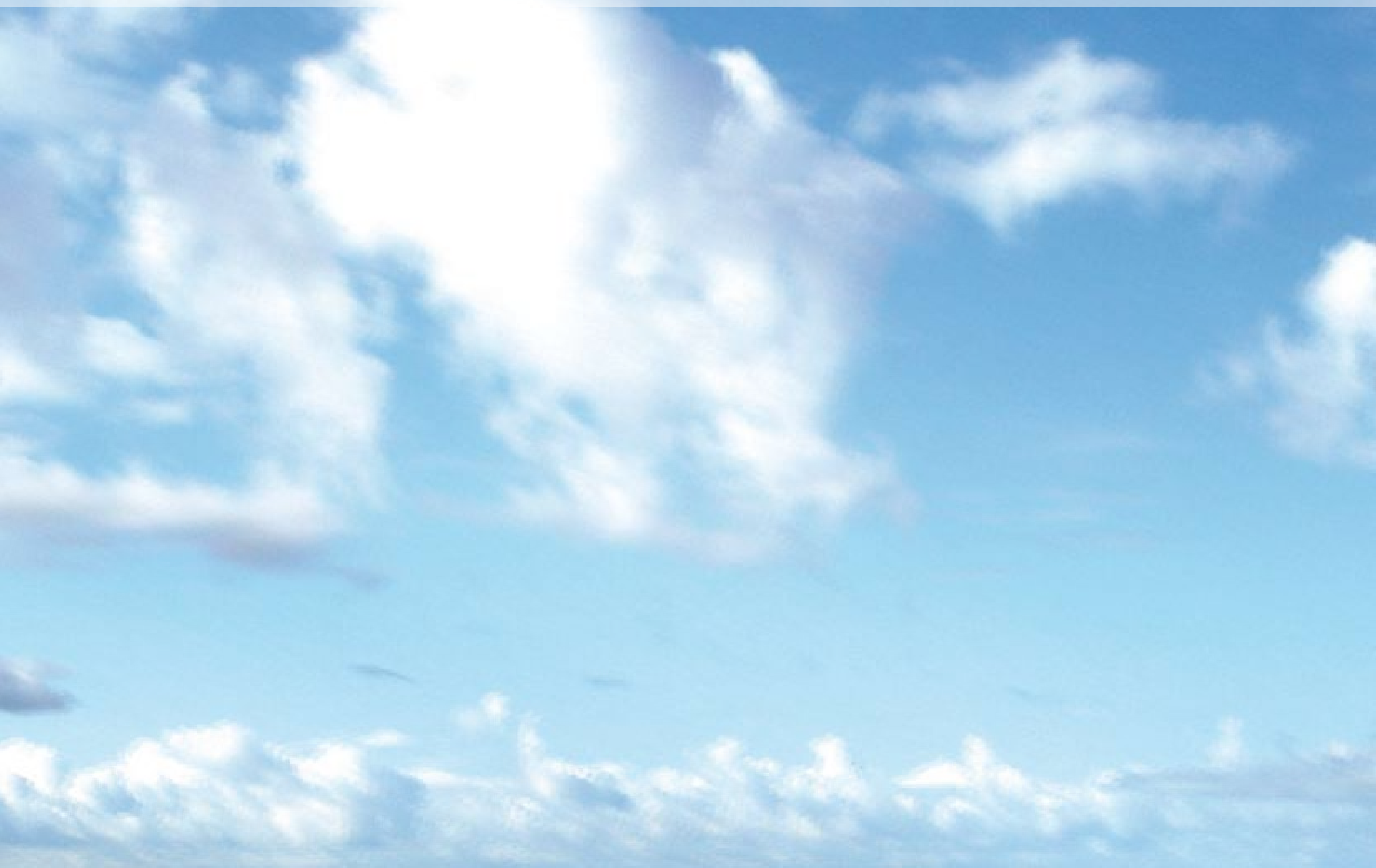
HOW TO IMPLEMENT A BIOMETHANE PROJECT

Decision Makers' Guide



BIOMETHANE AS A VEHICLE FUEL

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Acknowledgements

A large number of people from various organisations and countries have directly and indirectly contributed to the development, compilation and completion of this Decision Makers' Guide. This document would not have been possible without the support of the European Commission and all the partners comprising the BIOGASMAX project.
Their contributions, much based upon their experiences in their own communities, resulted in the development of this practical tool that should help foster greater use of renewable biomethane in the European transportation sector and beyond.

In addition, we would like to thank the stakeholders who aren't project partners, but still took the time to fill out our questionnaires. We would also like to express our gratitude to the participants, session leaders and co-organizers of the BIOGASMAX Symposium of Experts, where the research results were validated and in-depth discussions provided valuable insights into the policy making process and actions that are so essential in creating economical, sustainable, community-based renewable energy projects and programmes.

Your contributions and support are greatly appreciated.

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1.1

PURPOSE OF THIS GUIDE

introduction

The Biomethane Decision Guide for Urban and Municipal Policy Makers (referred to as the Biomethane Decision Guide or Decision Guide hereafter) came forth from the European Commission-funded 'Biogas as a vehicle fuel – Market Expansion to 2020 Air Quality" (BIOGASMAX) project.

The overall aim of this project is to support the European Community in reducing its dependency on oil and reducing gas emissions by providing knowledge about more efficient production, distribution and use of biogas (upgraded to biomethane) in the transport sector generated from a wide variety of renewable feedstocks available in Europe.

The Biomethane Decision Guide arose from an analysis of the criteria that lead decision makers to implement biomethane as a vehicle fuel with in a community, municipality or region. The BIOGASMAX project identified examples of good practices that have been established in different parts of Europe. The participating municipalities were Göteborg and Stockholm (Sweden), Rome (Italy), Torun and Zielona Góra (Poland), Lille (France) and Berne (Switzerland).

The information was drawn from the experience of BIOGASMAX project partners and other communities: the energetic, ecological, economic, social and political aspects of biomethane implementation in each community are outlined.

The Biomethane Decision Guide explains all aspects of the biomethane decision – from the biomethane pathway to biomethane business – with the aid of practical examples. As such, it intends to help other municipalities and regions in determining whether or not they are candidates for biomethane implementation and, in the case of a positive decision, what steps to take next.

This guide is intended to encourage municipal and regional decision makers to gain a deeper knowledge of the subject and to take on an active role in the development of biomethane as an energy source for vehicles.

1.2

DEFINITIONS OF METHANE

Discussions on the use of methane as a vehicle fuel often are blurred by the use of different terminology. In order to avoid confusion, the following terminology is used to indicate different kinds of methane-based products: natural gas, biogas, biomethane and synthetic gas, also called syngas.

Natural gas (also termed methane, CH_4, or simply gas) is a gaseous fossil fuel that consists of mostly methane (CH_4) and some carbon dioxide (CO_2). Natural gas is extracted from natural gas fields found underground or beneath the sea. It is also found in coal beds in smaller quantities. Naturally occurring biological sources of methane include termites, ruminants and cultivation. Natural gas is used for a variety of purposes in residential, commercial and industrial sectors. In addition, natural gas is a suitable vehicle fuel. Natural gas as a vehicle fuel is delivered as compressed natural gas (CNG) or liquefied natural gas (LNG) *[NA.2006.]*.

Biogas is a renewable resource that can be made from agricultural waste (both plants and manure), crops, urban waste, sewage from urban water purification processing, and - through a separate process - from wood. In order to generate this biological digestion process, the feedstock is heated to temperatures between 30-57°C and the waste materials transformed into mostly methane and carbon dioxide. Sometimes biogas is used to power electricity generators. When upgraded and compressed, biogas is called biomethane and can be used in natural gas vehicles (NGVs) directly or added to the existing natural gas pipeline networks.

Syngas consists of carbon monoxide (CO) and hydrogen (H_2). Through a process called thermal gasification, renewable sources like black lye, organic waste, straw and wood can be transformed into syngas. After methanization and drying this form of biomethane can be added to the natural gas grid to fuel vehicles or to be used in other sectors where natural gas is consumed.

This document focuses mainly on biogas and biomethane. The application of biomethane in vehicles is identical to the use of natural gas as a vehicle fuel. In addition to the definitions outlined above, other terms and definitions are provided in Annex I of this guide.

1) *Some caution is necessary when using the term 'gas' when indicating natural gas. Americans and Canadians also use this term to refer to gasoline (petrol) as 'gas'.*

THE ENVIRONMENTALLY CLOSED LOOP

Used as a vehicle fuel, biomethane creates an environmentally closed loop: waste products are used to create biogas, which is upgraded to biomethane that is used in vehicles, some of which collect the waste materials and return them to the bio-digesters where the process starts again.

The different elements of this environmentally closed loop comprise waste management, a clean water solution, and improved agricultural output through the use of biomethane production by-products. Furthermore, biogas upgraded and used in vehicles results in less air pollution than petroleum fuels. This chapter explains briefly how the environmentally closed loop works and what its different elements are. Details of the process are provided in the subsequent chapters of the Biomethane Decision Guide.

IMPACT OF BIOMETHANE ON GLOBAL WARMING

Biomethane mainly consists of carbon dioxide (CO_2) and methane (CH_4) , both of which are greenhouse gases. Biomethane production reduces global warming, because it is created in a closed system using waste products that otherwise would turn into natural methane sources released freely into the atmosphere.

The highest methane emissions result from other sources such as rice cultivation, cattle breeding and landfills *[LFU. 2004]*. On the contrary, by using biomethane as a vehicle fuel, one does not contribute to the greenhouse effect because it reduces natural methane production by using methane-forming products in a strictly controlled fuel production cycle in which the emissions of methane are minimized in all handling steps *[Jarvis. 2004]*.

The major sources of carbon dioxide pollution in the atmosphere are burning fossil fuels and land use change including vegetation fire *[Uherek (2). 2004],* which make CO_2 a bigger contributor to global warming than methane.

Furthermore, the widespread destruction of plant life and forests also contributes to the overall greenhouse effect since they act as a CO_2 ‘sink’, absorbing atmospheric CO_2 emissions. *[Jarvis. 2004]*.

BIOMETHANE PRODUCTION AS A WASTE MANAGEMENT STRATEGY & A CLEAN WATER SOLUTION

Biomethane can be made from a variety of sources within the forestry, agricultural, municipal and industrial waste streams. Within EU legislation "the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste" are termed biomass *[EC. 2005].*

Making biomethane from biomass prevents incineration or the creation of landfills, also a significant source of atmospheric methane. The controlled production of biomethane helps communities and regions dispose of agricultural and municipal waste and to purify wastewater while using the sewage sludge to transform it into a vehicle fuel.

IMPROVED AGRICULTURAL OUTPUT THROUGH BIOMETHANE PRODUCTION RESIDUES

A third advantage of biomethane production comes from the residues resulting from the biomethane production process. The remainders of biomethane production consist of inorganic and organic materials, as well as newly formed biomass.

This product is usable as bio-manure that can enrich agricultural land, and so closes the environmentally friendly biomethane loop. In contrast to other agricultural fertilizers, bio-manure does not contain phosphates that cause additional pollution when produced commercially.

2) Methane green house gas pollution potency is about twenty-one times that of carbon dioxide. Therefore it is very important to avoid emission of both into the atmosphere.

1.4

HOW TO USE THIS GUIDE

The information in this guide is, in part, drawn from a questionnaire sent out to forty organizations – private sector companies and municipalities – that produce biomethane. All the respondents have been active in the European biomethane market for about ten years.

Thirty five percent of those surveyed responded in detail, providing a representative base of experience from which this decision guide is developed. The scenarios presented in this guide provide examples of how successful biomethane production facilities can be developed. However, each has its unique characteristics that might not apply to all situations.

The different chapters of this guide refer to different aspects of biomethane production and business. After introducing basic concepts in this first chapter, the second chapter of this guide goes into the different elements of a decision to start producing and using biomethane as a vehicle fuel.

The third chapter is directed specifically at the biomethane pathway and its implications. Feedstock, biogas treatment and upgrading, outputs, distribution as well as biomethane application in vehicles are the topics of this part of the manual. In chapter four, the economics of the biomethane business are set out.

While biomethane production and use may seem complicated when new to the topic, keep in mind that many municipalities in Europe already have switched to this vehicle fuel. Some of their experiences can be found in the fifth chapter of this guide.

Site visits to communities that are working with biomethane will, without any doubt, enhance one's understanding of the subject matter. At the end, the fifth chapter also includes an overview of questions designed to stimulate the thought process on biomethane implementation.

2

THE BIOMETHANE DECISION

The idea to start a biomethane production and distribution network in a municipality or a region will most likely stem from different reasons. Possible motives can be, for example, the need to reduce traffic-induced CO_2 emissions or the desire to improve the 'environmental image' of a city. Typically a combination of environmental, economic and political factors plays a role in the decision for biomethane production and use. One of the biggest challenges of this process involves the creation of the appropriate synergies between the multifaceted urban problems such as waste management, water purification, and reduced emissions from the transportation sector. This chapter addresses the general objectives, challenges and strategies identified through the BIOGASMAX project, as well as in interviews with experts in the field.

2.1

IDENTIFYING THE STARTING POINT:

WHAT ARE YOUR OBJECTIVES?

There often are multiple reasons to opt for the biomethane option. Broadly there are three considerations: environmental, economic and political.

Whether motivated by regional governments (including the European Union), national or municipal policy makers, biomethane can be used to achieve environmental improvements through:

- Reduction of traffic induced CO_2 emissions;
- Replacement of fossil fuels;
- Improvement of municipal air quality;
- Sustainable waste management and soil conservation.

