on vehicles.

Other difficult issues were non-technical barriers. Since this was the first time public CNG filling sites were constructed in the area, at one case permitting authorities were not familiar with the specifics of installing such equipment, and they wanted to impose inexplicable requirements for new gasoline stations or convenience stores. Completion of the necessary permits required negotiations with multiple agencies. One waste management organisation was required to make changes to local roadways to improve traffic flow around its filling station. This increased permitting complexity as multiple authorities had to be contacted.

Vehicle configurations were not always optimal for the respective organisations from the beginning. One organisation found that the fuel tanks installed in the first two CNG garbage vehicles were too small, limiting the vehicles' driving range. To address this, the city specified that the next 13 trucks were to be fitted with frame extensions of a certain size to support larger CNG tanks behind the cab. On the downside, the frame extensions have increased the trucks' turning radius, so the city modified the truck routes to adjust for this reduced maneuverability.

Cost effects

Figure 8 shows the average fuel cost per mile for these waste management fleet trucks, which demonstrates the magnitude of the fuel cost savings possible with lower CNG prices.

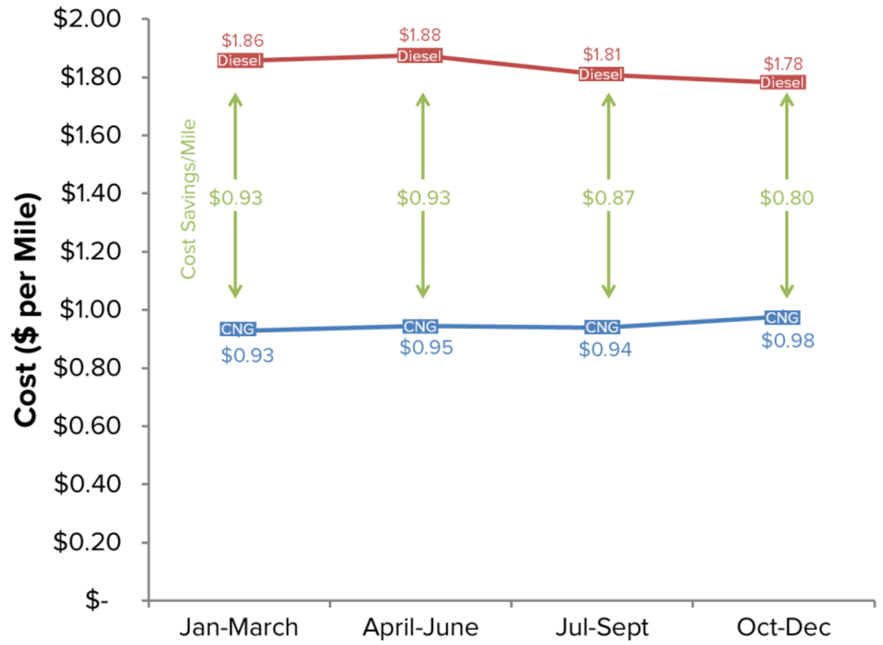


Figure 8: fuel cost savings per mile for CNG garbage trucks [red = Diesel costs; blue = CNG costs] (Laughlin & Burnham, 2014)

Conclusion

The waste management fleets in this case study encountered some initial implementation issues (including garage maintenance facility upgrades and public fuel resale complexities), but these issues now have been largely resolved. Each fleet in this case study plans to make additional purchases of CNG vehicles and expand filling infrastructure in the future as a result of their successful initial deployments.

2.4.2.1.2 Sobacken biogas plant, Borås, Sweden

At the biogas plant in Borås the biowaste from the surrounding region is treated. The biowaste consists of source-separated household waste and organic industrial waste both in solid and fluid form. The solid waste is disintegrated and diluted followed by separation of non-degradable parts in a bioseparator, where a slurry is formed. The substrate is hygienised, digested and the organic content is converted into biogas. The biogas produced is then upgraded to pure methane and used as fuel for waste collection trucks, city busses and public vehicles (Purac, 2016). Figure 9 illustrates the biomethane production process steps at the biogas plant in Borås.

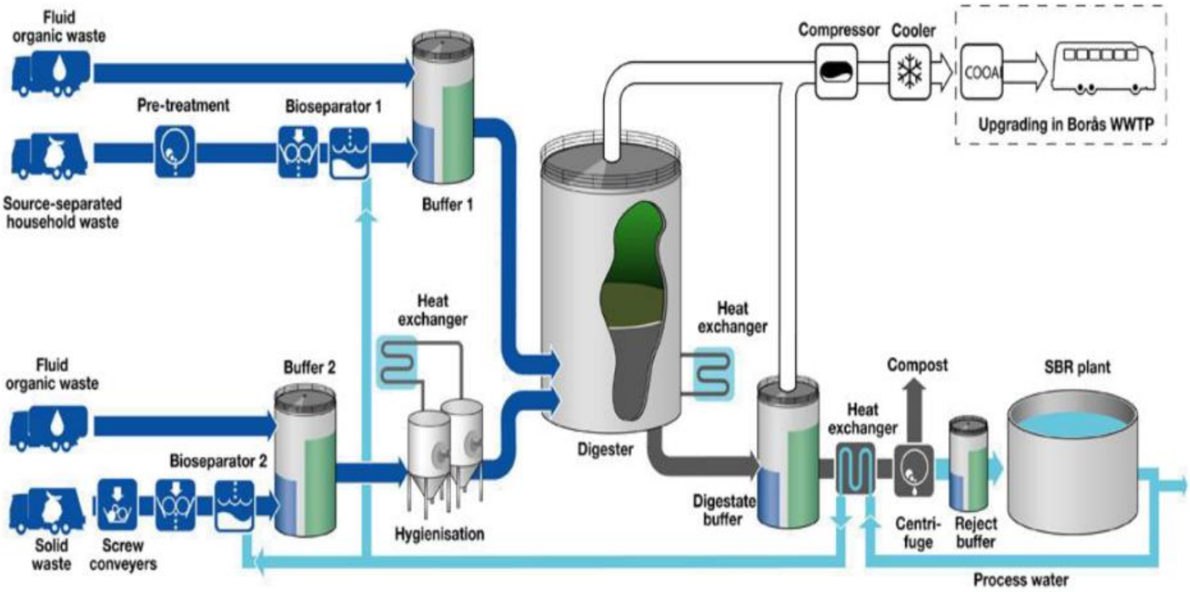


Figure 9: illustration of the biomethane production process steps at the biogas plant in Borås (Björk, 2011)

In 2009, the facility used 23,683 tons of waste to produce 2,546,629 m³ raw biogas. The waste fractions were composed of (Björk, 2011)

- 17% biodegradable waste from households from Borås
- 32% biodegradable waste from households from suburbs
- 10% biodegradable waste from trade and industry
- 41% biodegradable liquid waste from trade and industry

The biogas produced was upgraded to biomethane and utilized in following ways (Björk, 2011):

- 1,123,407 m³ biomethane as vehicle fuel
- 308,976 m³ biomethane for heating

Also in 2009, twelve waste collection trucks were operated with biomethane (as well as 59 busses from the local public transportation organisation) (Björk, 2011). Figure 10 shows a waste collection truck from Borås refilling at a CNG filling station.

Figure 10: waste management vehicle operated with biomethane at a filling station in Borås

3 Virtual biomethane

Biogas takes a special place in the field of energy carriers because of its versatility for utilization. But today, the majority of biogas is still burned directly at the plant sites in order to produce electricity and heat. However, a lot of existing biogas plants face the problem that they don't have the possibilities to use large amounts of the heat produced. This reduces the overall efficiency of the plant.

To get an energy carrier with a wider field of application, biogas can be purified and upgraded to a superior source of energy – biomethane. There are a lot of possibilities to use biogas in this form – from fuel for CNG-vehicles to household applications for heating and cooking. The way of its application is mainly defined by the current economic conditions of the region. However, for the most part biomethane is not directly utilized but injected into a local gas grid where it is mixed with natural gas. Once injected, you aren't able to separate natural gas from biomethane because the chemical composition is almost identical (nearly 100% methane [CH_4]). In this sense, one is only able to utilize biomethane in a calculated approach via certificate trading. Therefore we talk about 'virtual biomethane' (Hannesschläger, 2009).

The benefits of biomethane or virtual biogas lie not only in the location-independent usage, but also in the ability of the storage. Biogas is next to the storage of hydropower the only efficient storable renewable energy. Therefore the use of biomethane is time-independent and can provide valuable peak power or energy balance and close gaps in other renewable energies like wind and solar (Skupien, Jüly, & Koller, 2013).

4 Technical environment

In this section the technical environment will be described, which is used for the injection of biogas into the grid and for the withdrawal of biomethane from an existing grid. As the gas you are withdrawing is in principle normal methane you don't need special equipment for the withdrawal and utilization of biomethane. Therefore the focus of the latter aspect will be specifically on withdrawal for CNG filling stations.

4.1 Injection of biomethane into the local gas grid

Generally, for the injection of biomethane following technical aspects have to be planned or thought of (Adler, et al., 2014):

- Gas compression
- Gas storage
- Gas pressure regulating and metering stations
- Gas quality analysis
- Odorizing system
- Conditioning and gas mixing

4.1.1 Gas compression

At the grid injection it must be ensured that the gas is available with a higher pressure than the corresponding pressure in the gas grid at the feed point. Depending on the upgrading technology, the gas is sometimes already available with an appropriate pressure so that no further compression is necessary. However, compression of the gas takes place in the transfer station, where it is also filtered and odorized (Adler, et al., 2014).

Figure 11: gas compressors for a large time-fill CNG filling station

4.1.2 Gas storage

There are several reasons why a gas storage or buffering is required. The raw biogas is naturally subject to variations in its quantity and quality. A gas storage can help to compensate for this. Another case of a necessary storage may be buffering pulsations after the gas compression. Last but not least is a gas storage also able to homogenize the process, since it may be necessary in case of malfunctions or maintenance to store the gas temporary (Adler, et al., 2014).

4.1.3 Gas pressure regulating and metering stations

The gas pressure control systems are often combined with gas metering equipment to gas pressure regulating and metering stations so that the gas flow can be converted directly into a ‘flow rate’. If regulated to a predetermined amount of gas per unit of time, this is called flow control. In addition to the pressure regulation and flow measurement, the natural gas grid is protected by security devices against exceeding the allowable line pressure. In addition to the components for pressure control, flow measurement and safety, other plant parts are required, for example (Adler, et al., 2014)

- insulating joints,
- shut-off devices,
- filters and separators,
- possibly pre-heater and heater,
- thermometer,
- temperature sensors,
- pressure gauges,
- pressure transducers,
- power supply,
- data acquisition,
- data transmission,
- volume correctors,
- tariff devices
- and the building itself, which serves the weather protection of the components.

Figure 12 shows a transfer station in operation.

Figure 12: transfer station (Adler, et al., 2014)

4.1.4 Gas quality analysis

In order to be able to inject biomethane into a gas grid, the gas has to meet a certain quality and has to be pressurized. Here, the technical boundary conditions are defined through the existing gas grid and national regulations regarding the required quality standards for the respective gas. The quality of biomethane depends on the characteristics of the upgrading process/technology. Usually, the following quality aspects are considered in the national regulations (Adler, et al., 2014):

- Methane content
- Wobbe number
- Relative density
- Dew point and content of water
- Condensation point of hydrocarbons
- Contents of
    - Oxygen
    - Carbon dioxide
    - Hydrogen
    - Mercaptan sulphide
    - Hydrogen sulphide

Depending on the requirements and characteristics several different meters may be used (Adler, et al., 2014):

- process gas chromatographs

  for the determination of the main components as well as for the computational determination of the calorific value of the gas
- calorimeter

  for determining the gross calorific value
- density meters
- specific meters (e.g. CO_2, S, H_2, O_2)
- dew point monitor

  dew point measurement in hydrocarbons
- hygroscopes

  for determining the water dew point

Thus oxygen can be measured via an infrared measuring device, to measure paramagnetic or electrochemically. The latter is thereby the most cost effective alternative. When using a gas chromatograph it has to be ensured that they are suitable especially for biomethane. Gas chromatographs for natural gas are not suitable, because they cannot register the oxygen and hydrogen components in the gas and therefore can lead to incorrect measurements. For this reason, only approved devices must be used that include a limit value monitoring and react accordingly when the oxygen concentration is over 1% and the hydrogen concentration is over 0.2% (Adler, et al., 2014).

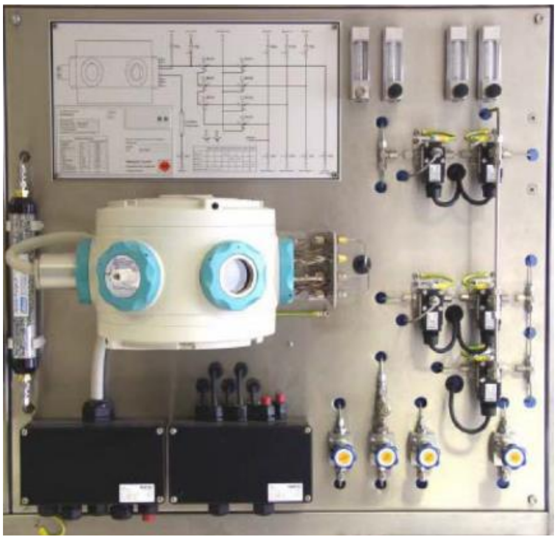


Figure 13: device for the measurement of the higher heating value (Schiffers, Vogel, & Meyer-Prescher, 2009)

4.1.5 Odorizing system

Gases, which come into the public gas supply, must be odorized to avoid danger to users and to the operating and maintenance personnel during the outflow of the odorless natural gas.

