Biogas as Vehicle Fuel

A European Overview

October 2003, Stockholm

Trendsetter Report No 2003:3

FOREWORD

The spontaneous development of transport in Europe is not sustainable. To change this it is necessary to mobilise and present a carefully chosen combination of measures that cover several areas and involve various responsibilities in the cities rather than a list of isolated efforts. In other words, to have an integrated approach.

The European project TRENDSETTER involves 50 individual projects, all of which aim to; improve mobility, quality of life, air quality, and reduce noise and traffic congestion. The cities of Stockholm, Lille, Graz, Prague and Pécs co-operate in the project to ensure real impact, by setting good examples and encouraging others to follow.

More information is available at http://www.trendsetter-europe.org

This report is produced within the framework of the Trendsetter project. It is a summary of European experiences of Biogas, with a focus on the use as a vehicle fuel. It highlights the lack of European legislation and regulation as a major barrier to the further development of biogas use, but also presents some examples of best practise and provides a guide for cities interested in producing and upgrading biogas.

The report has been compiled by Charlotte Plombin, Engineering student at the Ecole des Mines d´Albi, France, as a part of her internship at Stockholm Environment Administration.
Project Manager Björn Hugosson at Stockholm Environment Administration, supervised the work.

Stockholm, October 2003

Gustaf Landahl
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SUMMARY

This reports is a survey over biogas production and utilisation in the EU. The biogas is a non-fossil gas which is produced from sewage, manure, landfills or food industry waste. With those numerous and abundant origins, the potential of the European biogas production is so large that it could replace 12 to 20 % of the natural gas consumption. However, because of a high investment cost and a heavy infrastructure, only fifty percent of the biogas production is upgraded, and the natural gas replacement is very low.

This renewable energy is already used for heat and electricity production, but the best upgrading solution of this clean energy should be the injection into the natural gas grid or the production of vehicle fuel.

Today, the lack of European legislation and regulation on the renewable energies is a barrier to the development of upgraded biogas. Even if European and national incentives focused on the utilisation of clean energy and renewable fuel is now being discussed, the biogas future depends very much on national concerns.

There is evidence that a good natural gas infrastructure and a favourable legislation would permit a faster biogas development and spread (this is the case for Switzerland and South of Sweden). Nevertheless it is necessary to take in consideration that biogas is worth using rather than natural gas because of its renewable sources.

Despite of those obstacles, some European countries and cities have set up biogas as vehicle fuel projects. It is the case of Sweden, France, Switzerland, Iceland and Italy who started in the 90´s bus, lorries and cars biogas fleets. It is important to know that today, the development of the biogas production is more a question of marketing and industrialisation than a question of research and development.

With about 1500 vehicles and 22 biogas refuelling stations, Sweden is the most advanced country of Europe. It is followed by Switzerland who has about 600 biogas vehicles running on a mix of biogas and natural gas. At least, the cities of Lille (France, 124 vehicles), Reykjavik (Iceland, 44 vehicles) and Roma (Italy, 12 vehicles) developed viable and important biogas fleet realisations.

An analysis of those pilot biogas achievements shows incontestable positive results. From an environmental point of view, the biogas as vehicle fuel demonstrated its qualities in comparison with fossil fuels.

Even if there it is not economical profit yet, all those projects are economically viable because they respect some basic rules as providing a sufficient infrastructure, producing substantial volumes through industrial solutions, proposing favourable legislation, support by politics, reaching fixed goals and being helped by European Commission and International projects.
As a conclusion to the guideline, setting up a city biogas project needs a strategic alliance between the actors of the project (politics, producers, and distributors). But it is important to have in mind the satisfaction of the consumer that passes through a good infrastructure, an attractive product and a large communication.

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INTRODUCTION

The fossil resources of oil, gas and coal are not unlimited. The environmental problems caused by waste and wastewater have to be repaired and to be avoided in the future. Beside the above-mentioned problems there is to be regarded that water itself is also limited.