Economics inevitably play an important role in the decision to start up a biomethane business within the municipality or region. The economic objectives typically include:

- A commercial approach to fuel change management;
- The need for an economical and economically sustainable vehicle fuel solution;
- The development of new markets and/or job creation;
- The creation of stable supply and demand on the local, regional or national vehicle fuel market.

Political considerations also play a part in the decision to implement the biomethane solution. The political decision will most likely be based on the environmental and economic aspects of the biomethane project, but some additional objectives are:

- Image-building as a progressive municipality or region;
- Positive partnerships with new, community-based stakeholders;
- Development of efficient 'best-practices' related to solving different municipal problems.

All objectives that are set out while identifying the starting point will be translated into goals and targets that are approached in a strategic fashion. Such a process will not be without its many challenges. The keyword within the biomethane course of action is 'synergy'.

Implementing biomethane production simultaneously addresses specific strategic objectives and challenges while involving a multitude of local stakeholders, who all have something to gain in the process.

2.2

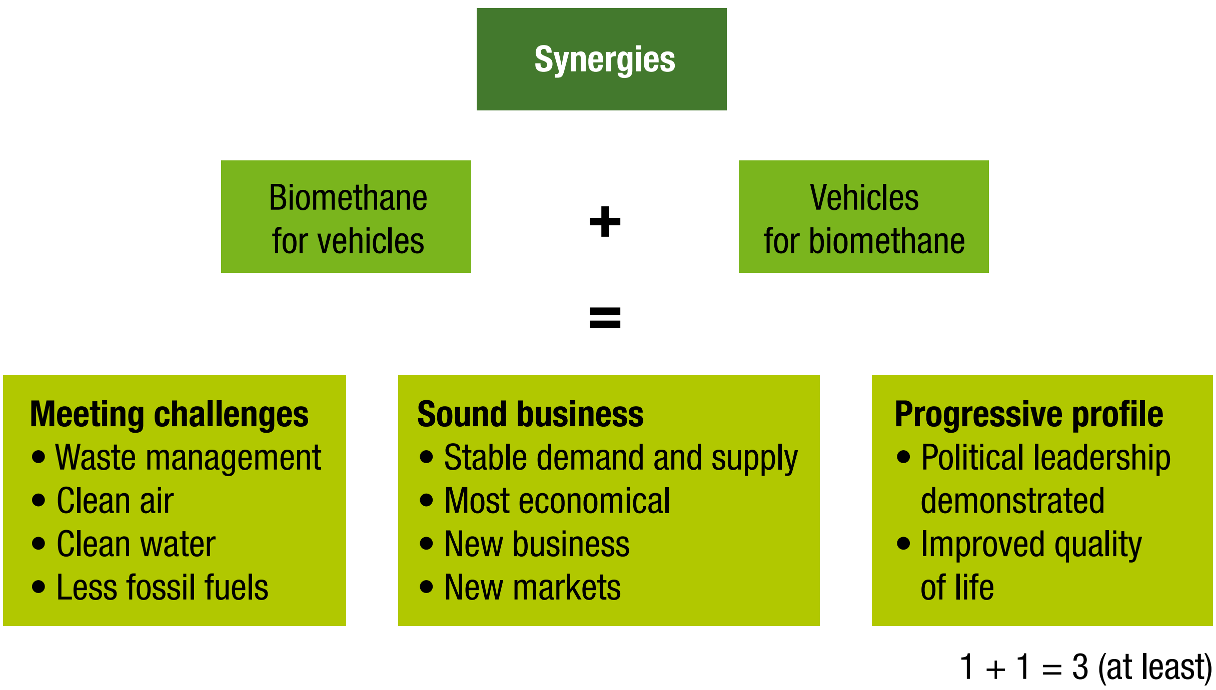
GUIDELINES FOR THE START-UP PHASE

VISION AND TARGETS

What challenges can be expected in the start-up phase of a biomethane project and what strategies are most likely to help in finding a solution to the difficulties encountered in this phase?

The key success factor in the overall biomethane organizational set up and development is the creation of and the ability to manage the various possible synergies. The drive for synergy is essential throughout the entire process, but it plays a particular role in the start-up phase when vision and targets will define outcomes for the rest of the project. This is reflected in figure 1:

Figure 1 **SYNERGIES**



The establishment of a partnership of a core group of stakeholders working to create the vision and targets of the biomethane project is the first step of the start-up phase.

The vision and targets of the project should communicate a consensus of the project objectives and the direction taken by its stakeholders.

A detailed review of the costs, competitive market pricing and profitability of such an enterprise, together with an assessment of the potential supply of biomass substrates will help determine the initial market size as well as the scope of the possibilities for growth once the venture becomes a fully established, viable business.

Underlying the vision and targets is a commercial approach. A focus on profit generation, maximized fiscal advantage, and investment grants from the state and the EU, as well as room for local small business growth have proven to be important factors to successful biomethane businesses in Europe.

Stability of the vision and targets as well as demanding, but realistic goals will help a biomethane project to remain successful and sustainable in the long term.

A broad selection of potential partners provides an opportunity to create different kinds of partnerships. It is advisable to envision partnerships as long-term commitments and as an excellent possibility to create the synergy needed to accomplish the original set of goals envisioned for the biomethane project.

Using the partnerships to create connections between different 'worlds', for example the rural and the urban or the political and the business world, is likely to lead to the maximum involvement of different stakeholders in the project.

This, ultimately, becomes a key to the long-term success of the project.

SETTING UP A SUCCESSFUL BIOMETHANE ENTERPRISE

Setting up a successful biomethane project is a long and complicated undertaking, which should be planned and budgeted for over a number of years. Following the creation of the vision, partnerships and 'political will', the development process can be divided into eight steps, each with its own characteristics and considerations. *[Krich et al. 2005].*

- Find a buyer for the biomethane;
- Obtain feedstock for digestion;
- Determine the means of transport and storage of the biomethane;
- Determine the location of the upgrading plant;
- Select the desired technology;
- Gain a detailed understanding of the economics and the finances;
- Develop a permitting plan;
- Select the designer and contractor to build the facility.

The first step to take when developing a biomethane enterprise is to ensure that there is one or more stable, consistent buyer(s) for the biomethane produced. Typically a stable demand for biomethane comes from big consumers such as bus fleet owners, who will guarantee consumption of a substantial amount of the produced biomethane.

Launching the municipal or regional biomethane market is often best done through the introduction of biomethane-run public fleets.

Developing a vehicle-based market for methane through a secure buyer can be done in different ways. A municipality or region can decide to switch one or more of its fleets to biomethane. On the national level, the government can be lobbied to support biomethane as an alternative fuel, even using the fuel in the government's fleet vehicles.

It is particularly helpful when the national government recognizes and defines environmentally friendly vehicles and supports biomethane as an environmentally beneficial alternative to petroleum fuels. At the municipal and regional levels, the use of biomethane vehicles can be stimulated by local incentives in the form of parking benefits, environmentally friendly taxi priority lanes and city access benefits at times when vehicles are banned from the city centre.

The second step in the process is to determine which feedstock source or sources will be used in the digester. When opting for a certain feedstock, it is important that quality feedstocks are available locally in substantial quantities on a year-round basis. The use of multiple feedstock sources also is a viable option, but a combination of leftover materials, often sold back to farmers as fertilizer, requires careful monitoring during the production process if the residuals are to be useful.

The third step in the initial development process is to determine the need for transporting various materials and fuels within the biomethane enterprise. This depends on several factors: What exactly needs to be transported (feedstock, biogas and/or biomethane); to which location the different products need to be transported (on-site, off-site, between different production locations, to the final market); and, over what distances transport is needed, which, in turn, will determine the choices of specific means of transport and storage.

Biogas and biomethane can be transported and stored in compressed or liquid form with dedicated pipelines, through the pre-existing natural gas grid, or in cylendars by truck.

Once these first three elements have been identified, the exact production location can be chosen. The location of the buyer, the feedstock and the transportation system required will provide the key criteria to determine the plant's location. Liquefied biomethane can be trucked over considerable distances. Injecting biomethane into the public natural gas grid also enables it to travel with relative ease.

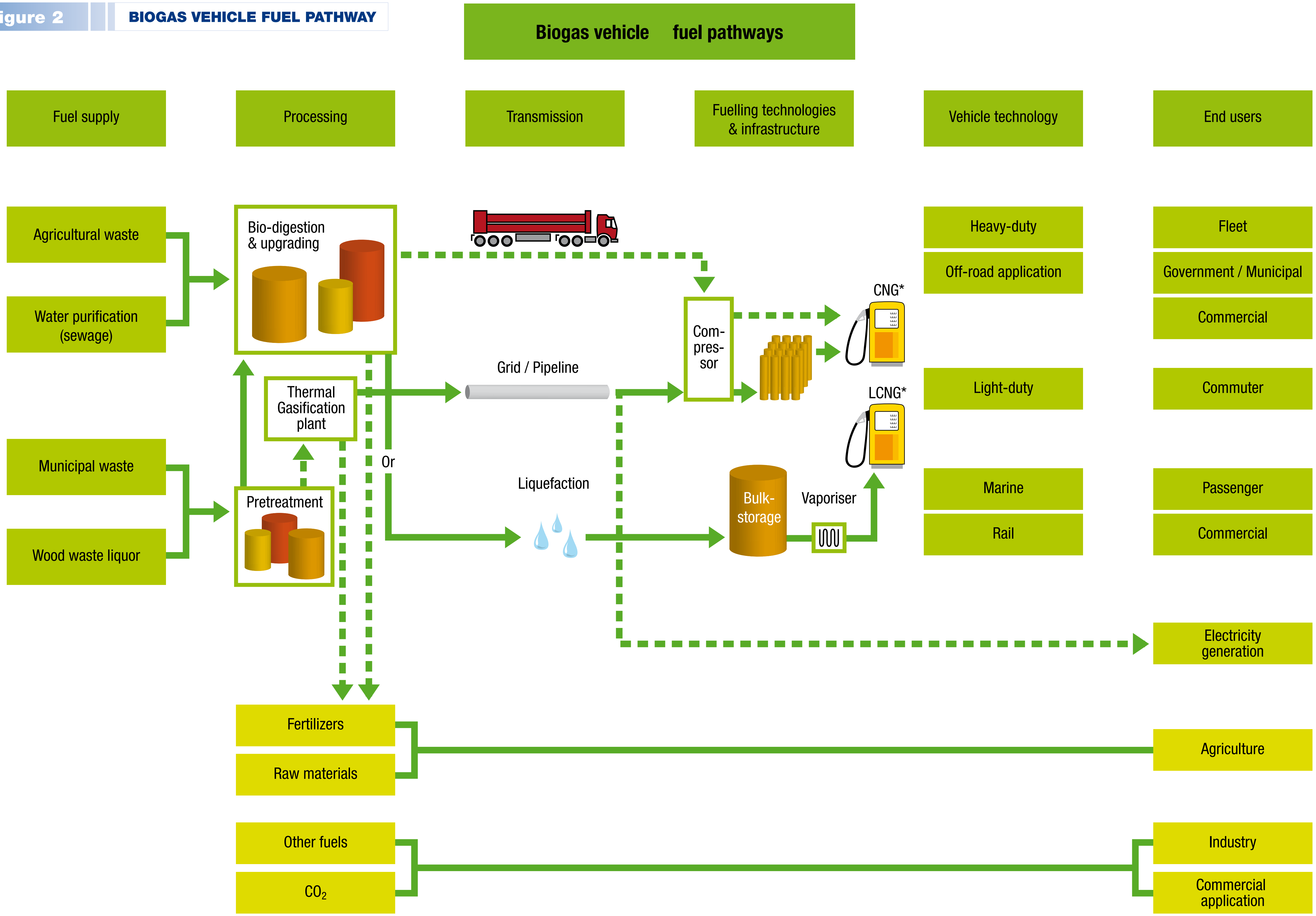
If, however, biomethane production requires the construction of a dedicated pipeline, distance becomes an issue due to the high costs of pipeline construction. The proximity of the feedstock, the buyer, the digester and the biomethane production location becomes especially important.

Once the location is determined, the fifth step follows: the selection of the right technology and the development of the operation plan. The entire biomethane production process is heavily based on modern technologies.

There are multiple technologies available for the (pre)treatment of the feedstock, anaerobic digestion, and upgrading. Careful examination of the techniques available is recommended before choosing the technology that best fits the feedstock used. Operational requirements, performance and capital costs are the three main criteria for technology selection.

The sixth step in the biomethane production set-up is the costs analysis, financial planning and the application for public funding if possible. (in the case of European funding, FEDER, FP7-Cooperation (DG-TREN) and CONCERTO calls for proposals are the best adapted.)

Figure 2 **BIOGAS VEHICLE FUEL PATHWAY**



3

THE BIOMETHANE PATHWAY

This chapter of the Biomethane Decision Guide provides insight into the different phases involved in creating biomethane, as well as the means of transmission, fuelling technologies and fuelling infrastructure that can be applied to facilitate the sale of biomethane as a vehicle fuel. Vehicle technology also is discussed in this text. In addition the residues of biomethane production will be taken into consideration. Please refer to figure 2 for a complete overview of the biomethane pathway.