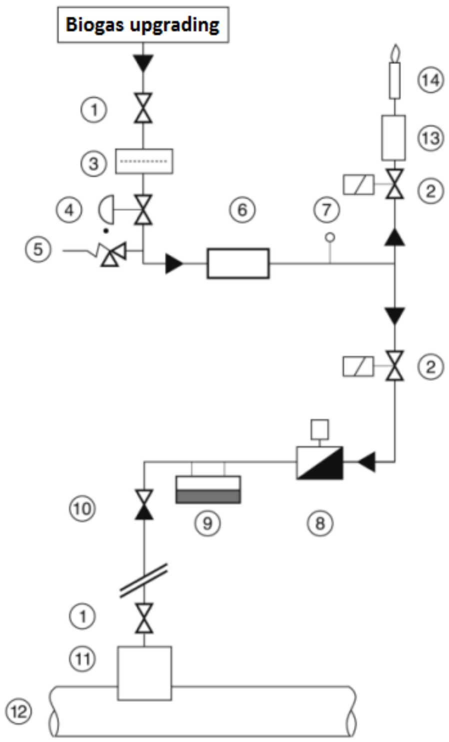
Basically, the odor perception can be categorized in 7 steps, from 0 (=imperceptible) to 6 (=extremely strong). Natural gas and accordingly also upgraded biogas have to be odorized to level 3 (=notable). This corresponds to the threshold as a warning odor which is perceived by any person with average olfactory function. The determination of the minimum amount of odorant is performed using the ‘K-value’, usually expressed in mg/m³. The amount must be chosen so that there is a constant odor level 3 before the gas concentration reaches a critical value. When feeding in transport lines odorizing the gas usually is not necessary, since these gases are not distributed directly to consumers, but are previously fed into downstream networks where odorization takes place. An odorization may also be omitted if only small quantities of gas are injected in comparison with the amounts already in the network. Odorization systems usually come with a quantity-dependent controlled dosage, wherein the odorant is introduced via an injection nozzle into the gas flow. Figure 14 shows an odorizing system in practice.

Figure 14: Odorizing system in practice (Adler, et al., 2014)

4.1.6 Conditioning and gas mixing

Conditioning and gas mixing devices normally work continuously and are used to adjust the calorific value or the Wobbe number. A consistent gas purchase should therefore be guaranteed. Significant variations of gas quantity and quality cause large effort for control. Therefore, prior conditioning is necessary. For this reason, in some circumstances an adjustment with liquefied petroleum gas (LPG) has to be made for particular gas networks, which leads to an increase of the calorific value. Since high additions of LPG lead to a reduction of the methane number, there may be a limited applicability in motor applications for the resulting gas, which has to be considered (Adler, et al., 2014).

These aspects are also illustrated in Figure 15, where a flow chart of the process from biogas upgrading to the injection of biomethane into a gas grid is shown.



1. Valve
2. Automatic valve
3. Filter
4. Gas pressure regulator
5. Safety relief valve
6. Device for determination of gas quality and heating value
7. Temperature sensor
8. Gas meter
9. Odorization
10. Check valve
11. Devices for mixture and flow control of gases
12. Gas grid
13. Fittings for the gas torch
14. Gas torch

Figure 15: Flow chart of the process from biogas upgrading to biomethane injection into the gas grid (Hofmann, 2005)

4.1.7 Case study – injection of biomethane in Bruck/Leitha (Austria)

The process of the injection of biomethane into gas grids is also shown with focus on the upgrading process on the basis of an existing facility – the demonstration plant in Bruck/Leitha in Austria. The biogas facility started operation in May 2004. Since 2007, they run an upgrading process of biogas and inject biomethane into the local gas grid. Approximately 800,000 m³ biomethane are annually injected into the grid (BMVIT, 2009). In order to upgrade biogas to biomethane, an innovative membrane technology has been implemented. The following illustration shows the process steps from production to injection.

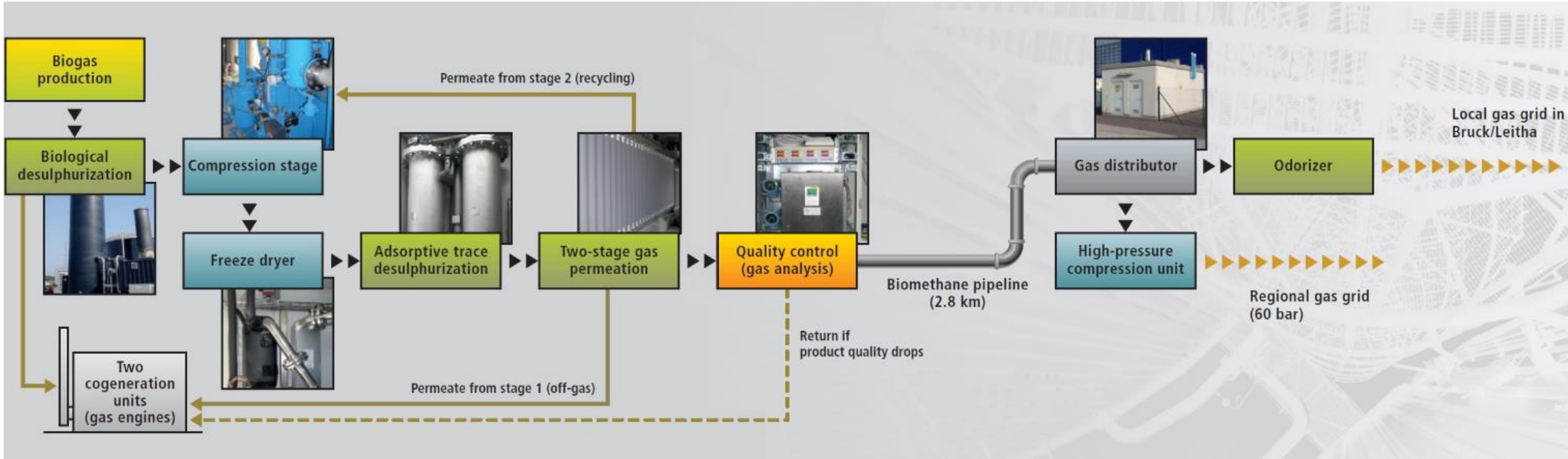


Figure 16: Process chain from biogas production to injection of biomethane into the gas grid at the biogas plant in Bruck/Leitha in Austria (adapted from BMVIT, 2009)

First of all, in a biological desulphurization the majority of sulphur is removed from the crude biogas. Then, the biogas is mixed with permeate recycled from the second membrane stage, compressed and cooled to a temperature below 7°C, which dries the gas. With waste heat from the compressor, the gas is afterwards heated to an ideal temperature for the subsequent process steps. In an adsorptive desulphurization the remaining parts of sulphur are removed to get a practically sulphur-free biogas.

For the removal of carbon-dioxide, membrane technology with a two-stage gas permeation process is implemented. This technology was chosen in order to minimize overall methane ‘losses’, which are burned in cogeneration units rather than injected into the gas grid. The permeate from stage 2, which contains considerably more methane than the permeate from stage 1, is returned to the compression stage where it is mixed with the crude gas from the biogas plant. With the removal of the permeate from stage 1 the content of carbon dioxide is taken out.

This off-gas leaves the treatment unit and is burned in a cogeneration unit in order to produce electricity and heat. As it is technically and economically not feasible to get 100% of methane in biogas through the upgrading process, the off-gas still contains a certain amount of methane, in this case about 2-3% of the biomethane produced. At the quality control stage a gas analysis is performed, where all relevant components of the gas are monitored – methane, carbon dioxide, oxygen, hydrogen sulphide and water vapour. If the product quality doesn’t meet the standards set by law, the supply line to the gas distributer is shut off immediately and the gas is passed to the cogeneration units and burned. Once the quality is satisfactory again, gas is refed into the grid. Upgraded biomethane is transported through a pipeline over 2.8 kilometres to a gas distributor, where it is pressurized and odorized and fed into the gas grid (BMVIT, 2009).

4.2 Withdrawal of biomethane for its utilization

As already stated in the introduction of this section, the gas you are withdrawing from a natural gas grid is in principle normal methane. So you don't need any special equipment for the withdrawal and utilization of biomethane in the sense of an equipment particular for biomethane. Therefore the focus of this paragraph will be specifically on withdrawal of (virtual) biomethane or natural gas for the utilization in CNG filling stations.

4.2.1 CNG – General remarks

Unlike liquid fuel, which consistently holds about the same volume of fuel across a broad range of conditions, compressed natural gas (CNG) can expand and contract significantly depending on temperature. For example, under industry standard conditions, a CNG tank on a vehicle may be able to hold the equivalent of 75 litres of diesel, but on a hot day the gas will expand and the tank may only fill to 75% (or less) of its potential. The newer, fast-fill dispensers equipped with a temperature compensation feature help vehicles get the best fill possible (U.S. Department of Energy, 2016).

The following aspects determine the amount of CNG that can be stored in a vehicle's tank (U.S. Department of Energy, 2016):

4.2.1.1 Filling rate

As the rate of filling increases, the temperature of the fuel also increases - dramatically. As the fuel warms up, it expands and becomes less dense, therefore containing less energy by volume when the fuel system reaches the rated pressure. For this reason, you are usually able to get more CNG into a tank with a time-fill versus a fast-fill application (see 4.2.2). This is because when gas molecules are compressed they create heat. The faster they are compressed, the more they heat up and expand. So when you compress the gas rapidly by using a fast-fill station, the molecules will heat up and expand more than if filled slowly over time.

4.2.1.2 Ambient temperature

The outside temperature affects the temperature of the CNG. At higher temperatures, CNG is less dense, and therefore does not contain as much energy per unit volume as it would at a lower temperature. When the CNG is stored in warm ambient temperatures, it expands and becomes less dense, so when the tank reaches the rated pressure, the CNG inside does not contain as much energy as it would at lower temperatures.

4.2.1.3 Pressure rating

The typical industry standard for CNG filling system pressure is 250 bar (based on 21°C ambient temperature). The cylinders are actually designed to hold up to 125% of their operating pressure. Thus, a 250 bar tank can be filled to 312 bar and a 300 tank can be filled to 375 bar. This makes it possible to fill a tank to a higher pressure on hot days when the gas is expanding, as well as compensate for the heat of recompression.

4.2.1.4 Cylinder type

There are four types of cylinders. They differ in the way the cylinder is made and the material it is made out of (aluminium, steel, carbon fibre, etc.). The material used to make the cylinder also affects the temperature in the tank, and thus, affects how 'full' you can fill the tank. For example, carbon fibre tanks hold heat better than steel tanks.

4.2.2 Types of filling stations

Generally there are two types of filling stations for compressed natural gas: fast-fill-stations and time-fill-stations. The main difference between these two technologies are the storage capacity and the size of the compressor, which determine the amount of fuel dispensed and the time it takes for the fuel to be delivered (U.S. Department of Energy, 2016).

4.2.2.1 Fast-fill

Generally, fast-fill stations are best suited for retail situations where cars and light-duty vehicles arrive randomly and need to fill up quickly. The space needed to store the equipment is about the size of a parking space. CNG can also be delivered via dispensers alongside gasoline or other alternative fuels dispensers. Fast-fill stations receive fuel from a local gas grid at a low pressure and then use a compressor on site to compress the gas to a high pressure. Once compressed, the CNG is available for a quick fill-up. Drivers filling up at a fast-fill station experience similar fill times to a conventional gasoline filling station. CNG at fast-fill stations is often stored in the vessels at a high service pressure (300 bar), so it can deliver fuel to a vehicle faster than the fuel coming directly from the compressor, which delivers fuel at a lower volume. Drivers use a dispenser to transfer CNG into the tank. The dispenser uses sensors to calculate pressure and measures the amount of gas delivered to the tank, taking temperature into account (U.S. Department of Energy, 2016).

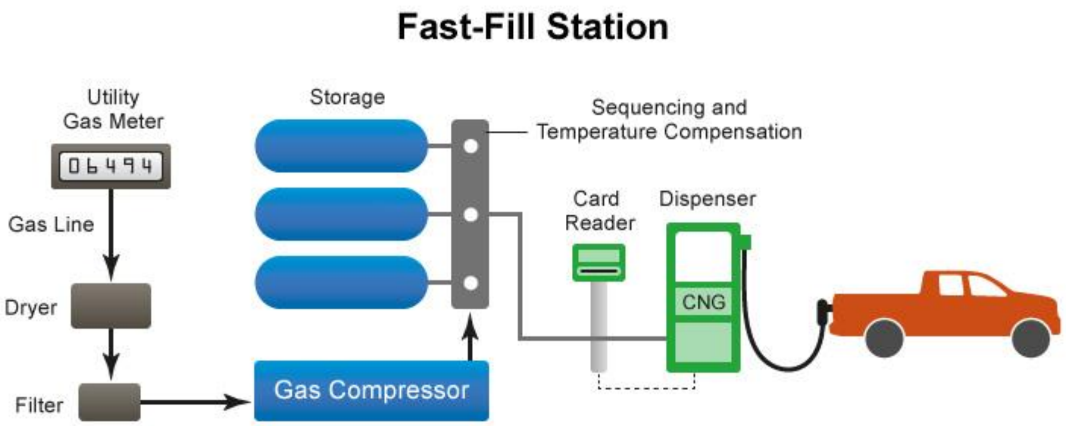


Figure 17: Example of a fast-fill compressed natural gas station configuration (U.S. Department of Energy, 2016)

4.2.2.2 Time-fill

Time-fill stations are used primarily by company fleets (e.g. waste management vehicles) and work best for vehicles with large tanks that refuel at a central location every night. At a time-fill station, a gas pipeline from a local gas grid delivers fuel at a low pressure to a compressor on site. Unlike fast-fill stations, vehicles at time-fill stations are generally filled directly from the compressor, not from fuel stored in tanks. The size of the compressor needed depends on the size of the fleet. Although there is a small buffer storage tank, its purpose is not to fill vehicles, but to keep the compressor from turning off and on unnecessarily—wasting electricity and causing undue wear and tear on the compressor.