One effective way to avoid these problems is biogas-plants; actually the biogas, which is produced by the fermentation of animal dungs, human sewage or agricultural residues, is rich in methane and has the same characteristics as the natural gas. The use of biogas as a clean fuel answers to current concerns dealing with economics, ecology and energetics:

- search on renewable energies while the fossil deposits are draining,
- reduction of the energetic dependence,
- limitation of the atmospheric pollution linked to the gas emissions,
- decrease of the smell and noise annoyances
- reduction of the green house effects.

Biogas fuels usually cause low pollution to the atmosphere and because they come from renewable energy resources, they have a great potential for future use.

For the last decade the use of biogas coming from sewage collection, farms and industrial treatment has risen constantly. Nowadays biogas plants are easily available in the market, and biogas constructions have been installed all over Europe. The upgraded biogas is mainly used for heat and electricity production. However more and more projects using biogas as vehicle fuel are set up in European cities. Indeed, this vehicle fuel is the best way to upgrade waste. Nevertheless a governmental support is needed in order to make the biogas market attractive because of its high investment costs.

1) Biogas: production and use

1-1. Conditions of production

- **Basic techniques**

The waste collected at the plant undergoes a chemical treatment in order to be turned into biogas. It is the anaerobic digestion, or methanisation

Methanisation is an anaerobic digestion process that follows a double incentive:

- energetic upgrading by production of methane (CH_4)
- stabilisation of the organic waste

The methane fermenting is a long known conversion process of the organic substance into energy in anaerobic conditions under the influence of bacterial flora. The biogas generated during the methanation represents itself the liquid methane, carbonic acid, up to 1% of sulphured hydrogen, not a large amount of nitrogen oxygen, hydrogen, ammonia and oxide of carbon.

Biogas average composition
CH_4 : 50 – 80 %
CO_2 : 15 – 45 %
H_2O : 5 %
H_2S : 0 – 2 %

Source: Chemical laboratory of Liège University

The anaerobic turning of the biomass is carried out by three constant stages:

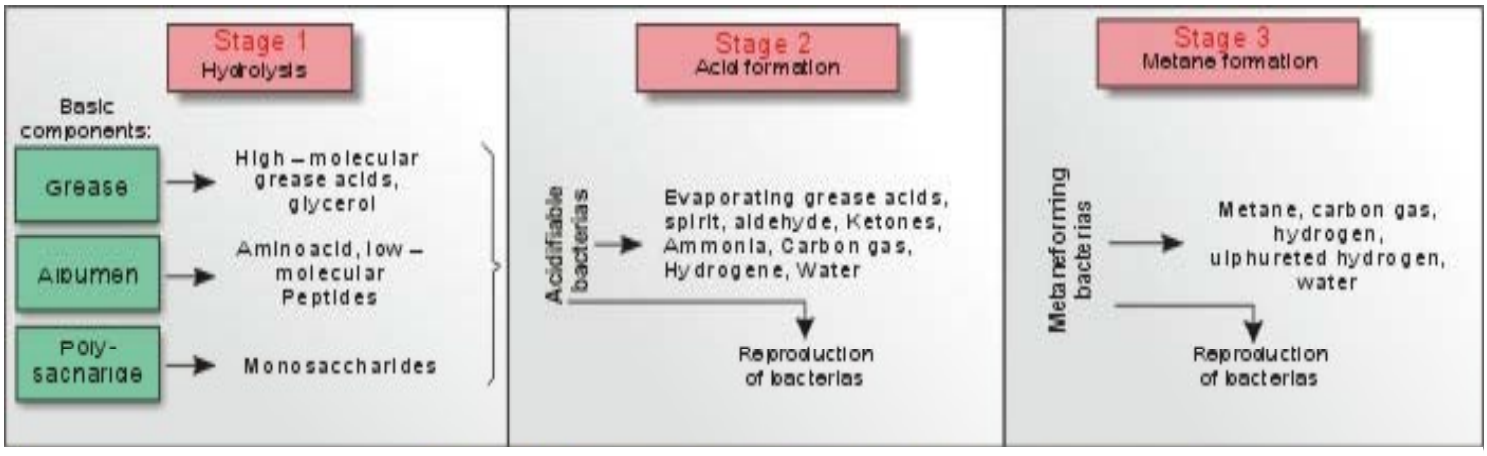


Fig. 1. Stages of the anaerobic digestion
Source: www.biogas.virtualave.net

A good quality of the produced biogas essentially depends on an optimal output of the bacteria and on a valuable environment (good substrate, absence of oxygen, optimal pH, high humidity, temperature around 35 °C and low amount of sulphate).