3.1

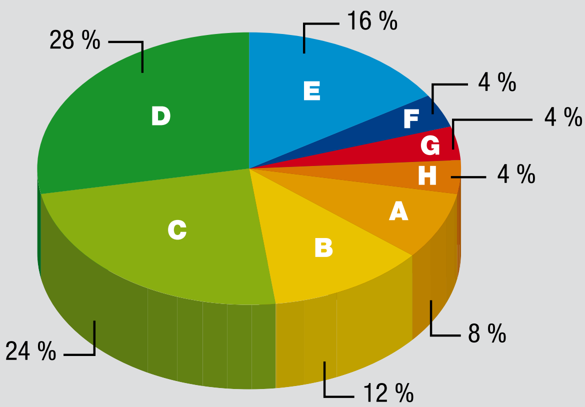
FEEDSTOCK

BIOMASS

Biomass is the most common basis for biomethane production. It is defined by the European Union as the organic products, by-products and waste streams from forestry and agriculture (including animal husbandry) as well as municipal and industrial waste streams *[EC. 2005]*. The use of biomass for fuel production has several advantages. Natural materials are plentiful and multiple types of biomass materials can be found easily in many different locations or at the same location. The most popular types of biomass for biomethane production are: sorted biodegradable municipal waste, sewage sludge, manure and leftover agricultural and agro-industrial products. In 2004 biogas production from these sources was 0.17 Exajoules (EJ). The EU estimates that it will be possible to produce 0.63 EJ by 2010 and 0.75 EJ by 2020.

Agricultural feedstock sources include crops, agricultural residues and by-products. Leguminous plants, grasses, residues of harvests and food production are examples of such feedstock sources. Animal manure and slaughterhouse by-products also belong to this category. An issue apart is the use of energy crops. Debates are ongoing about whether or not dedicated land should be used for the production of such feedstock. Wood can be used as a feedstock in a separate process called thermal gasification. The main source of urban feedstock is municipal waste with the possible addition of industrial waste of similar composition. After sorting, the biodegradable part of these sources can be used for the production of biogas. The BIOGASMAX respondents showed the following division of feedstock sources.

Figure 3 **FEEDSTOCK SOURCES**



A= Agricultural waste (vegetation)
B= Agricultural waste (animal waste)
C= Municipal waste/landfill
D= Sewage sludge
E= Slaughterhouse and food processing waste
F= Specifically grown crops
G= Wood waste (black liquour)
H= Pre-sorted household bio-waste

Note: Respondents could give more than one answer. In total 25 answers were counted, all of which are recorded in the graph to the left.

In addition to biogas, landfill gas and synthesis gas can also be used as a starting point for biomethane production. Landfill gas is the gaseous by-product of waste deposits in landfills, which would otherwise be flared off. Syngas – also known as synthesis gas – is another feedstock source for biomethane production. Both are described in more detail below.

LANDFILL GAS

Landfill gas is a 'waste' product that is extracted from landfills, where it is produced from organic and non-organic solid wastes. The release of landfill gas can have negative consequences for three reasons. First of all, the gas is an explosive, leading to potentially hazardous situations on-site. However, natural gas, being lighter than air, normally dissipates harmlessly into the atmosphere. Secondly, methane, as a greenhouse gas, released into the atmosphere contributes to global warming. Lastly, volatile organic compounds (VOCs) from other materials in the landfill that might be carried by the gas could be released into the atmosphere, risking potential soil, groundwater and air contamination. *[NA(2). 2006].* Currently, landfill gas is extracted for heating or electricity production, or it is flared. Instead of flaring off excess landfill gas, it also can be collected and used for biomethane production.

When using landfill gas as a feedstock source for biomethane production, attention must be paid to the composition of the gas in order to avoid the presence of oxygen and hazardous components during the production process. Most importantly, the gas must be free of impurities that are derived from many of the non-organic substances within the landfill to ensure that the biomethane is 'pipeline' quality, a concern of the natural gas industry.

BIOGAS

Biogas – sometimes also referred to as digestion gas - is a product of anaerobic digestion, which is the breakdown of organic materials in a completely oxygen free (anaerobic) environment. These organic materials include, for example, urban waste materials, manure, sewage sludge or crops. Different natural microorganisms digest the raw materials and transform them into biogas. Biogas is used for the production of electrical power and heat as well as to produce biomethane, a clean and efficient fuel for the transportation sector.

SYNGAS

Synthesis gas is a mixture of carbon monoxide and hydrogen, which can be transformed into synthetic natural gas. It can be produced through biomass gasification.

TREATMENT AND UPGRADING

PRE-TREATMENT

The quality of the waste materials has an effect on the quality of the biogas and biomethane that will be produced. All incoming feedstock materials need sorting before they can be transformed into biogas. Where possible it can be very useful to have an initial sorting of waste materials performed by the waste producer. The community of Borås in Sweden sets a good example in this respect. Residents of Borås are the first in the waste management chain who are responsible for sorting the waste. Biodegradable waste is collected in black bags, whereas all waste that remains after separation of hazardous, electronic and recyclable waste is collected in white bags.
The bags are collected together, but an optical reader at the collection point ensures that only black bags proceed to the biogas production section. Of course collecting different waste streams separately at an even earlier stage of the waste management process is another solution. Regardless of when (or by whom) the waste streams are separated, the waste offered as biodegradable surplus needs to be checked before it is used as feedstock. In Borås, the black bags and their contents are crushed, after which the remains are screened for non-biodegradable elements with the help of a sifter. *[Jonsson, M. 2001].*

In the example from Borås the feedstock materials are crushed to assure all particles are below 12mm, the size needed to facilitate anaerobic digestion *[City of Göteborg et al. 2005]*. Different feedstock materials are likely to require different types of fragmentation. Sorting, crushing and shredding are the most common methods used.
After feedstock quality is ensured, hygienization (cleaning) might be needed in order to avoid the presence of pathogenic substances in the material. Sewage sludge, manure and feedstock containing animal by-products, have to be heated to a constant temperature of 70°C for at least one hour to eliminate any potentially harmful organisms. In the thermophilic process in which higher working temperatures are used, hygienization is not always necessary. When it comes to hygienization, each country has its own rules in place for handling different categories of waste materials.

62% of the BIOGASMAX respondents apply one or more pre-treatments to the feedstock with the following goals:

Figure 4 **PRE-TREATMENT GOALS**

Goal of pre-treatment:	Used by ... % of respondents:
Hygienization of feedstock	53
Achieving a homogenous mixture	31
Removal of non-organic waste	8
Deferrization	8

ANAEROBIC DIGESTION

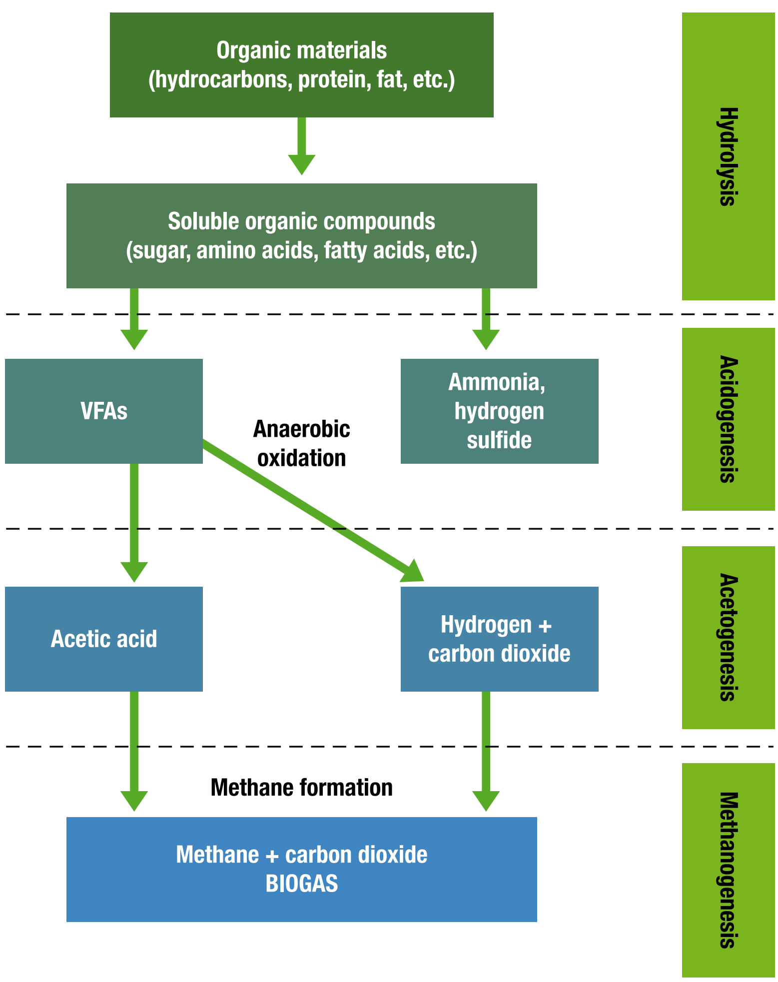
The prepared and cleaned feedstock is transformed into biogas and its by-products in a process called anaerobic digestion. Anaerobic digestion is the breakdown of organic materials in a completely oxygen-free environment. The digestion can take place as a liquid or a solid process. Solid processes (that contain approximately 25-30% dry matter) are used for municipal waste. Liquid processes are applied to sewage sludge and agricultural waste.
The two most common types are mesophilic and thermophilic fermentation. In the case of mesophilic digestion, the feedstock is digested in an environment where the temperature ranges from 30°C to 40°C. This process takes 20 to 25 days. Thermophilic fermentation refers to feedstock digestion at a temperature ranging between 50°C to 60°C, taking 15 to 18 days. The anaerobic digestion process includes four main phases: hydrolysis, acidogenisis, acetogenesis and methanogenisis.

In the first phase enzymes break down bigger molecules, for example protein and carbohydrates, into smaller ones, such as simple sugars, amino acids and fatty acids. In the next phase, acidogenesis, the smaller molecules are fermented by acidogens, and sometimes chemicals are used to accelerate this process. The products of this process include volatile fatty acids (VFA).

In the third phase of the degradation process, acetogenetic bacteria are active. They produce acetic acids, carbon dioxide and hydrogen from VFAs.

During the last phase, these intermediates are transformed into methane, and the result is called biogas. The efficiency of production across the four steps with current technologies ranges between 50 to 70%.

Figure 5 THE ANAEROBIC DIGESTION PROCESS



UPGRADING

In order to obtain a suitable fuel for vehicles or for delivery to the natural gas grid, the biogas needs to be transformed or upgraded into biomethane. Upgrading involves the removal of pathogenic substances, as well as siloxanes, water, nitrogen, hydrogen sulphide and carbon dioxide from the gas. Upgraded biogas used as a vehicle fuel thus does not contain contaminants that can damage or corrode mechanical components or systems. Additionally, reducing the moisture content also prevents the potential of ice formation in a gas engine. *[Wellinger, A. & Lindberg, A. 1999].*

Upgrading is often a two-step process performed in series. First the carbon dioxide is removed from the biogas. Afterwards other contaminants are removed. However, the most common upgrading process, water scrubbing, is a one-step process. The graph below shows the substances that are removed using different methods, as identified by the respondents involved in the BIOGASMAX project.

Figure 6 **UPGRADING METHODS**

Substances to be removed

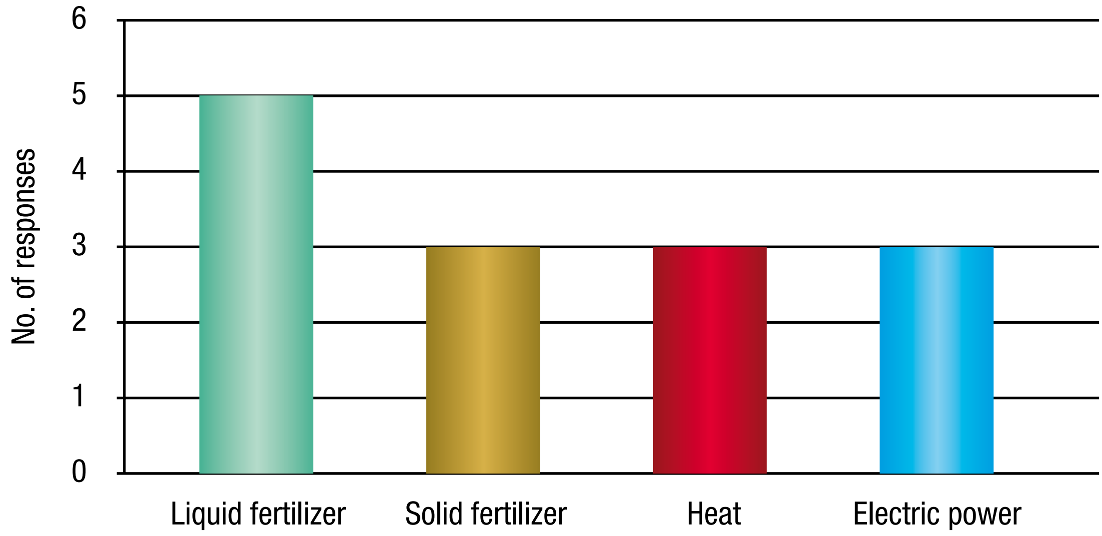
Methods of removal	Pathogenic substances	Siloxanes	Water	Nitrogen	Hydrogen sulphide	Carbon dioxide
Water scrubbing		X	X	X	X	X
Pressure swing absorption (carbon molucar sieves)			X		X	X
Drying			X			
Use of biocide	X					
Chemical scrubbing (absorption amines)		X			X	
Adsorption filter	X	X	X		X	X
Heat exchanger		X	X			
Chemical absorption in desulphuration tower				X		
Stripping						X

3.3

OUTPUT

The main output of the anaerobic digestion process is biogas, normally containing about 50-70% methane. Additionally, a variety of other by-products include raw materials used as fertilizers, carbon dioxide, and heat, which can be used in buildings, to generate electricity, or used as process heat in the biogas process. The BiogasMax participants generate the by-products shown in figure 7 during production of biogas.