The time it takes to fuel a vehicle depends on the number of vehicles, compressor size, and the amount of buffer storage. Vehicles may take several minutes to many hours to fill. The advantage of using a time-fill station is that the heat of recompression is less, so you usually get a fuller tank than with a fast-fill station. Also, with a time-fill station you can control when you fill the vehicles. This means you can choose to run the compressor during off-peak hours (like at night) to achieve lower electricity rates.

Time-fill stations are carefully architected based on the application they will be used for. For example, a transit bus company may need a larger compressor, while a waste management company can use a smaller compressor. These differences account for the large variance in the cost of installation (U.S. Department of Energy, 2016).

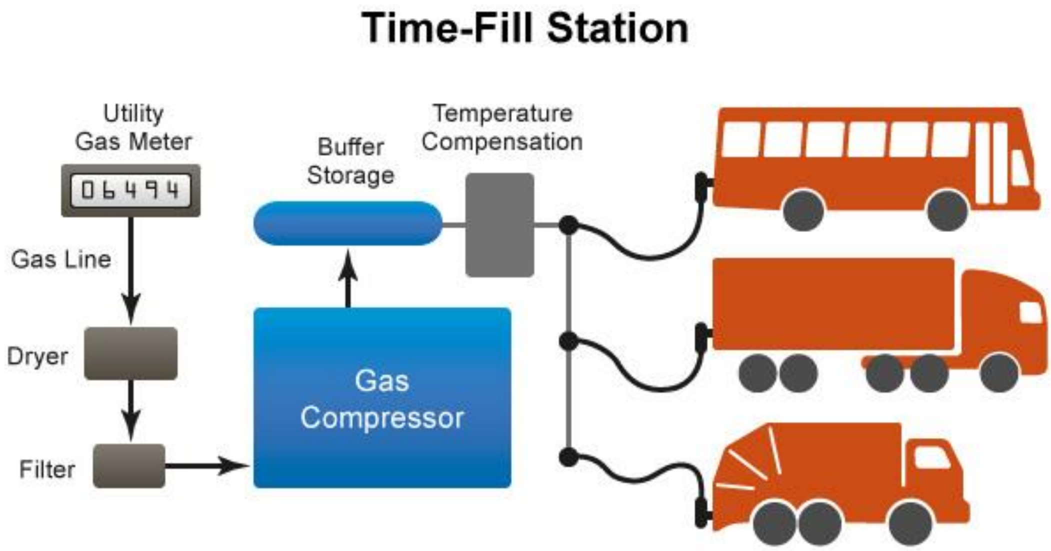


Figure 18: Example of a time-fill compressed natural gas station configuration (U.S. Department of Energy, 2016)

4.2.2.2.1 Case study – Time-fill station in Lille (France) for public transport

The public transport company Transpole in Lille (France) is operating their busses on 100% CNG (approximately 450 busses). They built a time-fill CNG station next to a waste biogas plant, where organic waste from the region of Lille is converted into biogas and injected into the gas grid.

The filling station processes about 20,000 m³ and allows to fill about 150 busses at once. The station is supplied both by the gas grid and the waste biogas plant. Three compressors processing 2,000 m³/h at 200 bar are used. Furthermore, a thermic camera is used to detect possible leaks.

The consumption of gas does not match the production of the biogas plant, since the filling occurs between 6 pm and 2 am and the production varies over the year (fluctuation of green waste production), therefore additional natural gas has to be taken from the natural gas grid. A time-fill-process is used, busses being filled overnight. The filling time depends on the number of buses to be filled. Buses can drive about 250-300 km with a full tank.

In the evening, a maintenance team cleans and fills the buses. In the morning, drivers come and take the busses. No specific training is required for maintenance.

Economic boundary conditions:

- Bus: 250,000 € (400,000 € for a bus with full equipment)
- Maintenance costs: 15% more expensive than diesel
- Biogas as fuel is cheaper than diesel

Figure 19: Time-fill station for the public transport busses

4.2.3 Basic technical equipment of natural gas filling stations

Unlike gasoline or diesel station, compressed natural gas filling stations are not ‘one size fits all’, which means that the main components of a gas filling station have to be thoroughly planned and constructed as the interaction of these elements define the performance of the filling station (U.S. Department of Energy, 2016). Today, standard natural gas filling stations have a capacity to supply 60 to 80 cars per day with fuel (Zukunft Erdgas GmbH, 2016).

In the following the basic components of a gas filling station are described:

4.2.3.1 Gas dryers

Gas dryers are needed to reduce the moisture content of the gas. Usually, station inlet drying is preferred over high-pressure drying. Inlet dryers have various advantages over outlet dryers, including a lower capital cost and lower operating and maintenance costs. They are also safer because drying is done at low pressures. To reduce capital and maintenance costs, a single tower dryer with a manual regeneration system can be used in many small- to medium-sized CNG stations (Adams, 2016).

Figure 20: Single tower dryer (Adams, 2016)

4.2.3.2 Compression system

Gas filling stations are mainly located in urban regions, where they are connected to gas grids with a lower pressure level than the transregional distribution systems. Usually gas is withdrawn at filling stations with a pressure in a range from some millibar to over 20 bar. The pressure used for storage and filling is about 250-300 bar, so at the first step the gas withdrawn is pressurized up to 300 bar (Zukunft Erdgas GmbH, 2016).

Figure 21: CNG compressors installed in Dublin at a public natural gas filling station (Ariel Corporation, 2016)

4.2.3.3 Gas storage

At CNG filling stations, compressed natural gas must be stored in storage systems in order to make the utilization of the station more efficient. There are two systems for storing natural gas – buffer and cascade storage systems. In buffer storage, CNG is stored at single high-pressure reservoirs. The cascade storage system is usually divided into three reservoirs, generally termed low, medium and high-pressure reservoirs (Farzaneh-Gord, Deymi-Dashtebayaz, & Rahbari, 2011).

Storage vessels should have a minimum design pressure of 380 bar and should be equipped with condensate drains. Generously sized storage will improve station performance and reliability (Adams, 2016).

Figure 22: Compressed natural gas storage vessels (CNG Center, 2016)

4.2.3.4 Pipeline

Natural gas is transported through pipes either underground or overground from the storage to the dispenser. These pipes have to be resistant to high pressure so the problem-free transport of pressurized natural gas with up to 300 bar can be ensured (Zukunft Erdgas GmbH, 2016).

Figure 23: CNG conventional high pressure pipe (LOMANI AUTO GAS, 2016)

4.2.3.5 Fuel dispenser

Today, there are many different types of dispensers from various producers available on the market. The capacity of the dispenser installed is determined at the planning stage. Common dispensers on the market have a mean filling capacity of about 6-7 kg per minute. Which means, that a car with a 20-kg-tank is filled in 2-3 minutes (Zukunft Erdgas GmbH, 2016). Some manufacturers on the EU-market for gas filling station equipment and dispensers are listed in another part of the project, namely the 'report on good practice of biomethane usage as a transportation fuel' (Doczekal, et al., 2015).

Figure 24: Common CNG dispenser (Censtar Science & Technology Co., Ltd., 2016)

5 Purchase and disposal of biomethane through a local gas grid

The regulation and administration of the process from biomethane injection into a gas grid to the consumption of virtual biomethane at some point of withdrawal differs from country to country. However, the overall procedure of injection and virtual withdrawal is pretty much the same, the main differences occur in details of administration of these procedures.

Even so, it has also to be taken into account that there might be considerable obstacles for the injection of biomethane from the beginning. These aspects might influence the economic boundary conditions on the one hand and on the other hand might even render the grid injection of biomethane impossible. In this sense, especially following issues have to be taken into consideration:

- **Access to the natural gas grid (network topology, restrictions of area)**

  What is the distance to the local natural gas grid? Is a connection technically even possible? Under which economic conditions?

- **Gas quality** (see 4.1)

  What are the requirements for the gas quality? Under which conditions is it possible to abide by the prevailing regulations regarding security, technique of application or settlement?

- **Conditions of the local natural gas grid**

  Even if the injected gas meets all the prevailing quality requirements, there is another requirement, which is as important as quality standards – there has to be a demand for the injected gas. Especially in times of low load in the grid, a biogas plant may provide more gas than the connected consumers might consume. This may lead to fluctuating upper limits for the amount of gas injected. The fluctuation can be subject to daily or seasonal load profiles. In extreme cases these variations in supply and demand can lead to temporary stops of grid injection.

  In this sense, the biggest obstacle here is the particular structure of the customers, which leads to these fluctuations in gas consumption. As the gas grid operators are not able to store the gas arbitrary, but pass the gas only through the network, the conditions of the gas grid connected with the available capacities for biomethane injection are strongly depending on the consumption from the respective customers.

  For a first estimation on the conditions of the local natural gas grid it is necessary to look at minimum load of the grid. These benchmark can already give you some information of the structure of the customers connected to the grid (Ramesohl, et al., 2006). Figure 25 shows the load profile of a local natural gas grid with a considerable share of industry. The fluctuations are shown depending on time and on different daily average temperatures.

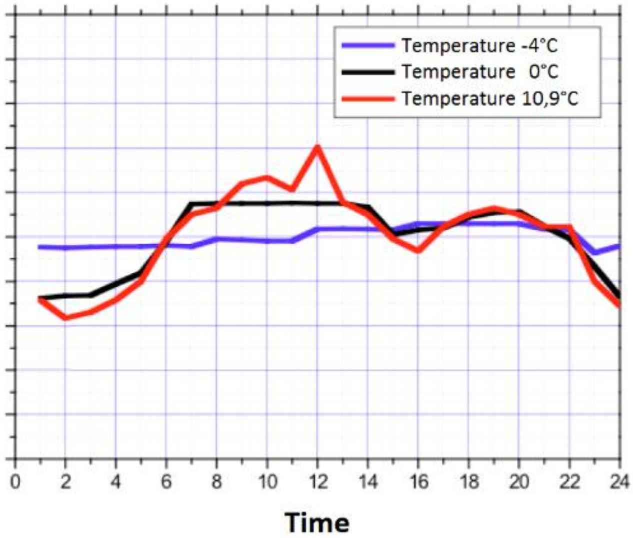


Figure 25: illustration of the load profile of a local natural gas grid with a considerable share of industry (modified after Ramesohl, et al., 2006)

Problems with the grid capacity might occur in rural regions in summertime, when there are relatively high amounts of biomethane on the one hand and a low population density with small demand of gas on the other hand (Ramesohl, et al., 2006).

Usually, in more urban regions, grid capacities don't play a big role, as the grids in these regions are able to buffer grid injections of biomethane better.

5.1 Administrative and legal conditions

Biomethane transport makes use of the natural gas infrastructure and thus underlies partly the rules of national gas trade. This requires calibrated metering and energy balancing.

Biomethane distinguishes from natural gas by an important feature: it is renewable and has the green feature. To keep track of this valuable characteristic after having been mixed with fossil natural gas, a tracking mechanism is needed. Mass or energy balances serve reliable and complete retracing of biomethane from its production site to the final consumer. They can serve various purposes (Strauch, Krassowski, & Singhal, 2013)

- Providing proof of the green feature
- Keeping track of the parameters related to the gas production that are relevant for financial support (kind of substrates used, plant size, certificate for complying with emission limits, energy efficiency of the plant etc.)
- Avoiding doubled sale

Therefore, several countries already established its national tracking system, which is called in some countries biogas register or biomethane register.

Biomethane trade predominantly takes place in the country of its production. There are only a few examples of physical cross border biomethane trade, e.g. from Germany to Sweden, and to the Netherlands as well as from the UK to the Netherlands. If the market is not balanced, meaning demand exceeds supply or vice versa, cross border trade is able to increase flexibility and transfer biomethane where it is needed. Barriers are often created by the different national regulatory frameworks, but they can be removed by harmonising the national tracking systems which means that two different biogas registers are able to exchange biomethane amounts from the country of production to the country of final consumption (Strauch, Krassowski, & Singhal, 2013).

The legal framework for biomethane purchase and disposal through a local gas grid is different in each European Country. Some frameworks only go so far to not prevent biomethane-injection and just regulate a non-discrimination of biomethane. On the other hand, legal frameworks of other countries are already very advanced and detailed in terms of gas quality and the administration of the whole process. The directives and laws implemented in each country have been investigated during this project and documented in the 'report on good practice of biomethane usage as a transportation fuel' (Doczekal, et al., 2015). Therefore, the focus of this section is on administrative procedures of biomethane injection and withdrawal.