The production of biogas follows this scheme:

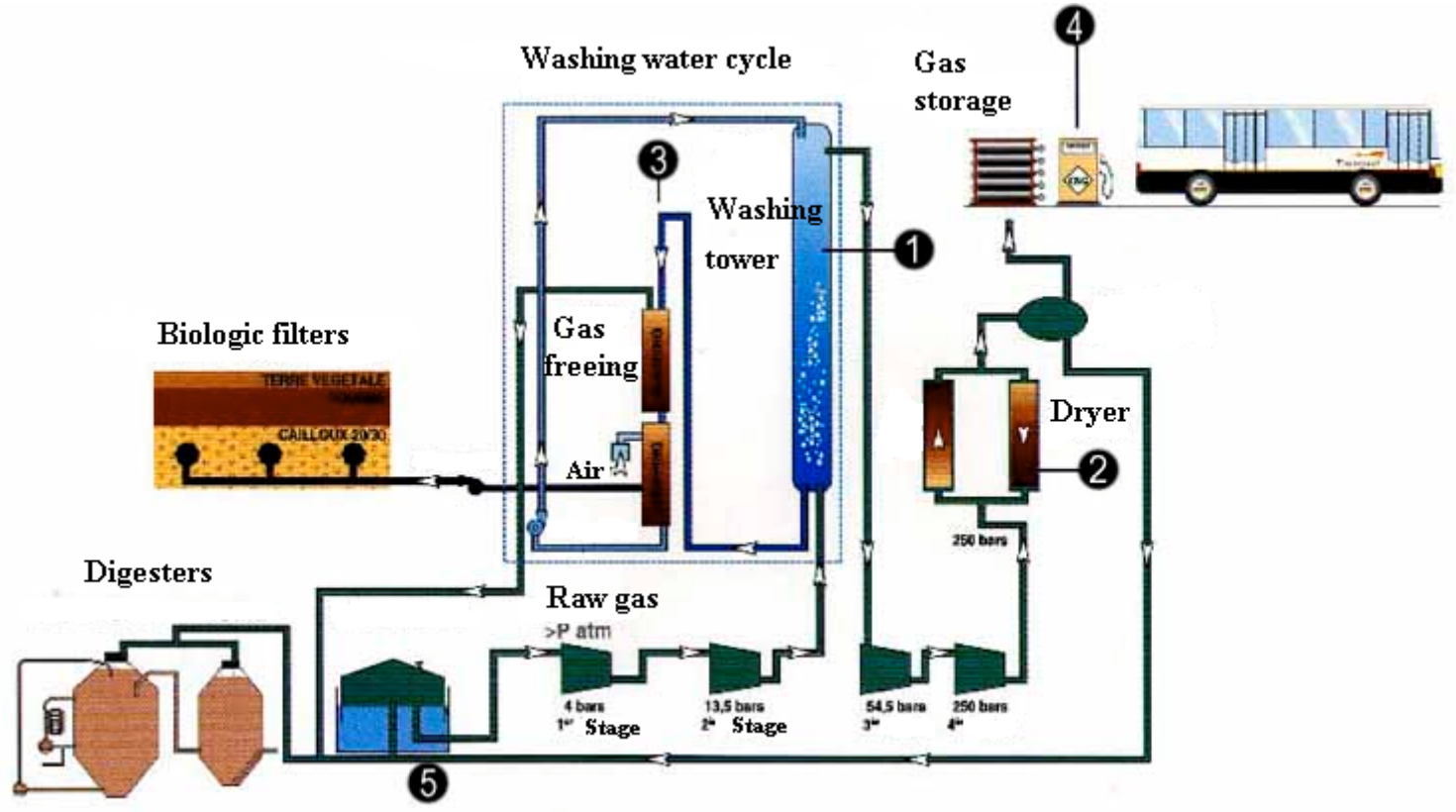


Fig. 2. The biogas plant principle
Source: Lille-Marquette biogas plant

1: The gas is compressed under 10 to 15 bars and injected in a washing pressure tower into which the water solubilizes the carbon dioxide and the H_2S of the biogas.