Figure 7 **BY-PRODUCTS**



Note: Each respondent could give more than one answer.

METHANE

Taking into account the possible feedstock sources, methane is a relatively abundant, environmentally friendly fuel. Methane is non-toxic, is lighter than air, and has a relatively narrow ignition range of about 5-15% methane-to-air. As such, methane dissipates and is rapidly diluted in the air, reducing the risk of ignition and explosion.

Since it is colorless and odorless, an odorant is added to allow early detection in case of a leak. Despite a risk of ignition and explosion, mostly in enclosed spaces, accidental fires or explosions involving methane-driven vehicles are rare.

CARBON DIOXIDE

Carbon dioxide is a by-product of the anaerobic digestion process. Normally, biogas yields between 30-35% carbon dioxide that can be sold for industrial and commercial applications, for example to create carbonated drinks or as input in greenhouses for fruit and vegetables to enhance growth. Currently, left-over CO_2 is mainly discharged into the atmosphere.
The European Union Emissions Trading Scheme (EU ETS) makes carbon emissions trading possible in its member states. While the initial focus of this cap-and-trade system is on carbon dioxide emissions from large industrial players, a broadening of this system could include companies in the biogas industry that seek to actively contribute to reducing greenhouse gas formation.

DIGESTATE AS A SUSTAINABLE FERTILISER

In addition to methane and carbon dioxide, the anaerobic digestion process also leaves undigested organic materials, inorganic materials (metals and minerals) as well as new biomass (microorganisms that grow during the digestion process) *[Jarvis. 2004].* This nutrient-rich residue can be sold as organic fertilizer, providing a potentially important revenue stream for the biogas manufacturer. The sale of fertilizer as a by-product from biomethane production is another benefit of carefully sorting and treating the feedstock sources before starting the anaerobic digestion process since contaminated feedstock is likely to lead to unusable fertilizer.

Once the quality control of residues is properly carried out there are several advantages to using this residue as a fertilizer. Firstly, digestate as fertilizer produces far less odor-release than raw organic fertilizers. Secondly, nitrogen, phosphorus and potassium (NPK) present in biogas residuals are more mineralized, implying that plants absorb them more easily. Finally, the fertilizer stemming from the anaerobic digestion process is a natural product based on NPK that were already present in the environment and, therefore, does not add any new nitrogen, phosphorus and potassium to the environment *[City of Göteborg et al. 2005].*

There are places, however, where there is no market for digestate fertilizer. For example in France, biogas plant operators have real difficulties finding farmers who are willing to use the digestate. Furthermore, the digestate must be post-composted and stored during the periods of the year when spreading on the land is not possible. There is no profit from fertilizer sales in that case.

DIGESTATE FOR LANDSCAPING

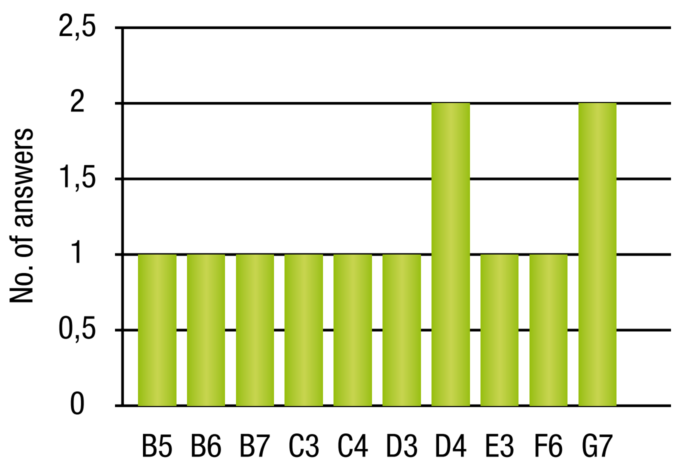
Digestate that is not used as an ecologically sustainable fertilizer also can be useful for general landscaping purposes as a substitute for natural soil.

OTHER FORMS OF ENERGY

Heat also is produced during the anaerobic digestion process and can be redistributed for industrial and commercial applications or applied again on site by providing the biomethane production plant with energy for heating or generating small amounts of electricity. Like the fertilizer produced, these products also can provide an additional revenue stream for the biogas manufacturer or can be reapplied internally to process the biogas.

Figure 8 identifies various markets that may exist for the sale or redistribution of these by-products, as identified by respondents to the BIOGASMAX questionnaire.

Figure 8 **BY-PRODUCTS MARKETS**



B5= CO_2 bought by industry
B6= Heat bought by powerplants
B7= Electric power bought by powerplants
C3= Liquid fertilizer bought by industries
C4= Solid fertilizer bought by industries
D3= Liquid fertilizer bought by cultivators/farmers
D4= Solid fertilizer bought by cultivators/farmers
E3= Liquid fertilizer bought by commercial enterprises
F6= Heat used in the biomethane production plant
G7= Electric power bought by the national electric network management company

Note: Each respondent could give more than one answer.
The graph is based on answers of 6 respondents.

3.4

DISTRIBUTION, STORAGE & FUELLING

Once the biomethane is produced, there are several ways of distributing it to the customer, either to fuelling stations or to a fleet depot.

The gas can be compressed and piped through a pipeline that was designed specifically for this purpose or it can be introduced into the existing natural gas grid. Alternatively it can be liquefied or compressed and, afterwards, trucked to a fuelling station.

BIOMETHANE DISTRIBUTION

Most vehicles that run on natural gas use compressed natural gas (CNG). Normally natural gas is taken from the natural gas network, compressed and pumped into vehicles. Biomethane also can be introduced into the natural gas grid since it is comprised mostly of methane, the same main component as natural gas.

This possibility is viable only when the natural gas grid is reasonably well developed. Introduction of biomethane into the natural gas grid is, however, subject to some restrictions:

• The biomethane has to be compressed to a pressure equal to that of the natural gas in the grid;

• The biomethane should be odorized with the same substance as the natural gas;

• In places where the natural gas has a high energy content, e.g. in Sweden, a small amount of propane needs to be mixed into the biomethane to achieve the same energy content as the natural gas *[City of Göteborg. 2005]*.

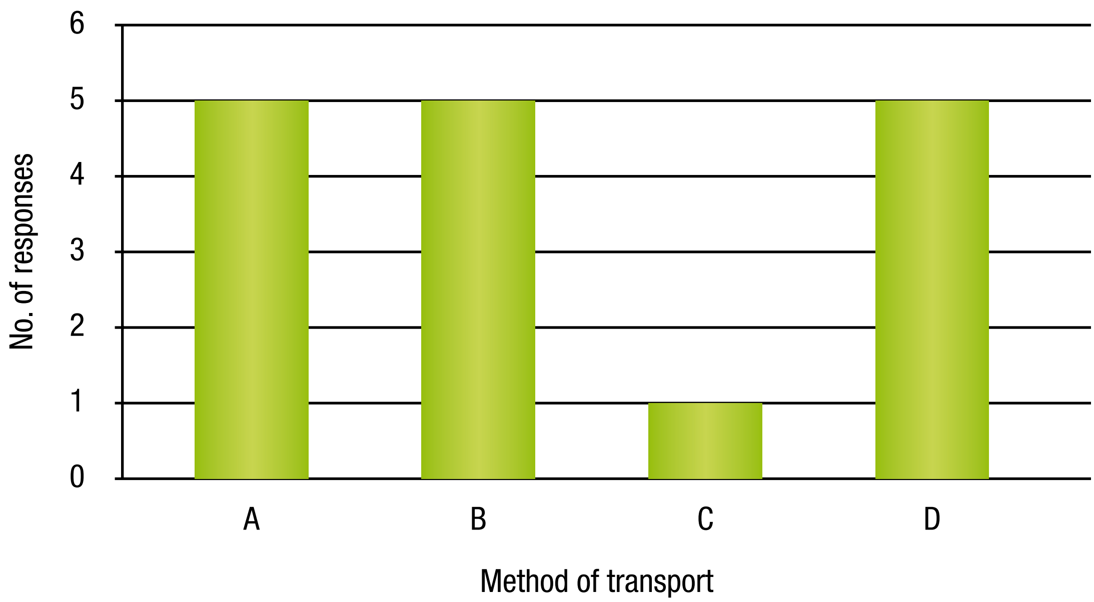
Where this is not the case, e.g. in the Netherlands or France, such measures are not needed. If no pipeline network exists, the gas can be compressed into CNG storage tanks on-board specially designed trucks and brought to a fuelling station where it can be distributed into vehicles.

An alternative to CNG is liquefied natural gas (LNG), which is natural gas and/or biomethane chilled to a temperature of -163°C. After transportation of the liquefied product, the methane needs to be vaporized and compressed before it is introduced in the CNG filling infrastructure. Another option is to vaporize the LNG directly into the CNG tanks without the use of a compressor. This liquefied-to-compressed option (L-CNG) provides fuelling flexibility since LNG or CNG can be fuelled at the same station. This practice is not common but is being considered as another way of expanding the gas-fuelling infrastructure.

Generally LNG is made in large, specially designed facilities used to prepare very large amounts of LNG for long-distance transportation to large storage facilities where it can be introduced into the natural gas grid. Small-scale liquefiers are available for on-site LNG production but only a few of these technologies are available and the cost-benefits have not been fully proven. On-site liquefaction of biogas as a purification/upgrading technique also is being explored; however, most biomethane will be transported and delivered in gaseous form, either added to an existing or specially built pipeline grid or, in the absence of a pipeline, by truck.

Figure 9 shows the methods used by the questionnaire respondents to transport gas between the upgrading site and the fuelling station.

Figure 9 **BIOMETHANE TRANSPORTATION METHODS**



A= On-site filling and/or depot integration

B= Compressed and trucked

C= Injected into the grid network that was developed for this purpose

D= Injected into existing grid network

Note: Respondents could give more than one answer. In total, 16 answers were provided.

RESIDUES DISTRIBUTION

The distribution of the residual materials used as fertilizer depends on whether it is a liquid or solid. The solid digestate slurry as well as the liquid product, liquor, are best transported in (tank) trucks. The slurry can be spread over the land with hoses, whereas liquor can be integrated into the crop cycle through the irrigation system. Any liquid or solid material that is not appropriate for use as fertilizer can be trucked to locations where it is used for topsoil or landscaping practices *[City of Göteborg et al. 2005].*

Electricity produced at the biogas production site is best used in on-site applications since this allows operators to avoid the costs of electricity supplied by the normal power grid. Alternatively, arrangements may be made to resell the electricity to the local power producer through the existing electrical grid.

CO_2 resulting from the biogas process can be compressed into tanks similar to the CNG storage cylinders and trucked to the location where it can be used.

BIOMETHANE STORAGE

Methane that is not immediately dispensed into a vehicle needs to be stored on site. Gas that is transported by truck, grid or pipeline will be compressed and stored in high-pressure (250 bar) cylinders at the fuelling station e.g. in the case of large bus fleets or public fuelling stations. LNG is stored in bulk-storage cryogenic tanks and then vaporized prior to dispensing into vehicles.

FUELLING

Fuelling a methane vehicle is, from the consumer’s perspective, a procedure not much more complicated than fuelling liquid petrol or diesel. Fast-fill dispensing takes only slightly longer than fuelling petrol.

Slow fill systems, normally associated with fleet applications is done when a fleet is parked in a depot overnight. Several varieties of slow-fill home compressors (vehicle refuelling appliances – VRAs) are available so that individual commuter cars can be refuelled at home. A home compressor for vehicle fuelling is, taking into account the installation costs and the monthly subscription fee, a solution that is less expensive than diesel fuel with a cost of 80 eurocents for an equivalent of a liter of petrol. *[Blaquiere. 2005].*

3,5

BIOMETHANE IN VEHICLES

Biomethane can be used in normal gasoline vehicles that have been designed to run on methane or that have been converted. These are typically called natural gas vehicles (NGVs). Most internal combustion engines, be they for light duty cars, heavy-duty trucks or off-road applications can be made to run on methane gas. Most NGVs today are bi-fuel, meaning that the vehicle can run on both methane and petrol. Historically this has been the case due to the lack of an extensive CNG fuelling station network. Dedicated (methane only) vehicles also are used, mostly in heavy-duty vehicles; since engines can be optimized to take advantage of methane's high octane, clean burning characteristics. As CNG fuelling station networks develop, it is anticipated that increasingly more dedicated passenger cars will be sold.

ORIGINAL EQUIPMENT

Over 40 manufacturers worldwide produce factory-built NGVs. The advantage of original equipment manufactured (OEM) methane vehicles is that these are specifically designed to run on methane and are, therefore, likely to perform optimally. Additionally, most of the current OEM vehicles install the CNG storage tanks within the chassis of the vehicle so no space inside the boot (trunk) space is sacrificed. These vehicles appear as normal gasoline vehicles, come with a full warranty and can be brought back to the manufacturer for maintenance and servicing.