The following paragraph describes how the administration of the injection through the biomethane register may work for countries with progressive legal regulations, based on regulations of the biomethane register in Austria (AGCS Gas Clearing and Settlement AG, 2016):

1. A biomethane producers injects the produced and upgraded biomethane into the local gas grid.
2. At the very moment the biomethane enters the gas grid, it merges into the gas grid and can be (calculatory) withdrawn at any point of the gas grid.
3. Every biomethane producing plant, which injects biomethane in the gas grid, is registered at a control authority. However, the control authority doesn't register any prices for biomethane. The prices are subject to negotiations between producer and consumer.
4. The amount of biomethane injected into the grid is measured by the grid operator and reported to the control authority once per month.
5. Based on this information, the control authority produces the biomethane certificates for the biomethane producer.
6. The biomethane producer gets the certificates from the control authority. The certificates can be sold to any consumer of gas from the gas grid. Thus, the physical disposal of biomethane is separated from the disposal, which takes place on a market level.
7. The biomethane certificates are also listed at the online system of the biomethane register, where a surveyor examines and validates every record in terms of amounts produced, origin and so on.
8. In order to get the subvention for green energy, biomethane producers have to transfer these validated records to the relevant authority.
9. With the certification system and the validation process of the biomethane register, the consumer can be sure that the gas, which was injected into the grid, meets the high requirements for biomethane according to the standards.

Through a biogas monitoring register and through the transfer of relevant evidence it is ensured that a certain amount of biomethane meets the criteria for biomethane. This simplifies the biomethane trade especially in the case, when producers and consumers of biomethane are no longer in a direct contractual relationship, which is the case when biomethane is traded over one or more intermediaries. The purchaser of biomethane can be reasonably sure that the biomethane comes from a plant which produces biomethane meeting the criteria set by law. In this sense, the certificate trading scheme of biogas registers replaces the personal knowledge of the contractor and the production circumstances, thus creating the necessary trust for business in trade chains.

Figure 26 illustrates this functioning principle of a biomethane register. In this illustration you can see basically the administration of the injection and withdrawal of biomethane described in the preceding paragraph with the difference that this scheme includes a trading person between the producer and consumer, which is also a possible option for the management of a biomethane register.

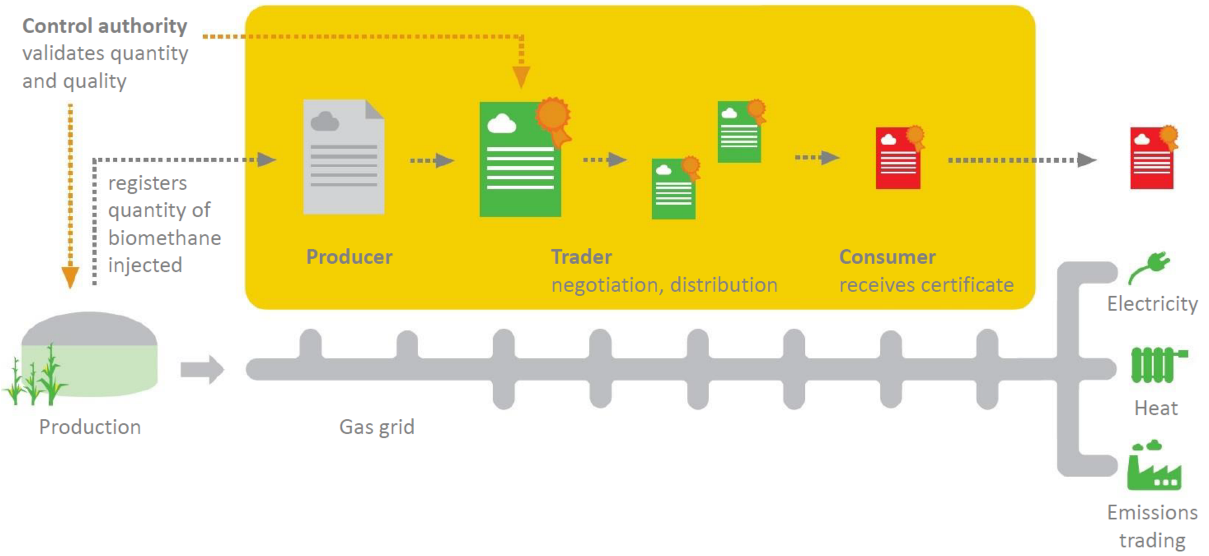


Figure 26: functional principle of the biomethane register in Germany (modified after Deutsche Energie-Agentur GmbH, 2016)

5.2 Non-technical barriers for the grid injection and the utilization of biomethane as transport fuel

The well planned and structured gas network in Europe offers in principal good conditions for the trade of biomethane across the borders. There is a growing interest in biomethane in many European countries, which is reflected through clear aims for biomethane in the field of energy carriers or through the implementation of incentives for biomethane. These promotional measures include feed-in tariffs for example in France and Great Britain or tax exemptions for biomethane as fuel in Sweden. Meanwhile new biomethane production plants have emerged in several European countries, by the end of 2014 there were around 330 plants in Europe which upgraded biogas to biomethane (Deutsche Energie-Agentur GmbH, 2015).

But the international trade of biomethane is still in its infancy. In many countries, imported biomethane is completely or partially excluded from national support mechanisms. Nor are there any uniform standards and procedures regarding properties and evidence of biomethane (trade) and how the information is transferred between the countries. Currently some biogas or biomethane registers are in collaboration with other European registry systems to reduce these barriers and to establish a transparent biomethane trading in Europe (Deutsche Energie-Agentur GmbH, 2015).

These aspects illustrate some of the existing non-technical barriers for the grid injection and the utilization of biomethane as transport fuel in Europe. As mentioned, there is already put some effort in the reduction of these barriers.

However, one particularly problematic issue is the large number of different stakeholder groups who have to contribute to achieving the targets: Vehicle manufacturers and dealers, research institutes, the gas industry (incl. biomethane producers), the petroleum industry with its filling station network, policy makers and finally the final consumers with their multiplicity of mobility needs (Deutsche Energie-Agentur GmbH, 2010). These interactions of the mentioned stakeholders is presented in Figure 27.

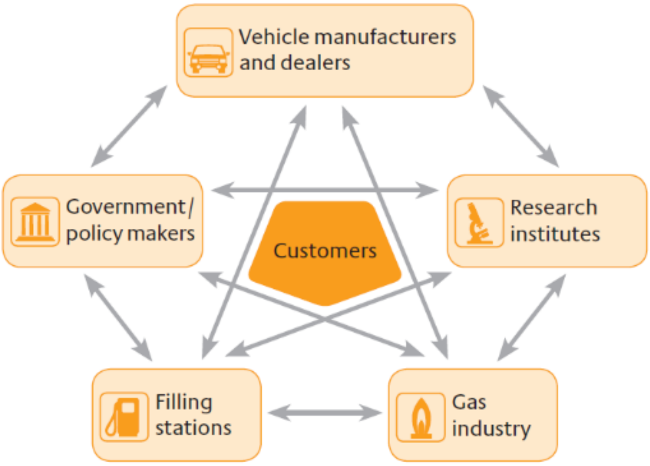


Figure 27: relevant stakeholder groups in establishing biomethane as transport fuel (Deutsche Energie-Agentur GmbH, 2010)

In the following a graphical summary of possible measures for reducing the named non-technical barriers is given. Figure 28 shows a catalogue of measures for the increase of the market share of biomethane in national energy mixes, especially in the transport sector, put together by the German Energy Agency.

<table>
<tr><th></th><th colspan="3">User groups</th></tr>
<tr><th>Purchasing criteria</th><th>Private</th><th>Commercial</th><th>Public</th></tr>
<tr><td rowspan="5">Differentiated range of vehicles and good marketing</td><td colspan="2">Provision of natural gas vehicles to cover all relevant brands and segments</td><td></td></tr>
<tr><td>Intensification of marketing efforts and consumer sales offensive (e.g. dealer training/incentivisation)</td><td>Intensification of marketing efforts and key account customer sales offensive</td><td></td></tr>
<tr><td></td><td>Consistent introduction of natural gas vehicles into own fleets</td><td>Consistent introduction of natural gas vehicles into own fleets by changing tendering practices (e.g. including public transport)</td></tr>
<tr><td colspan="3">Intensification of customer information campaigns about alternative motor fuels</td></tr>
<tr><td colspan="3">Feed-in and marketing of biomethane</td></tr>
<tr><td rowspan="4">Small purchasing price differential</td><td colspan="3">Modification of pricing policy (e.g. sales promotion)</td></tr>
<tr><td colspan="3">Modification of cost structure, for instance by research and development into vehicle natural gas components</td></tr>
<tr><td>Creation of public purchasing incentives (e.g. by scrappage scheme)</td><td rowspan="2">Differentiation of company car taxation on a CO_2 basis, including preferential tax treatment of energy-efficient natural gas vehicles</td><td rowspan="2">Promotion of conversion of municipal fleets (e.g. by subsidies)</td></tr>
<tr><td>Establishment of reduced interest rate loans for purchasing particularly energy-efficient vehicles</td></tr>
<tr><td rowspan="5">Low running costs (in particular fuel costs)</td><td colspan="3">Updating of federal government's fuel strategy, e.g. early continuation of energy tax relief for natural gas and biomethane as motor fuels and further development towards CO_2-based taxation of motor fuels</td></tr>
<tr><td colspan="3">Research into the climate advantages of biomethane as motor fuel</td></tr>
<tr><td colspan="3">Establishment of a technology-neutral "high efficiency vehicle" label with CO_2 thresholds or classes as the basis for straightforward and indisputable incentivisation of energy-efficient vehicles</td></tr>
<tr><td>Consumer-friendly changes to how motor fuel prices are stated, ensuring better comparability between the increasing number of different transport energy sources which will in future be available</td><td>Preferential treatment of energy-efficient taxis, e.g. natural gas fuelled, at railway stations, airports etc.</td><td>Introduction of key account customer tariffs for municipal fleet fuelling</td></tr>
<tr><td colspan="2">Free inner city parking for particularly energy-efficient vehicles</td><td></td></tr>
<tr><td rowspan="6">Dense filling station network and large vehicle range</td><td colspan="2">Demand-led extension of natural gas filling station network</td><td></td></tr>
<tr><td colspan="2">Stepping up the availability of natural gas filling stations along the federal motorways</td><td></td></tr>
<tr><td colspan="2">Increasing the visibility of natural gas at filling stations and uniform branding of this fuel</td><td></td></tr>
<tr><td></td><td colspan="2">Promotion of construction of filling stations at vehicle depots</td></tr>
<tr><td colspan="2">Increasing vehicle range in natural gas operation to the level of petrol vehicles</td><td></td></tr>
<tr><td></td><td>Introduction of common fuel cards for natural gas</td><td></td></tr>
</table>

Government/policy makers · *Filling stations* · *Gas industry* · *Vehicle manufacturers and dealers* · *Research institutes*

Figure 28: catalogue of measures to increase the market share of biomethane in national energy mixes, especially in the transport sector (modified after Deutsche Energie-Agentur GmbH, 2010)

5.3 Purchase and disposal of virtual biomethane from the viewpoint of biomethane producers

This market system of virtual purchase and disposal of biomethane includes among other things following advantages from the viewpoint of the producers (Wolf, 2012):

- A better marketability for biomethane
- Increase of the number of potential purchasers
- Better transferability of biomethane
- More fields of application for biomethane as a renewable energy carrier (the utilization is not bound to the local environment of production)

5.4 Purchase and disposal of virtual biomethane from the viewpoint of operators of filling stations

Advantages from the viewpoint of filling station operators (Wolf, 2012):

- Possibility to provide a green energy carrier – biomethane
- Easy administration and transfer of biomethane certificates
- Standardised market procedures

6 Economic approach

Overall, the production of biomethane is not mainly a question of technology or know-how, but strongly dependent on economic boundary conditions, which may vary to a high extent between countries or even within countries. Therefore the following section aims to describe these boundary conditions and give a guidance for first estimations on cost factors regarding biomethane production and utilization. Today, these estimations or calculations can be done computer-aided for different degrees of detail.

In 6.1 existing and free-available economic models are presented for various observations on economic boundary conditions.

In the course of this report a biomethane tool for economic analysis of biogas production, gas upgrading and utilization of biomethane was created, which is available on the project homepage. The development and functioning principle of this tool is described in paragraph 6.2.

In 6.3 the economic boundary conditions for biomethane producers and for operators of CNG filling stations are described.

6.1 Existing economic models

In the area of biomethane upgrading and for various ways of utilization there are already some technical/economical models available with different levels of quality and detail. In this paragraph some of these tools are shortly described to give an overview on already available models.

6.1.1 CNG ROI Calculator

The CNG Center (cngcenter.com) provides an online calculation tool for companies who want to convert their internal vehicles into natural gas vehicles and/or run an own CNG filling station (CNG Center, 2016).