2: Then the gas is dried on 2 molecular screens under 250 bars.

3: The washing water is recycled by gas freeing in two steps:

- first, the recuperated gas of the highest gas-freeing, rich in CO_2, H_2S and CH_4 is injected as raw gas into the pressure stages.
- secondly, the gas salted out in the lowest gas-freeing tour is sent back to the biologic filter where bacteria eat H_2S.

4: The dry and pure gas is stocked at 250 bars into steel bottles that feed the filling station.

5: The non-suitable gas is sent back to the beginning of the plant.

- **Purposes of the biogas production**

Producing biogas means enhancing the value of a renewable natural gas and reducing greenhouse gas. Whatever its origin, the non-upgraded biogas contributes to the greenhouse effect. Nevertheless the carbon dioxide liberated by the combustion of the biogas has no impact on the greenhouse effect. This CO_2 comes from the carbon dioxide stocked into the organic substance during the photosynthesis. Therefore there is no "additional" gas freeing, as it is the case for the fossil deposit.

Methane is a clean fuel: it owns a shorter carbon chain compared to the other fuels. Thanks to that, its combustion permits a reduction of 65% of the carbon oxides and 30% of the nitrogen oxide.

Moreover the use of the biogas as a clean fuel answers to current concerns dealing with economics, ecology and energetics:

- search on renewable energies while the fossil deposits are draining,
- reduction of the energetic dependence,
- limitation of the atmospheric pollution linked to the gas slops,
- decrease of the smell annoyances,
- needs three times less treatment area than composting.

Nowadays the development of the biogas production is more a question of marketing and industrialisation than a question of research and development.

1.2- The main upgrading solutions

Once the biogas is picked-up or produced, the best way to use it is enhancing its value. Several ways are possible: producing heat, electricity, cogeneration, vehicle fuel or injection in the natural gas grid.

The heat and electricity productions are now well known techniques whereas the two other ways are still on their development phase. The choice between those solutions depends on numerous technical and economical criteria into which the nature and the localisation of the production site are the main factors. Actually, the site may need intern energy (heat for the digester and premises, electricity in order to feed the machinery). It may happen that potential users of this energy are situated around the site (plants, heat grid, pipelines gas, transport fleet…). But the site is very often isolated (this is a common case for the dumps), and in this case the only possible upgrading is the production and sale of electricity.

- **The scrubbing techniques**[1]

Whatever the final use of the biogas is, it is nearly impossible to use it as it is produced. The only valuable fraction is the methane contained into the biogas; the other components are useless, objectionable or noxious. Consequently one or several treatment stages are necessary:

Upgrading use	***Components to eliminate***
Heat	Water, sulphur
Electricity / Cogeneration	Water, sulphur, organo-halogens
Fuel	Water, sulphur (H_2S), organo-halogens, carbon (CO_2)
Gas grid	Water, sulphur, organo-halogens, carbon, oxygen, metal

Source: www.biogaz.atee.fr

- It exists numerous solutions to eliminate the water, as using a diphasic separator. When using the biogas for the gas grid injection, the main techniques are the glycol absorption or the molecular screens. When the biogas is turned into fuel, the water concentration must be inferior to 15 mg/Nm^3: the best solution is the Pressure System Adsorption.
- A pass on iron oxide or activated carbon easily eliminates the sulphur (H_2S). A water scrubbing can also eliminate both sulphur and carbon dioxide.
- Scavenging of the organo-halogen components and the heavy metals is done thanks to a pass on activated carbon.
- The oxygen is eliminated with a catalytic treatment.

- **Heat recovery from biogas**

Test conditions

Burning biogas in a boiler or industrial furnace is the most commonly valorisation method developed. The methane content can go down until 20%, and the scrubbing techniques are light.

The machinery used for the heat production is very common: burners or classical injectors.

Economical conditions

It is admitted that the thermal upgrading of the biogas is profitable when the flow overpasses 100Nm^3/h.