CONVERSIONS

OEM NGVs have been in serial production since the early 1990s. Since they were introduced in Italy in the mid-1930s most NGVs have been converted gasoline vehicles or, in the case of heavy-duty diesel vehicles, converted to run on 100% natural gas. Many conversion companies exist worldwide and converted, bi-fuel NGVs remain popular since the OEMs do not yet produce their full line of vehicles to run on natural gas and biomethane. As countries develop networks of NGV fuelling stations, it is hoped that OEMs will expand their NGV product line. Until then, it is anticipated that converted vehicles also will remain popular.

A relatively new option is being developed for heavy-duty diesel vehicles to be converted to dual fuel operation. In this case the vehicle starts and idles on diesel and then, as the vehicle moves into operation, an increasingly larger percentage of methane is introduced, up to about 80%. In these technologies the diesel fuel is used as 'pilot ignition' in order to aid the combustion of the gas. Only a handful of manufacturers currently produce these engines although it is anticipated they will become more popular.

LIGHT-DUTY VEHICLES

Light-duty vehicles include passenger and commuter vehicles as well as small- and medium scale commercial vehicles. According to certain classifications of this category (mostly limited to European guidelines), medium-duty (in between light- and heavy-duty vehicles) vehicles also fall into this category.

HEAVY-DUTY VEHICLES

Heavy-duty vehicles are the heavier type of vehicles like buses and trucks. These are generally are dedicated, 100% natural gas vehicles or they can be converted to dual fuel, running on a mixture of gas and diesel (up to about 80-85% replacement of diesel).

OTHER VEHICLES

Because of their low polluting characteristics, natural gas vehicles/engines are ideal for indoor operation. Forklifts (also called lift-trucks) are a popular application for methane since they are low polluting and easy to refill quickly. Indoor ice-cleaning machines have been popular for the same reason. Even race cars are run on natural gas or biomethane since these have a 130 octane rating and provides good power and smooth running of the engine.

Railway applications of natural gas have been used mostly in demonstrations, but could be a large potential market for NGVs due to the huge amounts of fuel consumed by locomotives. Some trains have been run on compressed natural gas (CNG), however, large volumes of CNG cylinders are required to store an adequate amount of fuel.

Trains using liquefied natural gas (LNG) provide a more practical application for long distance transport. In urban settings, natural gas can be used to eliminate the black soot from diesel locomotives and provide a much quieter running engine making it more ‘friendly’ in dense urban settings.

Boats can be run on methane too. Canal boats for tourist trips are a good example of marine application of biomethane, which has as an additional benefit a low noise pollution effect. Large ships running on LNG are becoming popular in Norway where adequate supplies of LNG are available.

4

BIOMETHANE IN BUSINESS

4.1

BIOMETHANE BUSINESS MODEL

The pictorial model shown in figure 12 identifies the different elements that constitute a biomethane business. This chapter concentrates specifically on the stakeholders, partners, customers and customer relationships in the biomethane business, as well as the costs, revenue and economics of the biomethane production cycle and business.

STAKEHOLDERS

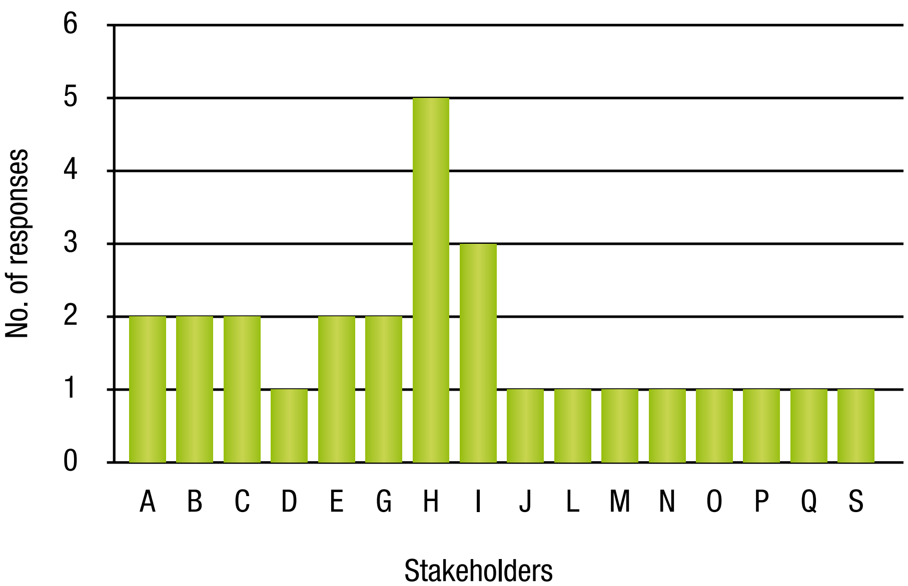
The core capabilities that enable successful biomethane production, distribution and sale require different professionals to be engaged in the process. Engineering expertise is required in the use of biomethane production technology; other professionals must run the business. The persons with organizational and political skills can help in the development of the project. Synergy between the different parties involved is crucial to a successful biomethane enterprise.

The BIOGASMAX questionnaire showed that different municipal stakeholders initiate a biomethane project. Municipal waste handling companies were ranked highest, followed by the municipal water works and the municipal leadership. Agriculture and forestry companies also were indicated as likely initiators of a biomethane enterprise.

Throughout the process the stakeholders are likely to change. As one respondent said:

"At the start, ownership was in the hands of three companies. Now only one of these three, the energy company, is the owner. The two other companies act as long-term, stable suppliers and customers, because it is important to define interests and priorities correctly".

Figure 10 **INITIATORS OF BIOMETHANE PROJECTS**



A= A company specialized in methane distribution for use in vehicles;
B= Agriculture or forestry company;
C= Municipal leadership;
D= National energy company;
E= National government;
G= Municipal energy company;
H= Municipal waste handling company;
I= Municipal water works;
J= Private energy company;
L= Regional leadership;
M= Private bus fleet company;
N= Local public bus company;
O= Plant supplier;
P= Private company;
Q= Local farmers;
S= Private waste handling company

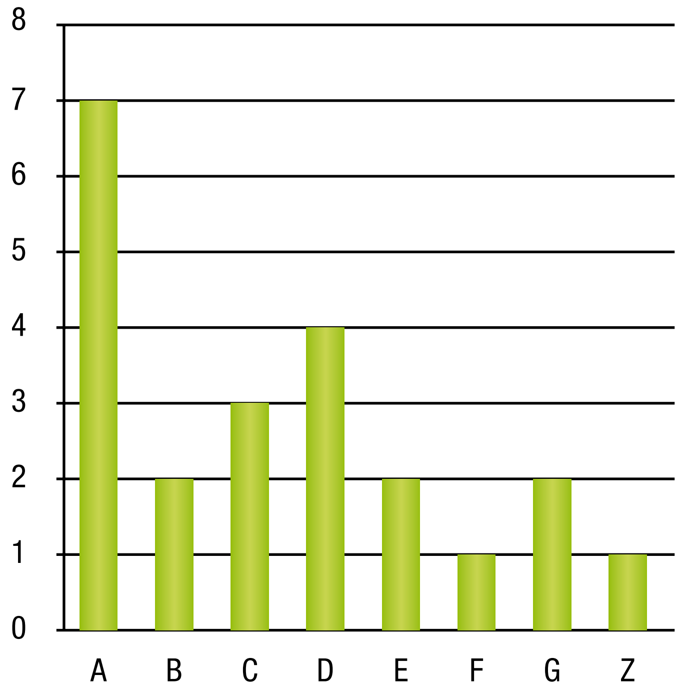
Note: Each respondent could give more than one answer. A total of 27 answers were given, all are represented above.

PARTNERS

The successful introduction of methane as a vehicle fuel in the city or region depends on support from key partners such as the European Union, the national government, regional and municipal authorities, the media, motorist and consumer organizations, gas distributors and original equipment manufacturers who build cars, trucks and buses *[City of Göteborg et al. 2005].* Some of these partners might already be stakeholders in the biogas business. If this is not the case, it is essential to ensure their involvement through positive cooperation.

Research from BIOGASMAX indicated that municipalities are the strongest supporters of biomethane use in general, followed by regional, federal and national authorities. The EU is ranked lowest in terms of support for biomethane use. When asked who they consider to be the strongest supporters of their biomethane enterprise, respondents provided similar answers, shown in Figure 11.

Figure 11 **STRONGEST BIOMETHANE SUPPORTERS**



A= Municipality where the plant is located;
B= Regional authorities;
C= Regional politicians;
D= National/federal authorities;
E= Politicians from nation-wide parties;
F= EU authorities;
G= Politicians from European political parties;
Z= None

Note:
This graph is based on a total of 22 responses provided by 14 respondents. Each respondent could give more than one answer.

Respondents' main motivations for running a biomethane business are the need for clean city air; reduced CO_2 emissions; and the necessity to reduce dependence on imported fuels. While these reasons are part of the political goals set by the European Union, their implementation lies primarily with the municipal and regional level actors. Support from these levels is, therefore, essential throughout the entire process.

Involvement of the media is necessary for both educational and publicity purposes. The media are the principal means through which the larger public can be educated on topics like climate change, alternative fuels and the need for responsible consumer choices.

The BIOGASMAX respondents indicate that news releases as well as stories or interviews in the local and national press are among the more effective promotion and publicity strategies.

Partnerships with motorist and consumer organizations are an important part of the political process. Frequent contact with independent organizations helps governmental and European decision makers balance their policies with the needs of producers and users. Non-governmental organizations and special interest groups representing various stakeholders can help producers and consumers to speak in a common voice.

Collaboration with gas distributors is generally based on technological needs. Without their support, there is simply no biomethane business. Generally, gas distributors are willing to work on and (partly) finance a biomethane project since new biogas opportunities can expand their services and are likely to bring positive returns on investment in the long run.

Like partnership with gas distributors, cooperation with vehicle manufacturers also is important. They provide methane vehicles and are a primary contact point where drivers can learn (more) about this environmentally-friendly transport option.

Local vehicle dealerships (as well as the OEMs) should be willing to develop and market (new) NGV models. It is an advantage if corporate policies and strategies are set up to stimulate NGV sales with resources and techniques comparable to those used to sell traditional petroleum-fuelled cars and trucks.

CUSTOMERS

Biomethane is a gaseous fuel, whose potential customers – despite the existence and familiarity of liquefied petroleum gas (LPG) – are not necessarily familiar with its as a use vehicle fuel. Perceptions that 'driving on gas is dangerous because of the explosion risks' is one of the misconceptions about methane that inhibits its ready acceptance as a vehicle fuel. Providing clear explanations about the safety of methane in transport applications, cost savings, environmental advantage for society, as well as the simple and safe fuelling of the vehicle are essential in the promotion of biomethane.

Other comments and issues that a biomethane entrepreneur are likely to encounter relate to the drivability of methane fuelled cars. While biomethane cars perform almost identically to petrol/diesel cars, one of the issues faced is the distance that can be driven on a full gas tank, which is less than that of a petroleum fuelled car. This is because there is less energy per volume with a gaseous fuel than there is with a liquid fuel.

The distance of a bi-fuel vehicle can be greater than a petrol vehicle since an additional fuelling system is being added to the normal petrol system, unless a vehicle manufacturer reduces the size of the petrol tank in order to install the compressed natural gas fuel cylinders. This will vary on a vehicle-by-vehicle basis. The fuelling of a methane car takes slightly more time than that of a liquid fuel car. Methane filling stations are typically found less frequently than petrol fuelling stations. The number of available methane fuelling stations does, however, continue to grow.

The different categories of methane vehicles lead to different groups of NGV users with different needs. Heavy-duty and off-road vehicles are most likely to be used in fleets, by governments or municipalities, and in commercial applications. Operators of large fleets typically will want their own centrally located fuelling stations, although smaller fleet operators tend to want public fuelling, similar to the average commuter who also want to make use of public fast-fill stations. The long-term development of an easily accessible fuel distribution infrastructure is critical.

Developing a critical mass of individual methane vehicle drivers is an essential and potentially challenging aspect of developing the biomethane market for vehicle applications. On the one hand, gas distributors as well as OEMs need a certain number of drivers in order to develop the fuelling infrastructure and make new vehicle models available. On the other hand, the public needs fuelling stations and the availability of methane vehicles. Consequently government subsidies and incentives to all parties involved are necessary in the early stages. Municipal, regional and national authorities have to 'start the pump'.