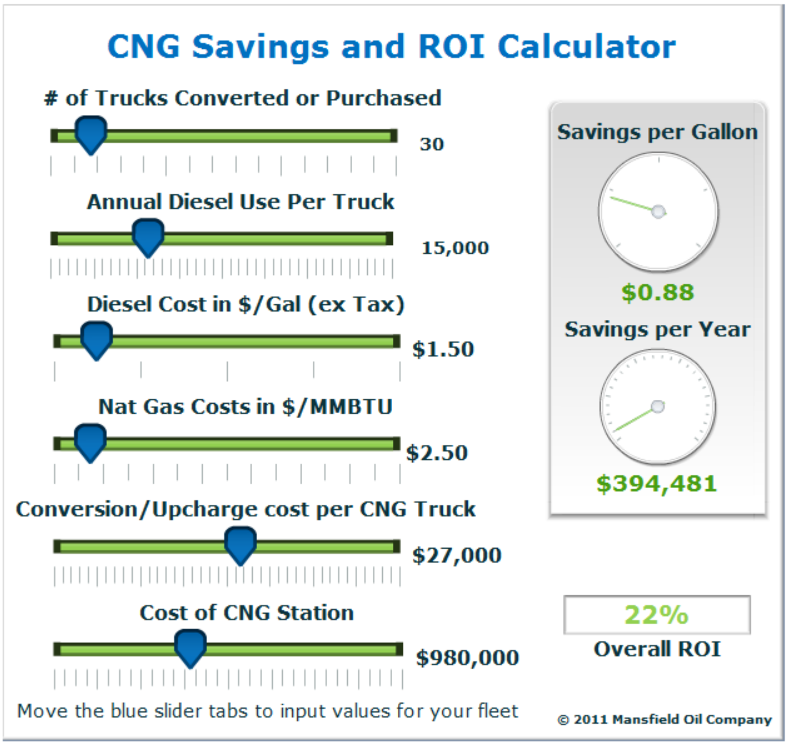


Figure 29: CNG ROI calculator from cngcenter.com (CNG Center, 2016)

The changeable parameters are the number of vehicles converted or purchased, the annual diesel use per vehicle, diesel and gas costs, conversion costs of the vehicles and costs of the CNG filling station.

6.1.2 Biomethane calculator

The Technical University of Vienna developed in the course of an EU-funded project 'bio-methane regions' a calculation tool to evaluate economic conditions for a biomethane upgrading plant with grid injection. The calculator is shown in Figure 30 and can be downloaded here: http://bio.methan.at/en/download_biomethane-calculator

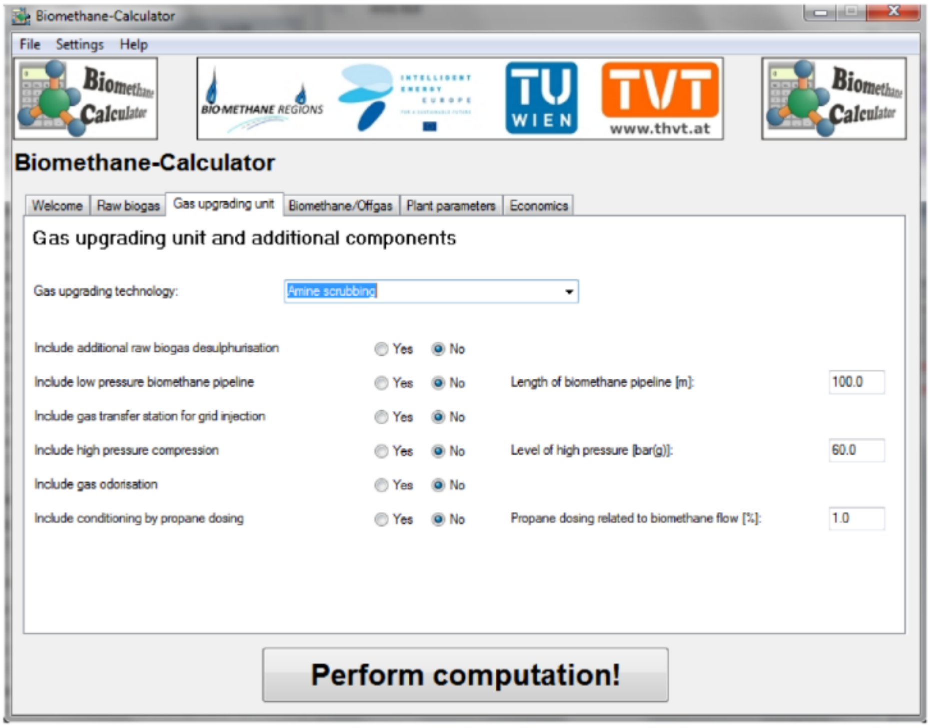


Figure 30: Biomethane calculator for technical and economical assessment (Bull, 2016)

6.1.3 Vehicle and Infrastructure Cash-Flow Evaluation Model

The U.S. department of energy offers a model for economic evaluation of CNG vehicles and infrastructure (http://www.afdc.energy.gov/vice_model/). It was developed for fleet managers to assess the financial soundness of converting their fleets to run on CNG.

The model is implemented in an Excel tool, where you can make a lot of specifications and, in this way, get relatively detailed results on your project. Figure 31 shows a part of the user interface of the model.

Section 4 - Infrastructure, Fuels, Operations, and Incentives

Infrastructure	Cell Name	Value	Unit	Default
CNG Station Salvage Value	CNG_Station_Salv	20%	% of original price	20%
Monthly Cost of Hostler	Hostler_Cost	$0,00	$/month	$4.167
Infrastructure tax credit rate	infra_tax_credit_rate	0%	percent	0%
Infrastructure tax credit cap	infra_tax_credit_cap	$30.000	$	$30.000
realized infrastructure tax credit	infra_tax_credit_realized	$0	$	Calculated
Fuels				
Alt Fuel Excise Tax Credit	Excise_Tax_Credit	$0,00	$/GGE	$0,00
Realized Alt Fuel Excise Tax Credit	Realized_Excise_Tax_Credit	$0,000	$/GGE	Calculated
Price of CNG (per GGE)	CNG_Price	$2,09	$/GGE	$2,09
CNG Price Increase	CNG_Inflation	2,7%	% per year	2,7%
CNG Lifecycle Greenhouse Gas Factor (per GGE)	CNG_GHG	22,5	lbs/GGE	22.5 lbs
Diesel Fuel Price	Diesel_Price	$3,91	$/gallon	$3,93
Diesel Price Increase	Diesel_Inflation	2,5%	%/year	2,5%
Federal Diesel Excise Tax	Fed_Diesel_tax	$0,244	$ per gallon	$0,244
State Diesel Excise Tax	State_Diesel_Tax	$0,195	$ per gallon	$0,195
Realized Diesel Excise Tax Exemption	Diesel_tax_exempt	$0,000	$ per gallon	Calculated
DGE/GGE Conversion factor	GGE_DGE_Conv	0,904	DGEs per GGE	0,904
Diesel Lifecycle Greenhouse Gas Factor (per GGE)	Diesel_GHG	25,4	lbs/GGE	25.4 lbs
Gasoline Fuel Price	Gasoline_Price	$3,45	$/gallon	$3,450
Gasoline Price Increase	Gasoline_Inflation	2,1%	%/year	2,1%
Federal Gasoline Excise Tax	Fed_Gas_tax	$0,184	$ per gallon	$0,184
State Gasoline Excise Tax	State_Gas_Tax	$0,214	$ per gallon	$0,214

Figure 31: Vehicle and Infrastructure Cash-Flow Evaluation Model of the U.S. department of energy (U.S. Department of Energy, 2016)

6.2 Development of a model

In this project a biomethane tool was developed for economic analysis of biogas production, gas upgrading and utilization of biomethane. The model was developed in Microsoft Excel, so that it is, in terms of technical accessibility, available for as many users as possible. The model is disseminated mainly through the homepage, where it is available for download.

As this tool might be used by various stakeholder groups – from experienced ones to stakeholders with a rather superficial knowledge in these topics – the requirements for the model have been set as follows:

- easy to use
- as little user input as possible to avoid errors (but options for advanced input/analysis)
- resistant to failure
- should be both useful for a rough estimation and for detailed analysis
- easy mode & expert mode

The present technic/economic biomethane tool aims to help planners in an early stage of project development to estimate costs of biogas production, gas upgrading and different ways of biomethane utilization and is developed to quickly get a first idea on economic conditions in these areas. It is designed for a rough estimation of investment, operating and production costs of different facilities on the various process steps from waste/substrate to biomethane utilization. Figure 32 shows the title page and the introduction section of the biomethane model in Excel. The introduction includes also a user manual. In the following the functioning principle of the biomethane tool is explained step by step to get an insight of how the model works.

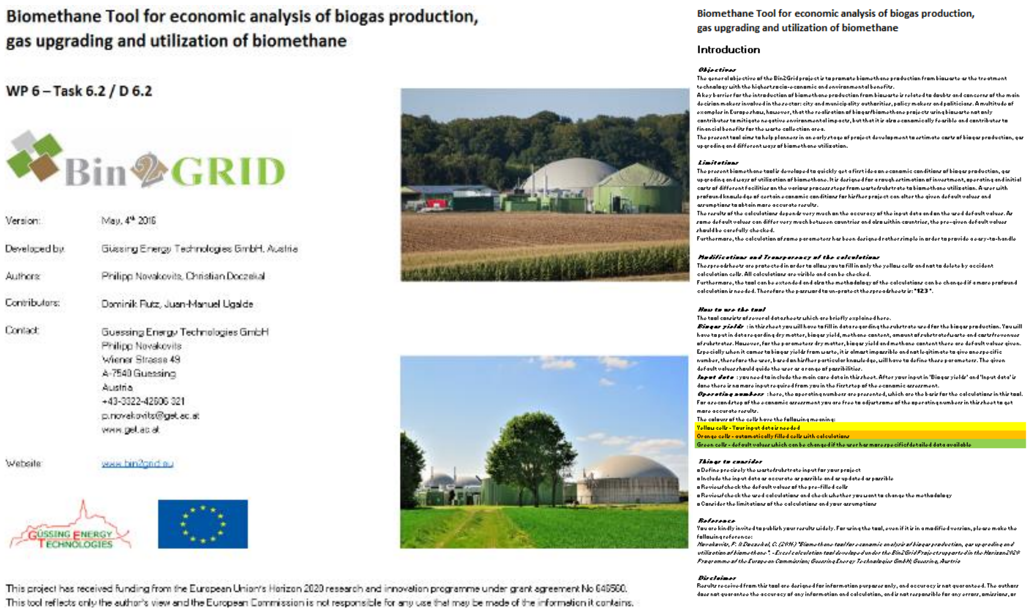


Figure 32: title page and introduction (with user manual) of the biomethane model

In the first step the user has to fill in data regarding the substrate for the biogas production. It is required to put in data of dry matter content, biogas yield of the substrate, methane content, amount of substrate and costs for the substrate (if substrate is for example agricultural feedstock) or revenue for the substrate (if substrate is waste and you get a fee for disposal of the waste). However, as the tool should be useful for as many people as possible, it doesn't limit the range of substrates only to biowaste. In this sense there are default values given for a wide range of substrates in following areas:

- Waste from the food industry
- Waste from beverage industry
- Vegetables, greens, grass
- Waste from households and canteens
- Animal by-products
- Manure

The given default values are mainly taken from the Bin2Grid report in work package 2: 'Catalogue of food waste types and energy potential'. Figure 33 shows the table for the input of substrates in the Excel tool.

		Default values			Actual values									
Waste category	Substrates	Dry matter	Biogas yield	Methane	Dry matter	Biogas yield	Methane	Amount of substrate	Cost of substrate	Revenue for waste	Total biogas yield	Total methane yield	Total costs	Total revenues
		[%]	[m³/t]	[%]	[%]	[m³/t]	[%]	[t FM/a]	[€/t FM]	[€/t FM]	[m³/a]	[m³/a]	[€/a]	[€/a]
Waste from the food industry	Mash from fruits	3-5	250 - 540	63							0	0	0	0
	Mash from distillations	3-8	400 - 450	62							0	0	0	0
	Cereal mash	5-8	80 - 100	63							0	0	0	0
	Potato mash, potato pulp	5-16	250 - 800	55							0	0	0	0
	Potato pulp dried	85	500 - 600	55							0	0	0	0
	Oilseed residuals, pressed	90	420 - 720	66							0	0	0	0
	Wheat flour	86	540	58							0	0	0	0
	Malt germ	90	580	55							0	0	0	0
	Baking waste	60 - 80	400 - 500	62							0	0	0	0
	Whey	4-6	50 - 140	58							0	0	0	0
	Skimmed milk, dry	75	400 - 520	60							0	0	0	0
	Cheese	30	320	58							0	0	0	0
Waste from beverage	Grains	20 - 25	180 - 300	60							0	0	0	0
	Grains, dry	90	550	62							0	0	0	0
	Apples	22 - 40	420 - 510	68							0	0	0	0
	Apple mash	2-5	420	60							0	0	0	0
	Fruits, mixed	25 - 45	400 - 650	68							0	0	0	0
	Vinasse from alcohol	8-12	50	55							0	0	0	0
Vegetables, greens, grass	Mixed vegetable waste	5-20	300 - 400	62							0	0	0	0
	Leaves	75 - 90	10 - 20	56							0	0	0	0
	Greens (fresh)	80	40 - 80	58							0	0	0	0
	Grass silage	22 - 36	320 - 420	55	35	180	54	1.800	18		324.000	174.960	32.400	0
	Whole crop silage	33	190	55							0	0	0	0
	Cereal grains	87	620	52							0	0	0	0
	Sugar beet	23	130	55							0	0	0	0
	Forage beet	16	90	56							0	0	0	0
	Maize silage	20 - 40	160 - 200	55	33	200	53	8.400	25		1.680.000	890.400	210.000	0
	Rice straw	25 - 50	320 - 450	50							0	0	0	0
	Market wastes	8-20	250 - 450	60							0	0	0	0
Wastes from households and canteens	Mixed biowaste from households*	35 - 75	100 - 200	62							0	0	0	0
	Grass, green waste	25	180	56							0	0	0	0
	Food leftovers (kitchen)*	9-37	150 - 300	58							0	0	0	0
	Waste from food retail (supermarkets)*	9 - 90	200 - 400	55							0	0	0	0
	Dry bread	65 - 90	620 - 880	58							0	0	0	0
	Mixed fat	80 - 95	1.100	66							0	0	0	0
	Eggs	25	380 - 520	54							0	0	0	0
	Low-fat milk	8	560	55							0	0	0	0
	Frying oil and fat	50 - 70	600 – 750	62							0	0	0	0
Animal by-products	Slaughterhouse waste	-	320 - 600	-							0	0	0	0
	Meat and bone meal	8-27	750 – 1,100	-							0	0	0	0
	Animal fat	-	1.000	65							0	0	0	0
	Blood liquid	18	420	-							0	0	0	0
	Guts (pigs)	-	60	55							0	0	0	0
Manure	Cow manure	10	25	56	10	25	56	4.000	5		100.000	56.000	20.000	0
	Pig manure	6	28	61							0	0	0	0
	Cow dung	25	80	55							0	0	0	0
	Pig doung	25	80	55							0	0	0	0
	Poultry doung	40	140	64							0	0	0	0
Own entries														

Annual biogas production	2.104.000	[m³/a]
Annual methane production	1.121.360	[m³/a]
Annual substrate costs	262.400	[€/a]
Annual revenues from waste	0	[€/a]
Annual input of fresh mass	14.200	[t FM/a]

Figure 33: table for the input of substrates for biogas production in the biomethane model

In the next step the user has to give some more input regarding each process step of the respective project. It is necessary to fill in data about biogas production, the upgrading of biogas and the particular way of utilization – mobile CNG storage and transport, grid injection of biomethane or operation of a CNG filling station. A part of the input table is shown in Figure 34.