[1] According to "Techniques de l´ingénieur", *Biofuel characteristics*, vol. BE and www.biogaz.atee.fr

- **Production of electricity**

Test conditions

Electricity production or cogeneration can be run with a biogas boiler followed by a vapor turbine. This classical method is easy to set in place and the scrubbing constraints are very light.

A new method was born a few years ago and consists in installing spark ignition engine or dual-fuel engines. This machinery is slower, more versatile, more durable, but twice more expensive than the former method. Besides they need a biogas containing at least 40% of methane.

Economical conditions

The electricity production becomes profitable when the biogas flow exceeds 400Nm^3/h.

- **Producing fuel**

Tests conditions

For this use, the purity specifications of the gas are stricter than the previous ones. Indeed, the biogas used as a fuel must contain a minimum of 96% of methane. Moreover the vapor content must be lower than 15 mg/Nm^3, the H_2S content does not exceed 100mg/Nm^3 and the particle size is limited at 40 microns.

The typical sequence for the preparation is:

- compression at 15-20 bars
- desulfurization and decarbonation by water scrubbing (loss of 8% of methane)
- dehydration by the process Pressure System Adsorption
- deshalogenation by a pass on activated carbon
- compression up to 250-350 bars.

Economical conditions

The economical analysis underlines that the gains are earned with the benefits done by comparison with an equivalent consumption of diesel fuel. In this valorisation the scale benefits are very important.

- **Injection into the natural gas grid**

Test conditions

The final composition of the injectable biogas depends on the grid specifications. Those requirements are focused on the contents of methane, carbon dioxide, oxygen, sulphur and halogens. Moreover the injectable gas must be odorised before the injection.

Economical conditions

As the production of fuel, the injection in the gas grid is a total valorisation, which is not affected to any combustion output. Nevertheless the treatments and the connecting pipes represent a heavy investment. It becomes profitable when the biogas flow exceeds 1000Nm^3/h.

1-3. Investments costs

NOTICE:

The following figures and costs investments come from different sources dated between 1999 and 2003[1]. Moreover the sources come from different countries; what means different fiscal policies. So the figures have to be read as European average of the investments into biogas plants and installations.

- **Heat recovery from biogas**

The investment for a boiler consuming 500m^3/h of biogas, and located nearby the source, is about 150 k€. This price recognises to studies and tests. The operating costs amount to 35k€/year. As the functioning benefits about 0,2M€/year of combustible, the returning time is very fast (less than 1 year). This economical balance sheet drifts downward once the distance between the biogas sources and the plant rises. A good financial output can be reached when the flow increases.

- **Electricity production**

Scale benefits permit to increase the output with the installed power. The investments costs fall from 1,5 to 1 k€/kW installed when the power passes from 150 to 1000kW. With an engine consuming 700m^3/year of biogas, and running 4760 hours, the returning time is about 4,5 years (including operating costs).

- **Biogas as fuel**

In this case, scale benefits are also very important. With a supply of 50m^3/h of biogas, capable to feed 8 buses or 32 cars, the investment is about 0,6 M€. The operating costs amount to 60 k€/year, what provide a biogas fuel price competitive with the diesel fuel (0,5€/m^3 or per litre).

Flow m^3/h	15	50	100
Price €/m^3	1	0,60	0,40

[1] According to ATEE-ENERGIE PLUS "*Biogas, the upgrading solutions*", May 2003

Returning time	No output	10 years	6 years

- **Gas grid injection**

The most expensive part of the gas grid injection is the pipes connection (if the plant is remote to the pipeline). Building a pipeline costs 150 000€/km, therefore the operation cannot be planned for a flow lower than 1000m^3/hour.

- **Abstract**

The following table shows the best upgrading solutions, depending on the biogas flow.