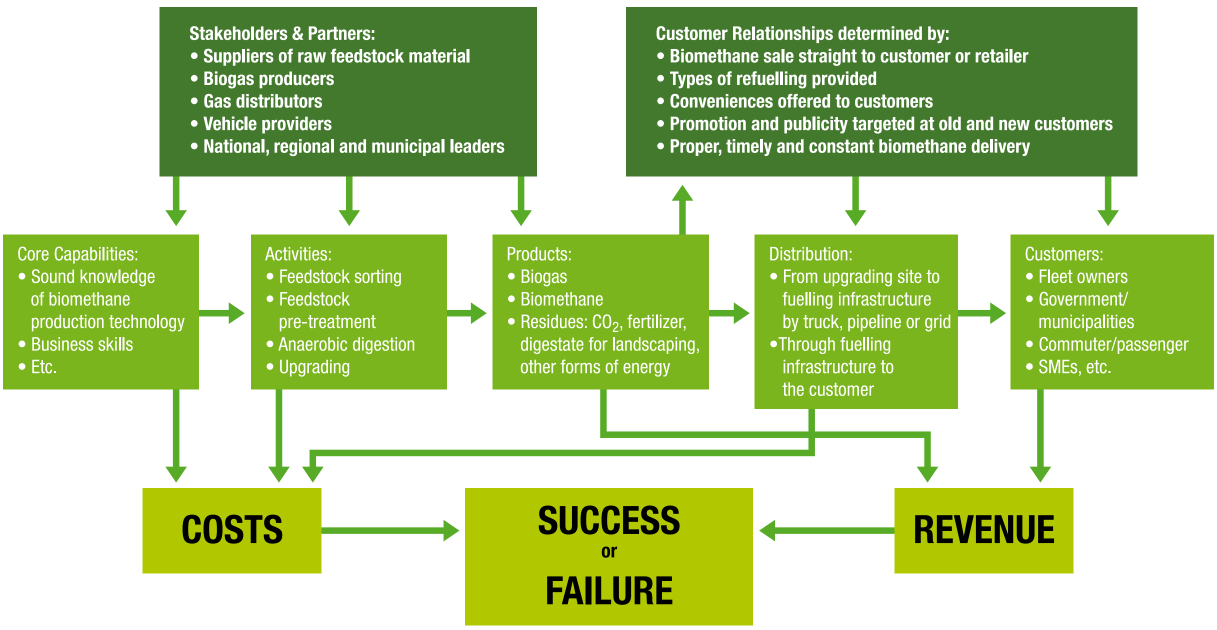
EXAMPLES OF GOVERNMENT INCENTIVES

There are a variety of incentives provided by governments to stimulate the NGV market. Financial incentives are proven to help stimulate the market, since economics is a prime motivation for customers to use NGVs. Stable and long-term governmental financial support can help convince more drivers to opt for an environmental friendly fuel option. Avoided costs, such as those associated with lowering air pollution, can be integrated into the economic calculations of the biomethane investment.

Experiences in Sweden, for example in the cities of Stockholm and Gothenburg, show that relatively simple measures can make the use of methane vehicles more attractive:
• Improved access to parking facilities for vehicles classified environmentally-friendly;
• Reduced parking fees for NGV users;
• Exemption from congestion charges for alternative fuel users;
• Priority for the user ordering a methane-run taxi;
• Priority lanes for taxis run on gas;
• Permission to drive in restricted areas with an NGV.

[Source: City of Göteborg et al. 2005]

Figure 12 **BIOMETHANE BUSINESS MODEL**



4.2

BIOMETHANE COSTS AND ECONOMICS

COST EVALUATION

In a direct cost evaluation biomethane may not, at first glance, appear to be the most cost-efficient fuel option available. Biomethane production and technology result in elevated costs vis-à-vis traditional vehicle fuels. Once the larger picture – including avoided societal and environmental costs - is taken into account, the cost benefit analysis changes.

INVESTMENTS

The BIOGASMAX respondents indicated that their total investments range from € 3.3 to 66.5 million. Investment costs vary according to many variables, including: the size and number of the plants, its engineering and location, the feedstock composition, the degree of pre-treatment needed *[NSCA. 2006]*, etc. Respondents indicated that the majority of the plants have been established mostly with private funds, followed by a smaller number of entirely publicly funded biomethane production facilities.

PRODUCTION AND OPERATION COSTS

Biomass is the starting material for biogas production. Forty three percent of the users surveyed buy feedstock at an established price, while 52% of the respondents establish the price through negotiation. A set price is most frequently based on gate or collection fees. In agricultural settings there also are cases where no payment is made for the feedstock, but where the farmers who deliver biomass receive digestate fertilizer in return.

Biogas upgrading costs also depend on the size of the biomethane production plant. Larger production will lead to lower upgrading costs. In 2004, a report of the Swedish Gas Center indicated upgrading costs ranging from 3-4 eurocents/kWh for a small biomethane production site to 1-1.5 eurocents/kWh for a larger facility *[Jönsson. 2004]*. In 2005, the Swedish Gas Council identified a range of 0.11 – 0.22 eurocents/Nm^3 *[Rietz. 2005]*.

Common biomethane operation costs are related to staff employment, insurance, feedstock transportation, licenses, pollution limitation and control, excess fertilizer disposal costs, as well as repair and maintenance *[NSCA. 2006]*. Research in Scotland indicates operation costs ranging from approximately 3,000 euros for small-scale plants to approximately 1,330,000 euros for a large-scale plant treating municipal waste *[Monnet. 2003].(1)*

DISTRIBUTION

The costs for methane distribution depend on the distribution and fuelling infrastructure available. In case pipelines are not available, costs can be higher. Construction of a pipeline costs 150,000 €/km; in congested city centers this cost is much higher. It is much more economical to construct a biogas plant in a location that is already connected to the natural gas grid.

Investments in a fuelling station include the costs of the compressor, intermediate storage capacity, dispensers and construction. Depending on these factors, a slow fill system capable of serving a few vehicles will cost € 3,500 – 10,000 whereas a large fast-fill station for more than a hundred vehicles can cost several hundred thousand euros or more *[Task Force Natural Gas Vehicles. 2000].* It is also important to recognize the influence of the fuelling station size on the fuel price:

"At smaller filling stations the investment costs have a crucial influence on the fuel price that means a reduction of the investment costs results in lower fuel prices. For larger fuelling stations the situation is the exact opposite. Gas supply and energy costs have a decisive influence on the fuel price."
[Task Force Natural Gas Vehicles. 2000 : 16]

In many cases the fleet operators pay for the installation of their own fuelling station (as opposed to a public station) so dealing with these economic and cost details, and how best to design a fuelling station for each fleet's need will not be a concern of the biogas producer. In cases where the biomethane is used to fuel the biogas producer's fleet, these costs would be a consideration as part of the overall investment in the production plant.

Downstream costs would be reduced if other fleets or private operators of NGVs in the neighbourhood of the biogas plant could purchase compressed methane directly from the biogas facility.

All numbers provided in this chapter are indicative, but not exact. Any potential biomethane enterprise should be based on a detailed cost benefit analysis tailored to the situation at hand.
(1) Currency conversion from UK£ to € at the rate of 1GBP to 1.48 EUR.

END USE

In order to be attractive to the average vehicle user, the cost of biomethane should be 30-50% lower, than petrol or diesel, compensate for the higher vehicle investment costs. The more kilometers traveled by the NGV – commercial or private, the faster the payback will be for the higher cost of the vehicle.

In the current market, light duty OEM NGVs can cost from € 1,500 to € 3,500 more than a petrol vehicle, depending upon the national tax regimes for new vehicles. Medium duty commercial vehicles can cost between € 5,000-7,500 more, depending upon the vehicle and its applications. Heavy-duty trucks and buses typically are about 20-25% more than comparable diesel vehicles. Prices for fleet purchasers of large volumes of vehicles will differ widely.

AVOIDED COSTS

The avoided costs of biomethane consumption consist of societal costs for avoided emissions like carbon dioxide (CO_2), nitrogen oxide (NOx) and particulate matter (PM). In Sweden, one of the less polluted countries in Europe, the societal costs for these emissions have been identified, as shown in figure 13.

Figure 13 **OFFICIAL SWEDISH SOCIETAL COSTS CAUSED BY EMISSIONS**

(€/kilo, year 2002)

Emission	Urban area	Additional value, central Stockholm	Total
NOx	6.5	3.1	9.6
PM		1,000	1,000
CO^2	0.16		0.16

Source: Wallman. 2006.

Replacing petrol and diesel by biomethane, 0.36 €/liter can be saved in Sweden on petrol pollution; 0.43 €/liter can be saved on diesel in the Swedish urban area; and 0.89 €/liter can be saved in Swedish city centers. In addition, reduced methane leakage due to avoided, uncontrolled fermentation of biomass saves another 0.24 € for each liter of petrol replaced and 0.26 € for each liter of diesel replaced (1). This leads to the following total estimated societal benefits for every liter of petrol or diesel replaced (figure 14).

Figure 14 **ESTIMATED SOCIETAL BENEFITS** PER LITER OF PETROL/DIESEL REPLACED

	Passenger cars			City center buses
	Petrol replaced	Diesel replaced		Diesel replaced
	(€)	Urban area (€)	City center (€)	(€)
Vehicle	0.36	0.43	0.89	0.82
Avoided methane leakage	0.24	0.26	0.26	0.26
Total	0.60	0.69	1.15	1.08

Source: Wallman. 2006.

(1) The Danish Energy Board states that for each m^3 biogas from anaerobic digestion, 0.2 m^3 natural methane leakage is avoided. The numbers in the text above are based on a conservatively estimated 10% leakage avoidance. (Source of estimations: Wallman. 2006).

REVENUE

Revenue streams can come from the sale of biomethane and by-products. The following indicators are used to evaluate biomethane plants' income:

- m^3 of biomethane produced / ton of waste treated
- The price of m^3 biomethane sold linked to the natural gas price
- Production cost: € / Nm^3
- Comparison of costs with partner plants
- Electric kWh input / thermal kWh produced
- Raw biogas input / upgraded biomethane output

5

BIOMETHANE PRODUCTION SCENARIOS

In this section, different biogas and biomethane production and distribution sites in France, Italy, Poland, Sweden and Switzerland are examined. Topics include motivations for biomethane implementation, technology, output(s), consumers, distribution as well as challenges and recommendations to others considering developing biomethane production sites. Also, guidelines and tips are provided towards the development of one's own biomethane production scenario.

5.1

BIOGASMAX BIOMETHANE SCENARIOS

5.1.1. BIOMETHANE MARKET BREAKTHROUGH: REGION OF GÖTEBORG, SWEDEN

Biogas West is a regional cooperative project in Western Sweden for the implementation of biomethane as a vehicle fuel. This activity is led by Business Region Göteborg and involves more than 25 stakeholders representing municipalities, organizations, authorities and companies. In the western region, among the participants are Göteborg Energi, Fordonsgas Sverige and the municipality of Falköping, all partners in the BIOGASMAX project.

MOTIVATIONS FOR BIOMETHANE IMPLEMENTATION

The purpose of Biogas West is to develop a new environmentally sound industry that stimulates the market development of production, distribution and use of biomethane as a vehicle fuel. This will contribute to creating job opportunities, while at the same time reducing greenhouse gas emissions in the area. In addition, it solves waste problems and stimulates the production of eco-fertilizers.

IMPLEMENTATION

In the Region of Göteborg, the entire public/private system is involved in the project. This synergy creates strong political support that can change the financial conditions and provide a long-term perspective, thus making a holistic view of biomethane implementation possible. This vision is based on what is termed 'the green gas principle', a concept that indicates the mixture of bio-methane and natural gas. A customer can fuel a methane vehicle at the local fuelling station with natural gas, and then the corresponding amount of biomethane is then injected into the natural gas grid afterwards.

ACHIEVEMENTS & FUTURE GOALS

As of December 2005, Biogas West had produced 126 GWh green gas, replacing 14.5 million liters of petrol. This means that the emission of greenhouse gasses in West Sweden has decreased by

17000 tons a year. In 2006, 35 fuelling stations ensured the circulation of 7000 methane vehicles in the area. Currently, Biogas West and the City of Stockholm are working together to establish the Biogas Highway, a main road connecting Göteborg and Stockholm, which the NGV driver can travel without having to worry whether there will be sufficient opportunities to fuel the vehicle on the road.
Working towards higher standards in the year 2010, Biogas West aims to have 16,000 methane vehicles on the road, including 300 buses and 200 heavy-duty vehicles. These will be fuelled by a total of 65 fuelling stations, including 6 fuelling stations for busses. In order to make this successful, 300 GWh green gas will have to be produced in 2010, including 180 GWh biomethane and 120 GWh natural gas. With the full implementation of the Biogas West program CO_2 emissions will be reduced by some 50000 tons a year. The targets set for the year 2020 are even stricter. By that year, 150 fuelling stations should fuel 100000 methane vehicles on the road in West Sweden. Consequently, 1500 GWh will have to be produced yearly by 2020.

The Biogas West stakeholders have a clear vision of their actions through 2020. On the basis of the production targets described above, they aim to contribute to the region's environmental goals by decreasing emissions of harmful substances and gases. The development of this ecological industry is to create new job opportunities and lead to new export opportunities. By replacing 20% fossil fuels through methane injection, Biogas West wants to remain Sweden's leading region in biomethane production, distribution and use. Keeping international perspectives open and receiving foreign visitors on a regular basis, Biogas West is keen to create a large international network of biomethane producers, distributors and users.

CHALLENGES & RECOMMENDATIONS

In 2006 a decision by Volvo Car Corporation, one of the major stakeholders in the Biogas West project, to stop methane vehicle production has had an impact on the project, illustrating the importance of long-term and stable commitment of stakeholders to biomethane projects. Private vehicle users expressed their discontent over Volvo's withdrawal from the market, which they feared would have a negative impact on the second hand market value of their vehicles. The original equipment market has, however, not been affected by Volvo's decision since German producers have very swiftly expanded their markets into Sweden.

The use of older equipment (dating from about ten years ago) has been an inhibiting factor to certain producers in the Göteborg region. Taking into account the costly set up of the production processes and the long pay-off time for equipment, it is advisable to opt for modern, efficient equipment right from the start.

In order to stimulate the use of biomethane as a vehicle fuel, the green gas concept has proven to be an extremely efficient method for biomethane market introduction and expansion. A good contact with local distributors has been essential from the start and has greatly stimulated the development and successful use of the green gas concept.

When planning investments, not only technology and facilities have to be taken into account. Investment in people is as important. Regular training of all employees, from mechanics to communication officers, will provide them with insights that will make the company a stronger undertaking.