Mobile CNG storage and transport

if no biomethane is distributed via mobile storage systems, there is no need to fill in these numbers

volume per mobile storage tank [Sm³]	2.300	
number of required mobile storage tanks [-]	3	
oneway route between gas upgrading and utilization of gas [km]	20	
costs of haulier, including connection and disconnection of storage systems [€/km]	2,5	
investment costs per storage system	80.000	
include investment costs of mobile CNG storage systems in economic assessment? [Y/N]	Y	*"Y" for Yes, "N" for No*
include operating costs of mobile CNG storage systems in economic assessment? [Y/N]	Y	*"Y" for Yes, "N" for No*

Grid Injection

if no biomethane is injected into a local natural gas grid, there is no need to fill in these numbers

distance to gas grid [m]	600	
pressure level of respective gas grid [bar]	50	
include investment costs of gas pipeline in economic assessment? [Y/N]	Y	*"Y" for Yes, "N" for No*
include investment costs of transfer/injection station in economic assessment? [Y/N]	Y	*"Y" for Yes, "N" for No*
include operating costs of transfer/injection station in economic assessment? [Y/N]	Y	*"Y" for Yes, "N" for No*
include operating costs of gas compression in economic assessment? [Y/N]	Y	*"Y" for Yes, "N" for No*

Local CNG Filling Station

if no biomethane is utilized at a CNG filling station, there is no need to fill in these numbers

capacity of compressor [Sm³/h]	50	
annual sales volume [Sm³/a]	296.712	
distance to gas source [m]	800	
include investment costs of CNG filling station in economic assessment? [Y/N]	Y	*"Y" for Yes, "N" for No*

Figure 34: a segment of the table for the user input in the biomethane model

The tool was designed in a way that in a first iteration the user doesn't have to put in a lot of data in detail. Often it is only necessary to decide whether to include some aspects in the economic assessment or not (=easy mode). When the user has a feeling on how the tool works and which parameters have which influence on the figures of his project or the user already has a profound knowledge of certain economic conditions for his project, it is possible to alter the given default values and assumptions to obtain more accurate results (=expert mode). This can be done on an extra page where the user has access to all operating numbers, which are the basis for the calculations. A protection/limited access for the user assures, that only changeable figures are modified so that a problem-free operation of the tool is ensured. Figure 35 shows an excerpt of some tables with operating numbers.

Biogas Production

conventional biogas plants

	model plant	plant I	plant II	plant III	plant IV	plant V	plant VI	plant VII	plant VIII	reference
	electric capacity [kW$_{el}$]	75	150	250	250	500	750	1.000	1.000	[1]
investment costs of conventional biogas plant										
	investment costs[1] [€]	564.196	710.263	1.103.856	1.199.270	1.779.940	2.344.745	2.675.305	2.753.352	[1]
	specific investment costs [€/kW$_{el}$]	7.523	4.735	4.415	4.797	3.560	3.126	2.675	2.753	
operating costs of biogas plant										
	operating costs[2] [€/a]	61.701	88.880	92.612	94.628	148.133	210.900	268.806	287.175	[1]
	specific operating costs [€/a*kW$_{el}$]	823	593	370	379	296	281	269	287	
other costs of biogas plant										
	insurance [€/a]	3.471	4.885	7.081	7.572	11.479	15.143	17.571	19.570	[1]
	labor costs [€/a]	9.570	12.146	14.331	14.335	18.116	20.852	22.962	22.962	[1]

additional costs of waste biogas plants in percent of investment costs of conventional biogas plants

	focus of waste biogas plant		reference
	no main focus on special waste types [%]	0	[9]
	main focus on food waste and waste from kitchens/canteens [%]	40	[9]
	main focus on oils and fats, grease traps [%]	10	[9]
	main focus on waste from organic waste collection bin [%]	250	[9]

Upgrading Of Biogas

	Capacity of upgrading plant	100 [Sm³ raw biogas/ h]	150 [Sm³ raw biogas/ h]	200 [Sm³ raw biogas/ h]	250 [Sm³ raw biogas/ h]	300 [Sm³ raw biogas/ h]	350 [Sm³ raw biogas/ h]	400 [Sm³ raw biogas/ h]	500 [Sm³ raw biogas/ h]	600 [Sm³ raw biogas/ h]	700 [Sm³ raw biogas/ h]	800 [Sm³ raw biogas/ h]	900 [Sm³ raw biogas/ h]	1000 [Sm³ raw biogas/ h]	reference
Pressure swing adsorption															
	investment costs [€]	933.397	982.691	1.031.984	1.081.278	1.130.572	1.179.865	1.229.159	1.327.747	1.426.334	1.524.921	1.623.509	1.722.096	1.820.684	[3]
	specific investment costs [€/(Sm³ raw biogas/h)]	9.334	6.551	5.160	4.325	3.769	3.371	3.073	2.655	2.377	2.178	2.029	1.913	1.821	
	operating costs [€/a]	70.924	87.792	104.661	121.529	138.397	155.266	172.134	205.870	239.607	273.344	307.080	340.817	374.554	[3]
	specific operating costs [€/(Sm³ raw biogas/h)]	709	585	523	486	461	444	430	412	399	390	384	379	375	
Pressurized water scrubbing															
	investment costs [€]	777.015	891.116	982.095	1.059.013	1.126.311	1.186.536	1.241.302	1.338.522	1.423.581	1.499.702	1.568.923	1.632.627	1.691.802	[3]
	specific investment costs [€/(Sm³ raw biogas/h)]	7.770	5.941	4.910	4.236	3.754	3.390	3.103	2.677	2.373	2.142	1.961	1.814	1.692	
	operating costs [€/a]	82.777	98.722	114.668	130.614	146.560	162.505	178.451	210.342	242.234	274.125	306.016	337.908	369.799	[3]
	specific operating costs [€/(Sm³ raw biogas/h)]	828	658	573	522	489	464	446	421	404	392	383	375	370	
Amine scrubbing															
	investment costs [€]	786.611	845.641	904.671	963.701	1.022.731	1.081.760	1.140.790	1.258.850	1.376.909	1.494.969	1.613.028	1.731.088	1.849.148	[3]

Figure 35: an excerpt of the operating numbers for the calculations in the biomethane model

The technical/economical results are presented in a group of tables (Figure 36) as well as in some graphical illustrations (Figure 37).

Upgrading of biogas

General data

selected upgrading technology	Pressurized water scrubbing	
full-load hours	8.585	[h/a]
gross raw biogas flow	240	[Sm³/h]
net raw biogas flow for upgrading	216	[Sm³/h]
biomethane flow	115	[Sm³/h]
annual amount of biomethane produced	989.040	[Sm³/a]

Costs of upgrading

investment costs	1.061.470	[€]
investment subsidy	50.000	[€]
total investment costs	1.011.470	[€]

leasing costs	92.760	[€/a]
operating costs (excl. LNG)	123.936	[€/a]
costs for adjustment of caloric value (LNG)	28.404	[€/a]
total running costs	245.100	[€/a]

production costs of biomethane after upgrading	0,77	[€/Sm³]
	77	[€/MWh]

Mobile CNG storage and transport

General data

annual amount of biomethane, which will be distributed via mobile storage systems	197.808	[Sm³/a]
annual number of trips	86	[1/a]
mileage of hauliers	3.440	[km/a]

Costs of mobile storage systems and transport

investment costs	240.000	[€]

Figure 36: an extract of the results table in the biomethane model

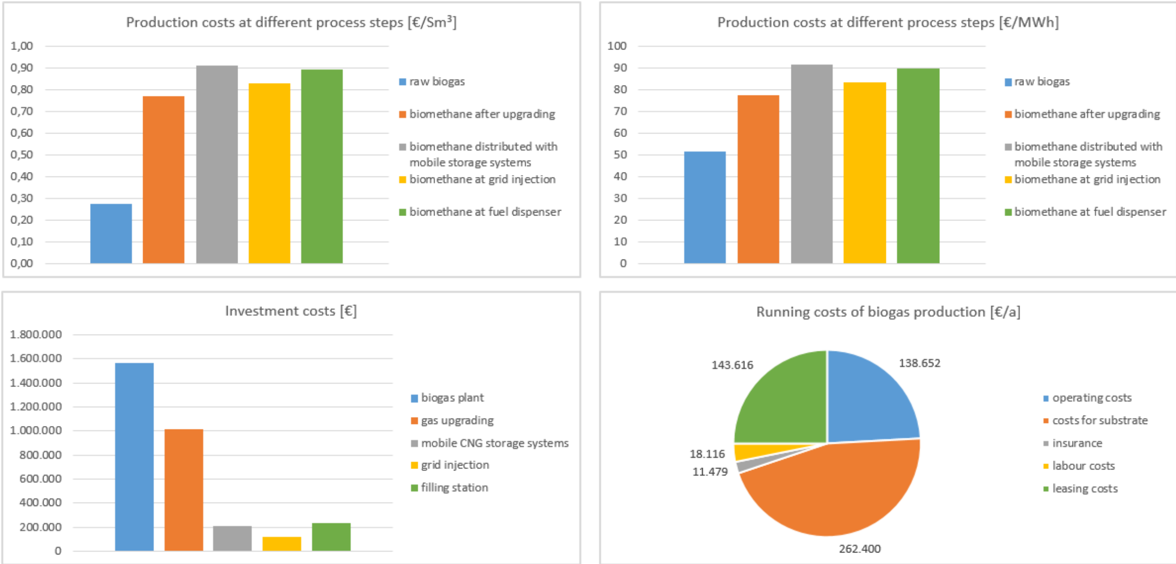


Figure 37: illustration of the graphical results in the biomethane model

At the end of the process a flow chart is shown, which contains the most important information for the user in one figure (Figure 38).

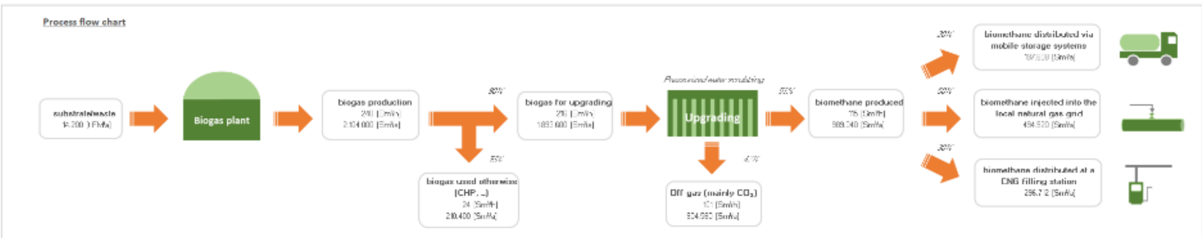


Figure 38: display of the process flow chart in the biomethane model

6.3 *Economic boundary conditions*

6.3.1 For biomethane producers

For the assessment of economic boundary conditions of biogas/biomethane production there is already a lot of literature available, therefore these aspects will be covered only briefly here. In the following the most important influencing factors for the economic boundary conditions are explained. For detailed economic analysis and sensitivity analysis it is referred to the 'Biomethane Tool for economic analysis of biogas production, gas upgrading and utilization of biomethane', which was developed in the course of the present report and presented/explained in paragraph 6.2.

Investment costs of a typical biogas plant consist of the following cost positions (FNR, 2013):

- Substrate storage and insertion
    - Silo
    - Weighbridge
    - Pre-tank including agitator
    - Vehicles
    - Devices for substrate insertion

- Digester
    - Digester building including heating, insulation and cladding
    - Agitators
    - Desulphurization
    - Gas storage
    - Gas and substrate pipes, pumps
    - Measurement, control and regulation technology
- Gas utilization
    - Cogeneration unit
    - Gas flare
    - Biogas upgrading facility
    - Biomethane injection
    - Measurement, control and regulation technology
- Management of the digestate
    - Digestate tank including cladding
    - Agitators
    - Gas storage
    - Gas and substrate pipes
    - Measurement, control and regulation technology
    - Devices for the separation of the digestate

The total production costs for upgraded biomethane suitable for use in vehicles are lowest for systems based on wastes or sewage, where feedstock costs are non-existent and capital costs are low. Large-scale production will, however, require the purchase of feedstocks (e.g. maize silage) for the majority of the throughput. It will therefore be more expensive, even after taking into account the economies of scale from moving to higher production capacities (Cleanleap, 2016).

Costs are also depending on the upgrading technology used, but these effects are not as crucial as the substrate costs. For example, there is little difference between the amortised capital and operating costs of water scrubbers and amine scrubbers. The most recent data suggests that upgrading systems based around water scrubbers will be somewhat cheaper than amine scrubber systems for capacities up to 1,000 m³/hour raw biogas processing capacities. However, cost differences become very small at higher capacities, and the key factor determining a choice will be the technical performance of the system depending on the biogas composition and the biomethane quality requirements (Cleanleap, 2016).

Figure 39 shows the total production costs for biomethane suitable for vehicle use by upgrader type and size.

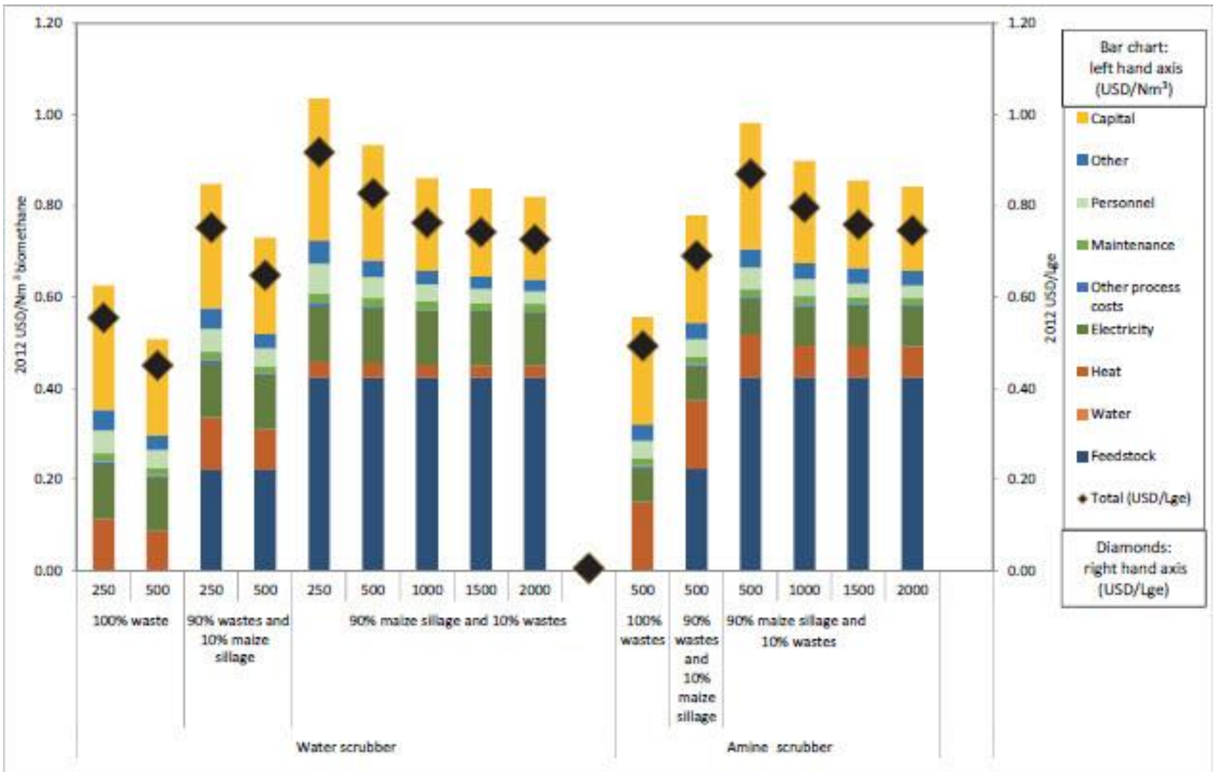


Figure 39: Total production costs for biomethane suitable for vehicle use by upgrader type and size (Cleanleap, 2016)

However, regarding especially the upgrading of biogas following cost factors have to be considered (Harasek, Financial aspects of biomethane production, 2012):

- Plant size
- Raw gas composition
    - Methane, carbon dioxide, oxygen, nitrogen, water, hydrogen sulphide, ammonia, other contaminants
- Product gas quality requirements
    - Local/regional gas grid quality
    - Heating value, maximum contaminant concentration
- Off-gas quality requirements
    - Off-gas treatment needs
    - Emission limits
- Gas pre-treatment technology / desulfurization
- Gas upgrading technology
- Delivery gas pressure requirement
- Biomethane heating value requirements
    - Need for propane addition / conditioning
- Biomethane quality monitoring requirements
    - Local/regional regulations
- Product gas odorization

- Biomethane pipeline
- Feed-in station
- Choice of biogas upgrading technology
    - Methane recovery / methane slip
    - Consumption of chemicals
    - Electrical energy consumption & heating/cooling requirements
    - Plant availability
- Off-gas treatment technology
    - Methane slip
    - Heat recovery from thermal/catalytical oxidation
- Legal aspects
    - Local regulations (safety regulations, quality regulations, grid access restrictions)
- Financial parameters
    - Capital costs
        - Interest rate on capital costs
        - Expected plant life-time / long-term contracts
        - Funding of investment costs
    - Operating costs
        - Personnel
        - Electricity
        - Materials / chemicals / analytics & calibration gases
    - Maintenance costs
        - Life-time of equipment components / replacement
    - Revenues
        - Feed-in tariff
        - Heat sales

6.3.2 For operators of filling stations

Operators of filling stations might decide to offer not only natural gas as a vehicle fuel but also biomethane. Here are two ways possible:

- Offering fuel from one dispenser with (calculatory) 100% biomethane
- Offering fuel from one or more (maybe even all) dispensers with a certain amount of biomethane, e.g. 60% natural gas, 40% biomethane

The success of these business models is primarily dependent on the willingness of the consumers to pay more for biomethane than for natural gas. Therefore, biomethane as fuel for vehicles is sold today mainly in a small share of offered fuel (e.g. 95% natural gas, 5% biomethane) or as a niche product in certain markets.

In some countries, like Germany, the cost disadvantage of biomethane compared to natural gas is reduced to some extent through avoided grid fees and taxes, which is a subsidy set by the government. In other countries, where these subsidies are not granted (yet), these reduced cost disadvantage does not apply.

However, the main economic boundary conditions for the operators of filling station are set by the investment and operating costs of the filling station facility, therefore the boundary conditions affecting these costs are described in the following.

The total cost of developing a CNG filling station depends on a number of factors, including the fuel demand from the fleet and other users, the fleet's applications and duty cycles, site conditions, the complexity of equipment installation and permitting processes. Consequently, costs can vary widely from one project to another.

Generally, a CNG station may be accessible only to a private fleet, open to the public, or a combination of the two (Smith & Gonzales, 2014):

- **Private stations** are only available for use by one fleet or several fleets that have contracts with the station owner. Fleets use private stations so they can ensure their vehicles have priority for filling and maximize vehicle operation time.
- **Public stations** are openly accessed by fleets and retail consumers, some public stations are only open during specified business hours. They have fuel management systems that allow for payment processing via credit card and fleet fuel card. Public stations are utilized by fleets that prefer not to build, operate or maintain their own infrastructure.
- **Public-private stations** are designed for a fleet to fuel its vehicles with fast-fill or time-fill privately, while also providing publicly available (or limited prearranged use) fast-fill dispensers. A fleet may choose a public-private design to meet fuel supplier throughput requirements, to benefit from economies of scale, or to meet requirements of a grant or incentive.

6.3.2.1 Factors Affecting CNG Station Costs

The most significant costs associated with developing a station are those related to land, engineering drawings, station design, equipment, and installation. The actual costs of a given project will vary according to the specific needs and constraints of the station and its users.

6.3.2.1.1 User needs and access

Station design

Time-fill stations are designed for vehicles that have a long filling window. At these stations, vehicles are generally filled directly from the compressor, not from storage tanks. At fast-fill stations, vehicles are filled from high-pressure storage tanks or compressors. Time-fill station development costs are typically *lower* than those of fast-fill stations, given that time-fill stations generally have smaller compressors and little to no storage. As shown in Figure 40, time-fill stations normally use unmetered fill posts instead of metered dispensers. Although fill posts are less expensive than metered dispensers, the station may require more of them because time-fill stations typically have one fill post per one to four vehicles. For larger fleets, a combination-fill station has the advantage of spreading out the filling load by time-filling overnight and fast-filling throughout the day (Smith & Gonzales, 2014).

Figure 40: CNG vehicles using unmetered time-fill posts (Smith & Gonzales, 2014)

Fleet size, fuel use, and filling window

Station design is determined by the number of vehicles that fuel at the station, the amount of fuel the vehicles use, and the drive and duty cycles of the vehicles and associated filling windows. Stations that serve large numbers of vehicles with short filling windows or unpredictable filling times may require large compressors, greater storage capacity, and/or a large number of dispensers. If vehicle filling can be organized on basis of a predictable schedule, a fleet may be able to reduce overall costs. Vehicles with high daily fuel use may have longer fill times, which affect filling schedules. If these vehicles have short filling windows, they may require a CNG station with significant storage or compression capacity (Smith & Gonzales, 2014).

Public, private, or public-private access

Some design and operational differences among public, private, and public-private stations can affect costs. Public-access stations usually require liability insurance. A public-private station has multiple filling areas, and there is an additional cost associated with extending the power and gas line to the public dispenser(s). A public-private station may have greater operating costs related to accounting and billing compared to a private station. If a fast-fill station is designed for filling many vehicles with short filling windows, it may require larger compressors and more storage capacity than would a site that serves the same number of vehicles with longer filling windows (Smith & Gonzales, 2014).

6.3.2.1.2 Installation and Site Parameters

Inlet gas pressure

The available gas pressure (inlet pressure) in the supply gas line can have a significant impact (positive or negative) on station costs. If a site has low gas pressure in the gas line, additional compression may be needed, which will increase investment and operating costs.

Conversely, if a site has high gas pressure in the gas line, costs associated with compressors may be lower than average. Operational costs may also be lower in this scenario, because less power will be needed to achieve a given filling rate (Smith & Gonzales, 2014).

CNG station installation

CNG station installation costs include those associated with laying concrete, trenching, ductwork, plumbing, electrical connection and upgrades, and material shipping. Many factors affect installation costs, including the following (Smith & Gonzales, 2014):

- **Site layout**

  This must take into account the distances to buildings and property lines.

- **Available power supply**

If a site does not have adequate electrical capacity for CNG filling equipment, an electrical upgrade may be necessary.

- **Space constraints**

  A site with space constraints may require additional engineering and installation costs.

- **Proximity to gas pipeline**

  If the gas line needs to be brought closer to the station site, it will result in additional costs. Depending on the circumstances, such as the fleet committing to a minimum throughput volume, the utility may cover a portion of this cost.

The following site considerations also affect station installation costs (Smith & Gonzales, 2014):

- Signage, lighting, and security fencing
- Availability of other types of fuels to be dispensed from the same location
- Filling island canopy
- Size and weight of vehicles to be served by the station, which affect pavement type and turn-radius requirements
- Soil conditions, which can impact foundation requirements
- Driveways, grading, and other general site upgrades.

Land costs and general site work

The site location and preparation needed for the CNG station will have a significant effect on the overall development cost. Land costs vary based on many factors, such as location and size. Prior to installing CNG filling equipment, general site work may be needed, such as grading, filling, compacting, paving, and rainwater management. A developer may incur additional costs for certain measures, such as a geotechnical survey of the site to ensure the soil conditions can support the weight of the station equipment (Smith & Gonzales, 2014).

Project management

Increased costs may result from project management challenges, such as supplier reliability, expediting equipment delivery or installation, or regional labour costs. Research into the experience and qualifications of vendors and engineering service providers should help to avoid any unnecessary costs (Smith & Gonzales, 2014).

Station commissioning

After the CNG station equipment is installed, a commissioning process ensures the station functions properly. During this process, the station components are tested under various conditions, and adjustments are made if needed. Commissioning may be performed by the contractor who built the station or by a third-party expert (Smith & Gonzales, 2014).

6.3.2.1.3 Station Design

Compressor redundancy

It is considered a best practice to design a station with multiple compressors so that the total compressor power is greater than what is necessary for the anticipated fuel throughput. Installing additional compressors, which is referred to as compressor redundancy, allows the station to continue operating in the event that one compressor stops functioning or is undergoing scheduled maintenance. A fleet may choose a design with 100% redundancy. A lower-cost design option is to have two compressors, each capable of providing 50% to 70% of the total required flow. In this scenario, fleets typically select two identical compressors because they will have the same maintenance procedures and spare parts. This option allows the main compressor to run until the demand for fuel requires the second compressor to start (Smith & Gonzales, 2014).