5.1.2. TOWARDS 100% GREEN PUBLIC TRANSPORT: LILLE METROPOLITAN, FRANCE

Having experienced two centuries of intensive industrial activity, the Urban Community of Lille has undergone deep restructuring and has experienced sustainable development as a cultural revolution and rebirth for over ten years. Nowadays, the population of Lille is willing to recognize environmental needs and benefits.

MOTIVATIONS FOR BIOMETHANE IMPLEMENTATION

The search for ecologically viable waste management has led the community of Lille to implement biomethane as a vehicle fuel in the municipality.

This sustainable solution helps Lille decrease waste volumes caused by the gradual phasing out of the use of landfills. In addition, it facilitates the increase of the waste management services' energy production and enables the city to develop a 100% clean public transport system.

IMPLEMENTATION

Starting in the early 1990s, the city of Lille has brought biomethane production to full maturity in the region. In 1990, the first experiments in selective waste collection took place. In the context of its energy control policy, the community implemented a combined heat and power (CHP) facility on a sewage treatment site to recover the biogas produced from the sludge. This program provided for the construction of a scrubbing unit for the surplus of biogas that was previously flared. Biogas-based methane production followed in 1994, with the capacity to fuel four buses. Five years later the Urban Community of Lille decided to progressively replace the entire diesel bus fleet with natural gas and biomethane buses, to be fuelled with the biogas produced from the ecological waste-treatment process.

ACHIEVEMENTS & FUTURE GOALS

By 2003, 70,000 tons of clean, dry waste was recycled in the community of Lille and an additional 60,000 tons of bio-waste was recycled. The construction of the Organic Treatment Centre (CVO) in Loos/Sequedin in 2005 allowed for the treatment of 100,000 tons of biowaste a year. With the additional construction of a natural gas/biomethane bus terminal in the same year, 100 of the 150 buses run on methane. In 2007 the CVO was opened and biomethane production equivalent to 4,5 million liters of diesel/year now will be possible.

CHALLENGES & RECOMMENDATIONS

Experience in Lille proved that it is necessary to know precisely (i.e. quantitatively) the potential for biogas production in the region. This means that the potential feedstock sources and the range of their energy production potential need to be established in the business-planning phase. In addition, one should not hesitate to over-size the production infrastructure to be sure that the objectives set for biomethane quality and quantities can be reached.

The infrastructure builders should be asked to guarantee results in order to avoid major disappointments in the end. Also, it is important to realize that these technologies are still 'semi-industrial'. Adjustment periods can be expected and extra time should be allocated in the business planning. The biogas and biomethane production technologies develop rapidly but, as is the case with all new developments, fine-tuning takes time. Another important consideration is the impact upon the production facilities of seasonal climatic variations: extreme heat or cold will affect the technologies used and their production efficiency.

5.1.3. A CLEAN STRATEGY IN THE MAKING: ROME, ITALY

Environmental and conservation concerns have led the leadership of the historical city of Rome to work towards more environmentally-sound strategies. The Mediterranean climatic conditions and the large physical area covered by the city helped determine the most suitable waste management strategies that paved the way for biomethane production and use. AMA, the Roman Environmental Municipal Agency, is taking the lead in this project.

MOTIVATIONS FOR BIOMETHANE IMPLEMENTATION

The municipality of Rome strongly encourages the use of alternative fuels in public and private fleets to comply with environmental standards and requirements, to save energy and to reduce oil-dependence.

IMPLEMENTATION

The sole biogas provider in Rome is the landfill and biogas plant of Malagrotta, which is owned by a private company. The processed and landfill waste produces a considerable amount of biogas, which has been used mostly to fuel Malagrotta's own electric power plant. Part of the biogas is now upgraded to biomethane quality for use in AMA's heavy-duty waste collection trucks.

ACHIEVEMENTS & FUTURE GOALS

Working to expand an initial fleet of ten vehicles, Rome aims to at least double the number of biomethane-fuelled waste collection trucks. The city is investigating the possibility to exploit more organic waste (a total of 65000 tons / year) in a new anaerobic plant that should produce 10.000.000 Nm^3 of raw biogas, including 1.800.000 Nm^3 of biogas upgraded to biomethane.

In order to ensure more balanced urban development with minimal environmental damage, AMA is examining the city waste management strategies. Waste collection should be complemented increasingly with the use of waste products. This requires adaptation of current facilities, reallocation of facilities, and re-design of the waste collection services to overcome logistic and technical problems related to biomethane and CNG use in its fleet.

Considering that the Malagrotta location faces saturation, Rome prioritizes the development of a new waste management approach that integrates different forms of waste management schemes, including application of the organic waste potential. AMA has identified three waste treatment plants in Maccarese (presently producing compost but to be increased with an anaerobic unit) as a source to supply the growing agency fleet with biomethane in the future.

CHALLENGES & RECOMMENDATIONS

Throughout the past ten years of operation, biomethane quality remained the main issue of concern in Rome. The Malagrotta plant only performs limited waste sorting, which results in highly contaminated biogas that needs to be worked heavily in the upgrading process. Consequently, the upgrading process has been rather costly and produced biomethane that required considerable engine maintenance on AMA´s vehicles. Such additional costs can be avoided so long as the specific end uses of the gas and the required gas quality are considered from the start to the end of the production process.

5.1.4. PREPARED FOR FURTHER EXPANSION: STOCKHOLM, SWEDEN

The breakthrough concept of biomethane sales in Stockholm has been successful in the past years. Volumes have increased considerably and developments are extremely positive. However, this success has caused demand and supply to become unbalanced. Work is now ongoing to meet the increased fuel demand by producing more biomethane and expanding the infrastructure of biomethane fuelling stations.

MOTIVATIONS FOR BIOMETHANE IMPLEMENTATION

The municipality of Stockholm has set a goal to become a fossil fuel free city by 2050.

IMPLEMENTATION

Biomethane has been produced in the Stockholm area since 1996. The pioneer consumer of biomethane was the community itself. Several measures helped the city to expand its market to other customers. The municipality introduced free parking in the city for clean vehicles and biomethane has been made cheaper than petrol using a variety of government-sponsored financial and tax incentives. In addition, subsidies towards clean vehicle use are provided by the state. Finally, the municipality maintains an active communications program to the public and specific target groups with general and specific information on biomethane production, distribution and use.

ACHIEVEMENTS & FUTURE GOALS

Aiming for the goal to become a fossil fuel free city by 2050, the city of Stockholm continuously works towards improved environmentally friendly transport solutions. Within the context of the BIOGASMAX project, the city will extend the number of fuelling stations available in the city and its surroundings by a factor of four.

In addition, the existing biomethane vehicle fleets will be extended with a fleet of 25 heavy-duty and 80 light-duty methane-powered vehicles. This will increase participation in Stockholm's Clean Drivers' Network with more than ten new members.

CHALLENGES & RECOMMENDATIONS

Firstly, in order to produce more biomethane, Stockholm is attempting to optimize its gas production. Additionally, new sources for biomethane production are likely to come from the agricultural sector.

By using a mix of sludge, waste and crops, more biogas can be produced. Currently demonstrations with such feedstock mixes have created the basis for a new renewable energy scenario in the Stockholm region.

5.1.5. BIOGAS POTENTIALS: THE REGIONS OF ZIELONA GÓRA AND TORUN, POLAND

Rapid economic development has made the Central European area attractive to local and foreign investors. The large amounts of biomass present in the new EU member states could give these countries a natural advantage in the energy market, including the market for clean vehicle fuels. In Poland, Zielona Góra and Torun are taking the lead in promoting biomethane as a vehicle fuel.

MOTIVATIONS FOR BIOMETHANE IMPLEMENTATION

The potential for biogas production in Poland is significant. There is an abundance of possible biomass sources, from dedicated crops and agricultural residues to industrial and urban waste. This potential is, to date, largely unexploited mainly due to low awareness about renewable energy, the lack of a legal framework for optimal biogas production and usage, as well as the need for financial incentives.

Solutions and operational models demonstrated within the BIOGASMAX project could be used to promote the usage of biomethane in transport. In Poland wastewater plants and landfills still flare most of the residual biogas. In the cases where the biogas is retrieved, it is used most often to produce electric and thermal energy.

The use of biogas as an alternative energy source presents several advantages to the regions of Torun and Zielona Góra. The growth of energy crops and targeted biomass collection can help the regions' economic development. Biogas and biomethane production would create new employment opportunities, allowing for agricultural wastelands to be used and the agriculture at large to develop in this new direction.

IMPLEMENTATION

The biogas installation in Torun allows for a change from the usual biogas flaring practices. The site specializes in the recuperation and use of waste gas. It is the first in this area of Europe to have modern, high quality technology producing electricity and thermal energy, while also being suitable for cogeneration. This not only allows for the elimination of harmful impacts of landfill gas emissions that aggravate the greenhouse effect, but also improves the regional image and environment through sustainable energy production.

ACHIEVEMENTS & FUTURE GOALS

The City of Zielona Góra is one of the first cities in Poland to have developed and implemented a strategy for waste management including the retrieval and the use of biogas. The city is represented by the Institute of Environmental Engineering of the University of Zielona Góra. A plantation and facilities for energy production from biomass are to be developed on the 400 hectares of land belonging to the university, where biogas production will be demonstrated as part of a larger educational programme. Biogas production from the sewage and landfill waste in Torun amounts to approximately 5 million m^3 a year. Due to the application of cogeneration and professional operation, the biogas recuperation facility functions with significantly higher efficiency than originally assumed. Over 3 million m^3 of biogas with levels of methane contents of 45-55% are produced annually from the municipal landfill waste. The biogas from the landfill is used to generate about 5,500 MWh of electrical power and 25,000 GJ thermal energy, which is transmitted to the municipal thermal grid. It is expected, that the installation will be in operation for about 20 years, generating 4,000 MWh of power and 38,000 GJ of heat per year.

CHALLENGES & RECOMMENDATIONS

Taking into consideration the rural character of vast areas around cities and the existence of the national gas grid, Poland has considerable energy potential by producing biogas. The absence of a government policy related to the use of renewable energy sources is the factor most inhibiting the sufficient exploitation of the Polish biomass potential at the moment, as well as the absence of pricing incentives for different parts of the biomethane cycle: from biomass production to fuelling infrastructure development and methane vehicle purchase.

Training and education have been identified as potential breakthrough factors. The public sector as well as the local and national government decision makers need to learn more about the implementation and use of renewable energy sources. In addition, engineers, architects, as well as energy and bank sector representatives need additional education to be able to integrate sustainability in their respective fields of work so that various stakeholders can be united in support of a sustainable national (or regional/local) renewable energy policy.

ConVoco, Biogaz Inwestor and the University of Zielona Góra are working together to exploit the potential of the biogas production in Poland and to create pathways for its usage in transport. Together these groups estimate the production potentials and develop strategies for biogas production and usage in the region, benchmark the available production technologies, promote dedicated plantations for biomass production, and lobby for a suitable legal framework as well as price incentives in order to prepare the introduction of the full well-to-wheel biomethane cycle in Poland.

5.1.6. A LIGHTHOUSE PROJECT IN THE MOUNTAINS: BERNE, SWITZERLAND

The city of Berne is committed to efficient use and ecological production of energy. Participation in the BIOGASMAX project allows the city to build on existing biomethane projects and to continue actively to promote this alternative fuel in the Swiss capital.

MOTIVATIONS FOR BIOMETHANE IMPLEMENTATION

Improving air quality and reducing noise pollution have been the main reasons for introducing biomethane in Berne.

IMPLEMENTATION

Since 1989 Berne carries the label Energiestadt (Energy City). The municipality feels obliged to permanently show and act with a high degree of climate consciousness. The Local Agenda 21 organization supports projects that contribute to the quality of life and make the city more attractive. Nature, economy and society are its main focus points.

In 2006 the active promotion of biofuels has started at the local level. The introduction of biomethane is the main initiative to reduce the emissions of green house gases in the city.

ACHIEVEMENTS & FUTURE GOALS

Making use of what is termed the Ökofund (Ecofund), the local energy and water company succeeded in bringing an initial ten methane-fuelled busses into the municipal transport system. By the end of 2006, an additional 22 were delivered. In 2008, a total of 60 biomethane-driven buses are expected to be running in Berne. This number will increase until 100% green public transport is reached in 2010 at the latest.

CHALLENGES & RECOMMENDATIONS

The methane-fuelled public buses in Berne make use of fast-fill and slow-fill indoor facilities. The building of these indoor filling stations was a complicated regulatory project, mainly due to the limited familiarity of inspectors with the gas fuelling stations.

It has been hard to convince the bus drivers and mechanics of the advantages to switch to biomethane. Offering them the necessary training has helped overcome their resistance. Both drivers and mechanics now take profit of their extended knowledge of alternative fuel and fuelling systems.

It is equally important that vehicle sales people are well informed about the advantages and disadvantages of biomethane vehicles.
In Switzerland they do, for example, need to know that biomethane is a tax-free fuel. In addition, the purchase of an NGV is subsidized or a certain amount of free gas is provided. In Berne, training has contributed to extended knowledge and awareness among retailers and sales people.

BUILD YOUR OWN BIOMETHANE SCENARIO

The ultimate scenario that can provide potential biomethane producers and users with a standard format does not exist.
There are, however, a series of elements that each and every producer or user will have to take into account when shaping their own ideas.
These elements are explored and highlighted in this section.