Figure 41: redundant compressors at a CNG filling station (Smith & Gonzales, 2014)

Compressor enclosures

Some compressors are protected from inclement weather to prevent premature wear and reliability issues. A shelter can be constructed around the compressor, or the compressor can be enclosed in a box. However, there is very little room to perform maintenance on enclosed compressors. Basic compressor enclosures add approximately 10% to the cost of the compressor (Smith & Gonzales, 2014).

Figure 42: two enclosed compressors, protected from bad weather (Smith & Gonzales, 2014)

Planning for growth

If a station is designed to accommodate an anticipated future increase in throughput, there may be additional initial costs associated with station development. However, such investments may result in less expensive upgrades and expansions in the long run. For example, a single compressor can be installed in the initial phase, with a second compressor added as demand increases. This also builds in redundancy. Similarly, leaving space and planning for utility lines to serve additional dispensers and/or more storage may save time and money in the future (Smith & Gonzales, 2014).

Figure 43: this CNG filling station was built with three storage tanks and has space to add more tanks in the future (Smith & Gonzales, 2014)

Regulatory and permitting issues

Regulatory and permitting requirements can be significant factors in the costs associated with station engineering, equipment, and installation. The cost and time required for obtaining necessary permits will vary based on the respective regulations (Smith & Gonzales, 2014).

Metering system

Choosing to meter only the total fuel flow at the station, rather than metering the amount used at each fast-fill dispenser, can decrease equipment costs significantly. However, metering only total fuel flow may not allow for necessary data collection related to taxes, revenues, expenses, or vehicle preventive maintenance (Smith & Gonzales, 2014).

6.3.2.1.4 Other Factors to Consider

Operations and maintenance

Operational costs such as electricity, insurance, and accounting software should be taken into consideration and accounted for in the fuel price. Electricity charges include consumption and demand charges, which vary across the country. The accounting system processes fuel purchases and ensures that relevant taxes are applied. It is important to note that a maintenance contract is critical for the long-term performance of a station. Minor preventive maintenance is scheduled on a regular basis, along with periodic major maintenance activities (Smith & Gonzales, 2014).

Geographic location and weather

Geographic location and weather impact the costs of equipment, installation, and permitting. In extremely cold climates, more elaborate equipment may be needed, including additional heaters. Bad weather during construction can add to installation costs (Smith & Gonzales, 2014).

6.3.2.2 Estimated CNG costs

Figure 44 shows costs of equipment of CNG filling stations, estimated by Smith & Gonzales (2014).

Equipment	Cost Range	Description
Compressor • 1–8 scfm (1–4 gge/hr) • 20–40 scfm (10–19 gge/hr) • 50–75 scfm (24–36 gge/hr) • 100–150 scfm (48–71 gge/hr) • 250–650 scfm (119–310 gge/hr)	\$4,000–\$550,000 \$4,000–\$22,000 \$50,000–\$90,000 \$80,000–\$150,000 \$100,000–\$250,000 \$200,000–\$550,000	The compressor takes inlet gas at low pressure and compresses it to the pressure necessary for filling a vehicle to 3,600 psi. The compressor's horsepower (HP) rating and the inlet pressure (psi) determine the flow rate, which is measured in standard cubic feet per minute (scfm) or gasoline gallon equivalent per hour (gge/hr). Compressors that offer similar flow rates vary in price based on their horsepower rating and manufacturer.
Dispenser	\$25,000–\$60,000	At fast-fill stations, drivers use a dispenser to quickly transfer CNG to the vehicle tank. Dispensers vary in cost depending on the number of hoses, fuel management system, and other features.
Dual-hose time-fill post	\$4,000–\$7,000	At time-fill stations, vehicles are connected to a simple fill post, typically overnight. The tanks are filled as fuel is available, which depends on the compressor flow rate and the number of vehicles. Two vehicles can connect to a dual-hose time-fill post.
Storage tank	\$70,000–\$130,000	Once natural gas is compressed, it can be stored in tanks for later use. The storage capacity and compressor size are balanced to ensure that fuel is available within the necessary timeframe and the number of times the compressor turns off and on is minimized.
Card reader/fuel management system	\$10,000–\$30,000	Card readers allow the driver to access fuel using a fleet card or credit card. A fuel management system is software that enables tracking of driver and vehicle fueling habits.
Gas dryer	\$10,000–\$300,000	A gas dryer removes moisture from the gas prior to compression, which is a good practice for all CNG stations.

Figure 44: Estimated costs of equipment of a CNG filling station (Smith & Gonzales, 2014)

It is important to note that the cost of a CNG station may vary substantially from the estimates listed here. For detailed numbers on investment or operating costs you have to contact a CNG equipment supplier or engineer who specializes in CNG station design to determine the appropriate design and cost for a specific application (Smith & Gonzales, 2014).

7 References

Adams, R. (2016, February 3). *Designing a CNG Fueling Station*. Retrieved from http://www.government-fleet.com/article/story/2014/06/designing-a-cng-fueling-station.aspx

Adler, P., Billig, E., Brosowski, A., Daniel-Gromke, J., Falke, I., Fischer, E., . . . Urban, W. (2014). *Leitfaden Biogasaufbereitung und -Einspeisung.* Gülzow: Fachagentur Nachwachsende Rohstoffe e.V.

AGCS Gas Clearing and Settlement AG. (2016, January 27). *Biomethanregister*. Retrieved from http://www.biomethanregister.at/de/register/funktionsweise

Amon, T., & Boxberger, J. (1999). Organic wastes for co-digestion in agricultural biogas plants: Guidelines and legal conditions in Austria. *IEA Bioenergy Workshop: Hygenic and Environmental Aspects on Anaerobic Digestion: Legislation and Experiences in Europe. Vol. II; International Energy Agency Task-Group 24* (pp. 86-94). s.a.: Deutsche Veterinärmedizinische Gesellschaft e.V.

Ariel Corporation. (2016, February 2). *Ariel Corporation*. Retrieved from https://www.arielcorp.com/Media/News-Story/Ariel-Compressors-Installed-in-City-of-Dublin-Public-CNG-Station/8589938396/

Bel, J. (2015). *Food waste from food and beverage industry.* Paris: ORDIF.

Bel, J., Craddock, F., Puksec, T., Aguilar, I., Canaveral, A., Mitkovski, D., & Petrushevski, K. (2016). *Guidelines for the anaerobic digestion of food and beverage industry waste.* Paris: ORDIF.

Björk, H. (2011). *Zero Waste Society in Borås City, Sweden - Strategies to Action.* Borås: University of Borås.

BMVIT. (2009). *Feeding biogas into the grid - demonstration facility in Bruck an der Leitha.* Wien: Projektfabrik Waldhör KG.

Bull, A. (2016, February 3). *Bio-methane Regions*. Retrieved from www.bio-methaneregions.eu

Censtar Science & Technology Co., Ltd. (2016, February 2). *Censtar*. Retrieved from http://www.censtarfueldispenser.com/fuel-dispensing/cng-dispenser.html

Cleanleap. (2016, May 23). *Total biogas production costs to produce biomethane for vehicles*. Retrieved from http://cleanleap.com/6-biogas/63-total-biogas-production-costs-produce-biomethane-vehicles

CNG Center. (2016, February 2). *CNG Storage: CNG Vessels, CNG Spheres*. Retrieved from http://cngcenter.com/cng-storage-cng-vessels-cng-spheres/

CNG Center. (2016, February 3). *CNG vs Diesel and ROI Calculator*. Retrieved from http://cngcenter.com/cng-vs-diesel-calculator/

Deutsche Energie-Agentur GmbH. (2010). *The role of natural gas and biomethane in the fuel mix of the future in Germany.* Berlin: Deutsche Energie-Agentur GmbH.

Deutsche Energie-Agentur GmbH. (2015). *Zukunft Biomethan. Perspektiven und Handlungsempfehlungen für die Rolle von Biomethan im zukünftigen Energiesystem.* Berlin: Deutsche Energie-Agentur GmbH.

Deutsche Energie-Agentur GmbH. (2016, January 27). *Biogasregister.* Retrieved from https://www.biogasregister.de/startseite/informationen/funktionsweise.html

Doczekal, C., Gruevska, A., Rutz, D., Aguilar, I., Bel, J., & Puksec, T. (2015). *Report on good practice of biomethane usage as a transportation fuel.* Güssing: Güssing Energy Technologies GmbH.

European Biogas Association. (2016). *Biomethane in Transport.* Brussels: EBA.

European Biogas Association. (s.a.). *EBA's BIOMETHANE fact sheet.* Brussels: EBA.

European Comission. (2016, March 30). *Biodegredable Waste*. Retrieved from http://ec.europa.eu/environment/waste/compost/

Farzaneh-Gord, M., Deymi-Dashtebayaz, M., & Rahbari, H. R. (2011, March). Studying effects of storage types on performance of CNG filling stations. *Journal of Natural Gas Science and Engineering*, pp. 334-340.

Favoino, E. (2002). *Drivers for separate collection in the EU, optimization and cost assessment of high capture schemes. Proceedings of EC Conference on Biological Treatment of Biodegredable Waste.* Brussels.

FNR. (2013). *Leitfaden Biogas.* Gülzow: Fachagentur Nachwachsende Rohstoffe e.V.

Hannesschläger, M. (2009). *Virtuelles Biogas.* Wien: Klima- und Energiefonds.

Harasek, M. (2012). *Financial aspects of biomethane production.* Vienna: TU Wien.

Harasek, M. (2016, May 17). *Biogas upgrading*. Retrieved from http://bio.methan.at/en/upgrading

Hofmann, F. (2005). *Evaluierung der Möglichkeit zur Einspeisung von Biogas in das Erdgasnetz.* Leipzig: Fachagentur Nachwachsende Rohstoffe e.V.

Kaltschmitt, M., Hartmann, H., & Hofbauer, H. (2009). *Energie aus Biomasse.* Springer Verlag: Leipzig/Hamburg, Straubing, Vienna.

Laughlin, M., & Burnham, A. (2014). *Case Study - Compressed Natural Gas Refuse Fleets.* s.l.: U.S. Department of Energy.

LOMANI AUTO GAS. (2016, February 2). *Accesories CNG*. Retrieved from http://lomani.in/new/products/cng-kits/accessories-cng/

Morales, I., Doczekal, C., Zweiler, R., Bel, J., Craddock, F., Rutz, D., & Ribic, B. (2015). *Good practice on segregated collection of food waste.* Zagreb: Zagrebacki Holding doo.

Okello, W. (2016, May 17). *Africa Engineering News*. Retrieved from http://www.africaengineeringnews.com/nairobi-waste-energy-project-set-generate-power-create-jobs-clean-environment/

PlanET Biogastechnik GmbH. (2016, May 17). *Nutzungspfade Biogas*. Retrieved from http://www.planet-biogas.com/biogas/nutzungspfade/

Puksec, T. (2016). *Factsheets on current biogas/biomethane handling practices.* Zagreb: University of Zagreb.

Purac. (2016, June 2). *Sobacken biogas plant, Borås, Sweden*. Retrieved from http://purac.se/?page_id=1260&lang=en

Ramesohl, S., Arnold, K., Kaltschmitt, M., Scholwin, F., Hofmann, F., Plättner, A., . . . Burmeister, F. (2006). *Analyse und Bewertung der Nutzungsmöglichkeiten von Biomasse.* Wuppertal, Leipzig, Oberhausen, Essen: Fraunhofer UMSICHT.

Ribic, B. (2015). *Catalogue of food waste types and energy potential.* Zagreb: Zagrebacki Holding doo.

Schiffers, J., Vogel, A., & Meyer-Prescher, B. (2009). *Biogaseinspeisung. Band 5: Technische, rechtliche und ökonomische Hemmnisse und Lösungen bei der Einspeisung von Biomethan in das Erdgasnetz aus Sicht eines Gasunternehmens.* Oberhausen: Fraunhofer UMSICHT.

Skupien, S., Jüly, J., & Koller, N. (2013). *SEBE – Sustainable and Innovative European Biogas Environment.* Graz: ICS Internationalisierungscenter.

Smith, M., & Gonzales, J. (2014). *Costs Associated With Compressed Natural Gas Vehicle Fueling Infrastructure.* s.a.: U.S. Department of Energy.

Strauch, S., Krassowski, J., & Singhal, A. (2013). *Biomethane Guide for Decision Makers. Policy guide on biogas injection into the natural gas grid.* Oberhausen: Fraunhofer UMSICHT.

Theißing, M. (2005). *BIOGas - Einspeisung und Systemintegration in bestehende Gasnetze.* Wien: BMVIT.

U.S. Department of Energy. (2016, February 2). *Alternative Fuels Data Center*. Retrieved from http://www.afdc.energy.gov/fuels/

U.S. Department of Energy. (2016, February 12). *Alternative Fuels Data Center*. Retrieved from http://www.afdc.energy.gov/vice_model/

Urban, W. (2013). *Experiences and future perspectives of biomethane in Germany from a regulatory perspective.* Berlin: Ecologic Institute.

Wellinger, A., Murphy, J., & Baxter, D. (2013). *The biogas handbook: Science, production and applications.* s.a.: Woodhead Publishing.

Wolf, A. (2012). *Biogasregister Österreich.* Wien: AGCS.

Zukunft Erdgas GmbH. (2016, February 1). *Erdgas Mobil*. Retrieved from https://www.erdgas-mobil.de/tankstellenbetreiber/tankstellen-technik/