Figure 15 provides an overview of all aspects of the biomethane business start-up, and the general timeframe of decisions and developments that may be required. An overview of the questions one can ask when preparing a biomethane scenario also is provided.

These questions point to factors that can make the municipal or regional biomethane enterprise a success; particularly by taking advantage of things that others have already learned. Please note that the timeframe for this process can vary widely depending upon many variables involving the overall commitment being made by governments at all levels, the human and financial resources available, permitting, public acceptance, etc.

However, the elements in the decision process should not change dramatically.

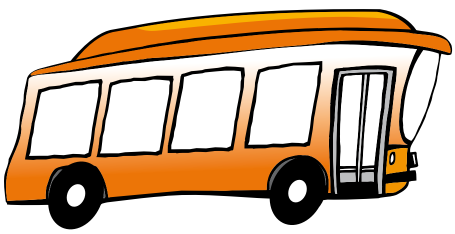
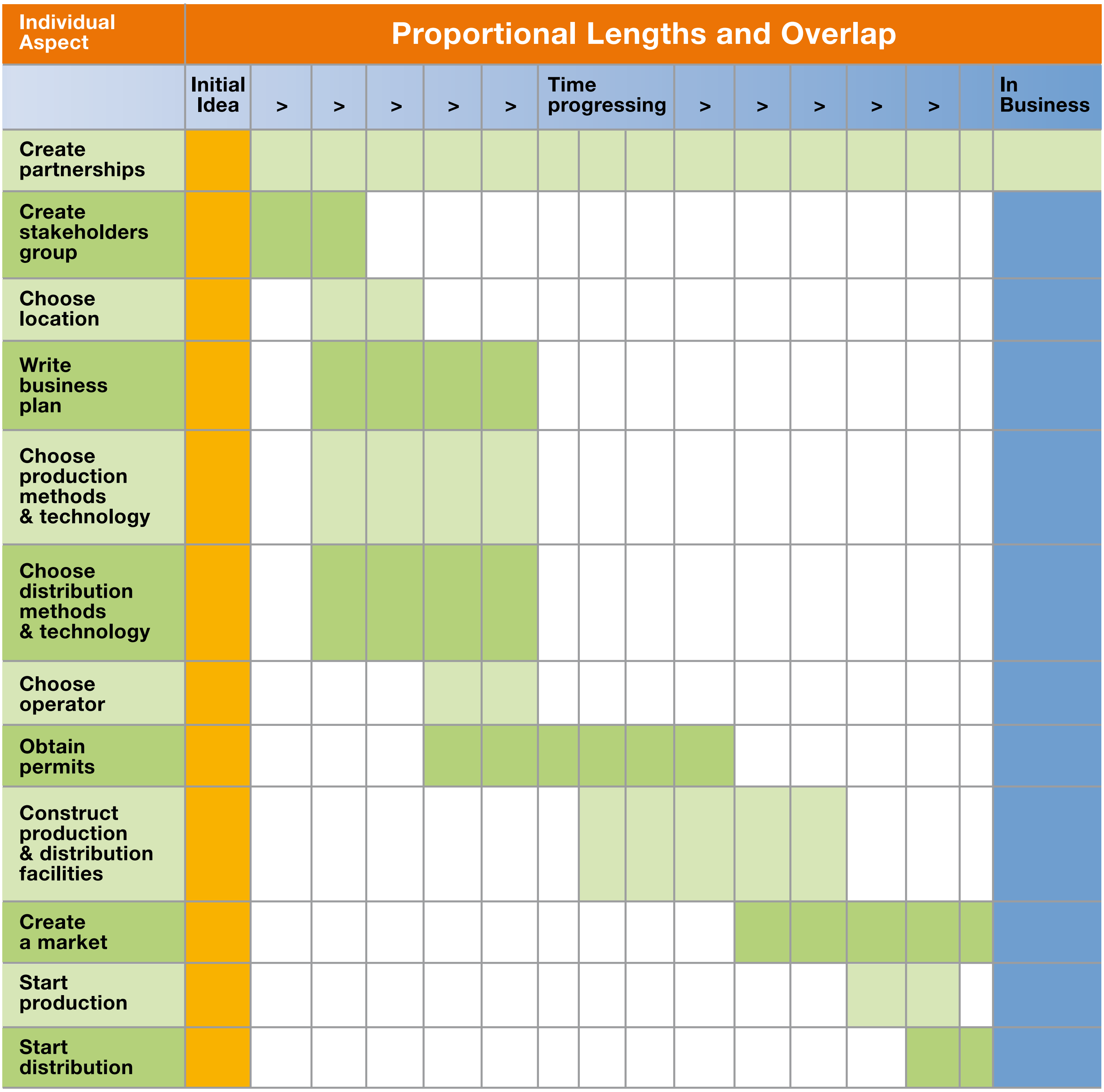


Figure 15 **ASPECTS OF THE BIOMETHANE BUSINESS START-UP**



CREATING PARTNERSHIPS

- *Are there contacts among the following entities available to create partnerships?*
  - Municipal, regional, federal and national policy and decision makers
  - Municipal, regional, federal and national institutions and authorities
  - Vehicle manufacturers
  - Feedstock providers and/or biogas producers
  - Natural gas distributors and suppliers
  - Potential consumers
- *In what way(s) can basic cooperation and active involvement of partners be initiated, continued and enhanced?*

CREATING THE STAKEHOLDERS GROUP

- *Is there at least one representative stakeholder for each of the following?*
  - Feedstock sources
  - Biogas/biomethane production
  - Biomethane market
- *In case biomethane is not yet being used in the municipality or region: Is there at least one committed biomethane buyer who can guarantee a market at the beginning of the undertaking?*
- *Does the stakeholders group cover the necessary core capabilities?*
- *Do all stakeholders have a basic commitment to cooperation?*
- *Can the stakeholders create synergies?*

CHOOSING THE LOCATION

- *What is the proximity of the location with regard to the following?*
  - Possible feedstock sources
  - Existing distribution infrastructure(s)
  - The future market(s)
- *Is it probable that permits will be given for biomethane production at this location?*
- *Is this environment conducive to creating synergies between stakeholders?*

WRITING THE BUSINESS PLAN

• *Which costs are foreseen for the following elements of the biomethane business?*

- Investment(s)
- Production and operation
- Distribution
- Vehicles

• *What revenue streams are expected?*

• *Which (societal) costs are avoided with the replacement of fossil fuels by biomethane?*

CHOOSING THE RIGHT PRODUCTION METHODS AND TECHNOLOGY

• *Given the local situation, what are the best technologies for the following production elements?*

- Feedstock fragmentation
- Feedstock hygienization
- Digestion
- Biogas production
- Upgrading

• *What climatic influences can be expected: which facilities can be placed outdoors and which facilities need to be placed indoors?*

CHOOSING THE RIGHT DISTRIBUTION METHODS AND TECHNOLOGY

• *Is the production facility connected to the gas grid (or in close proximity to the gas grid)?*

• *Will the fuelling unit be placed inside or outside?*

• *What is the distance of the production facility to the biomethane consumer(s)?*

• *How will the residuals be distributed?*

PLANT DESIGN CRITERIA

• *Is the constancy of the methane flow taken as the focus of the plant design?*

• *Are back-up storage facilities foreseen in case of down time of the upgrading facility?*

• *Is the plant output measured correctly against the customer demand for gas?*

• *Has emergency flaring equipment been taken into consideration?*

• *Is it possible and economically viable to receive biogas from several locations and upgrade the gas centrally or will the entire production process take place in one centralized location?*

OBTAINING PERMITS

- *Which permits are needed?*
- *Where can these permits be obtained?*
- *What obstacles or objections can be expected?*
- *How can these be overcome?*
- *How long might the process take?*

PUBLIC CONSULTATION PROCESS

- *Will public consultation be required?*
- *Will an environmental impact analysis be required?*

CONSTRUCTING THE PRODUCTION AND DISTRIBUTION FACILITIES

- *Have all construction related permits been obtained?*
- *Is the local climatic condition expected to influence the time needed for construction and finishing?*
- *Where do the materials and production installations need to come from?*
- *How much time is needed for the delivery of materials and the construction?*
- *Are the materials and installations suppliers guaranteeing deadlines and results?*

CREATING A MARKET

- *Is there at least one committed, long-term buyer with whom to start the market development?*
- *How will other potential customers and consumers be targeted?*
- *What existing subsidies and incentives can help the biomethane market creation and expansion?*
- *What subsidies and incentives could be created to stimulate market development?*

STARTING PRODUCTION

- *Have all production related permits been obtained?*
- *For how long will the production trial period last?*
- *What technological adjustments are likely to be needed before market entry?*
- *Are buyers and users being prepared for the distribution start?*

STARTING DISTRIBUTION

- *Have all distribution related permits been obtained?*
- *For how long will the distribution trial period last?*
- *What technological adjustments are likely to be needed before full distribution starts?*
- *Are buyers and distributors ready for the distribution start?*

6

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annex 1

TERMS & DEFINITIONS	
Biogas	Biogas is a renewable resource that can be made from agricultural waste (both plants and manure), crops, urban waste, sewage from urban water purification processing, and - through a separate process - from wood. The feedstock is heated at about 30°C and the waste material transforms into mostly methane (CH_4) and carbon dioxide (CO_2).
BIOGASMAX	The European Commission funded ‘Biogas as a vehicle fuel – Market Expansion to 2020 Air Quality’ project. *[contract number # 019795]*
Biomass	Biomass is the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste. *[EC. 2005]*
Biomethane	Biomethane is the upgraded version of biogas, which means that it has been made suitable for use as a vehicle fuel.
Bi-fuel natural gas vehicle	A vehicle designed or adapted to run on either natural gas/methane or petrol
CH_4	Methane
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CVO	Municipality of Lille Organic Treatment Center in Loos/Sequedin
Dedicated vehicle	A NGV running on methane solely (as compared to a bi-fuel vehicle)
E	Energy
EJ	Exajoules, equal to 1018 joules
ETS	The EU Emissions Trade Scheme
EU	European Union
GWh	Gigawatt-hour (109)

H_2	**Hydrogen**
KWh	**Kilo-watt hour (103)**
L-CNG	**Liquefied-to-Compressed Natural Gas, whereby LNG is vaporized into a vehicle as CNG**
LNG	**Liquefied Natural Gas**
m^3	**Cubic meter (also shortened for standard cubic meter Sm^3, standard at 15 degrees Celsius at 1013.25 millibar)**
MGV / MGVs	**Methane Gas Vehicle / Methane Gas Vehicles**
Natural gas	**Natural gas (also termed methane, CH_4, or simply gas) is a gaseous fossil fuel that consists of mostly methane (CH_4) and some carbon dioxide (CO_2). Natural gas is extracted from oil and natural gas fields. It is also found in coal beds in smaller quantities. Biological sources of methane are termites, ruminants and cultivation. In addition to other uses, natural gas is a suitable vehicle fuel. Natural gas gets delivered to the customer as compressed natural gas (CNG) or liquefied natural gas (LNG)** ***[NA. 2006].***
NGV / NGVs	**Natural Gas Vehicle / Natural Gas Vehicles**
Nm^3	**Normal cubic meter (measured at 0 degrees Celsius at 1000 millibar. 1 Nm^3 = 1.056 Sm^3)**
NOx	**Nitrogen oxide**
NPK	**Nitrogen, phosphorus, potassium**
OEM	**Original Equipment Manufacturer**
PM	**Particulate matter**
Quick fill	**Filling up the tank of a NGV at the speed approximately equivalent to petrol (gasoline) filling.**
Slow fill	**Filling up the tank of a NGV over a number of hours.**
SMEs	**Small and Medium Enterprises**
Syngas	**Also known as synthesis gas. A mixture of carbon dioxide and hydrogen that can function as feedstock for biomethane production.**
VFA	**Volatile fatty acid**
VRA	**Vehicle refuelling appliance (slow fill)**

annex 2

VEHICLE TYPE COMPARISON

LIGHT-DUTY VEHICLES :

Dedicated light-duty vehicles	Bi-fuel/dual-fuel light-duty vehicles
Advantages:	**Advantages:**
• Optimal engine use leading to higher power output, lower fuel consumption and better exhaust gas emissions • More available space for CNG tanks • Better access to incentive programs	• Low cost system (only for retrofit systems) • Not dependent on fuelling infrastructure • Higher total range due to double fuel system • Fuel efficiency will be on par with petrol engines, meaning considerably reduced operating costs
Disadvantages:	**Disadvantages:**
• Higher system price • Restricted total range • Dependency on fuelling station availability	• Compromise on engine technology • Restricted range operating only on natural gas

HEAVY-DUTY VEHICLES:

Dedicated heavy-duty vehicles	Dual-fuel heavy-duty vehicles
Advantages:	**Advantages:**
• Optimal power output, emission and drivability • Negligible particulate matter (PM) emissions • Secured use of CNG infrastructure	• Low cost engine development for retrofits • Less CNG storage space required in comparison to dedicated heavy-duty vehicles, which results in a lower vehicle weight • Diesel mode as a back-up • Drivability comparable to a diesel vehicle • Better resale value for base vehicle
Disadvantages:	**Disadvantages:**
• High costs for engine development • Technology relatively unknown to heavy-duty service networks • Restricted to CNG infrastructure	• Compromise in diesel vs. methane technology • Emission results are not optimized, e.g. particulate matter exist in exhaustion fumes • Fuel costs are higher when the diesel mode is used more frequently

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