FLOW (m^3/h)	**>50**	**>100**	**>500**	**>1000**
Upgrading treatment	**Fuel**	**Heat recovery**	**Electricity**	**Gas grid injection**
Cost investments	600k€	75k€	1300k€	150 000€/km
Operating costs	60k€/year	35k€/year		
Selling price of the biogas (just after production)	0,5€/m^3	Combustible benefits 0,2 M€/year	Electricity price 75c€/kWh	Natural gas price

Production: 350 000 Nm^3/ year Production: 700Nm^3/h

Source: www.atee.biogaz.fr

This summary report underlines why the most common upgrading treatment for biogas is the heat recovery. Indeed, with a low cost investment and a very short recovering-time (1 year), this solution is the cheapest and easiest way to make money with biogas. However we will see in the next part that with new EU policies and supports, the other solutions are more and more developed.

2) European state of the art

2.1. General points

For the last decade, the use of biogas coming from sewage collection, farms and industrial treatment has risen constantly. Nowadays biogas plants are easily available in the market, and biogas constructions have been installed all over Europe. Nevertheless a governmental support is needed in order to make the biogas market attractive.

The European biogas production potential is so large that it could replace 12 to 20 % of the natural gas consumption. However, because of a high investment cost and a heavy infrastructure, only fifty percent of the biogas production is upgraded, and the natural gas replacement is quasi null. Today about 130000m^3 raw biogases are upgraded per hour in Europe, corresponding to about 2000MW per year. The largest potential for biogas is in agriculture, about 80% of the total. In most European countries with a dense natural gas grid, the opportunities for biogas injection are very good. Through the gas grid, biogas could be used for all applications, which are known for natural gas. But an essential precondition to enter into this use and investment is a proper legal situation to promote the use of the renewable energy gas from biomass.

- **Legal actions at EU level**[2]

The anaerobic digestion is involved in legislation of waste and digestate management, electricity injection, emissions as well as planning and constructing safety. Until now, anaerobic digestion in most countries is not a well-known form of waste management and almost all regulations have to be adapted to the needs of biogas sites.

Legislation regulations are different in each country. Denmark has been a pioneer in this sector by creating the first regulations of biogas. In the last years, Germany, Austria and Sweden have promoted biogas technology and used the Danish experience for their own regulations.

Right now there are two regulations under discussion on EU-Level which will have an impact on future development of the anaerobic digestion:

- Health rules concerning animal by-products not intended for human consumption (becoming into force in 2003).
- A working document on biodegradable waste management.

The European Commission also proposed alternative fuels policy in December 2001 called "20% Replacement of petroleum in transport sector targeted for 2020"[3]. They have adopted an action plan and two proposals for Directive to foster the use of alternative fuels for transport. The Commission considers that the use of fuel (such as ethanol and biogas) derived from agricultural sources is the technology with the greatest potential in the short-to-medium term.

[1] From Dr. Wolfgang Tentscher "*biogas in the internal market gas*", June 2002
[3] According to ENGVA, European Natural Gas Vehicle Association

Moreover the EU environment committee has suggested a draft amendment of the directive on gas, which contained formulations in favour of biogas and gas from biomass.

Recommendations for priority of biogas and gas from biomass 98/30/EC to MEPs and the Commission, 17th January 2002:

Justification for priority of biogas and gas from biomass in the internal market for gas:

- Environmental protection is highly important. The European treaty gives priority to environmental protection to other goals in the treaty.
- Protection of health through maintaining and restoring health promoting environmental conditions has priority to economic interests.
- The energy ministers of the EU have decided upon a new policy on energy in Europe, which has the target of using renewable sources of energy as the key source of energy supply
- Basic right of equal rights, obligations and chances for renewable energies in the internal markets for gas and electricity

Fig.3. Extract from the 98/30/EC article

The same rights, obligations and quotas for renewable energies should apply for the internal market of gas, i.e. for biogas and gas from biomass [*see ANNEX 1*].

- **European production of biogas**

What are the different ways of producing biogas?

Between 1990 and 2000, Europe faced a constant and slow growth of its biogas units. Today it is estimated that there are nearly 4000 methanisation plants in Europe to which the 450 waste storage centres that upgrade biogas must be added. Annual production of these installations is estimated at 2304 ktep (KiloTone Equivalent Petrol/Oil that means the energy produced compared to a kiloton of petrol/oil). The sector represents approximately 5% of all the energy resulting from biomass in Europe. Part of this production (about one half) does not find any market outlet and ends up being burnt off in flare stacks.

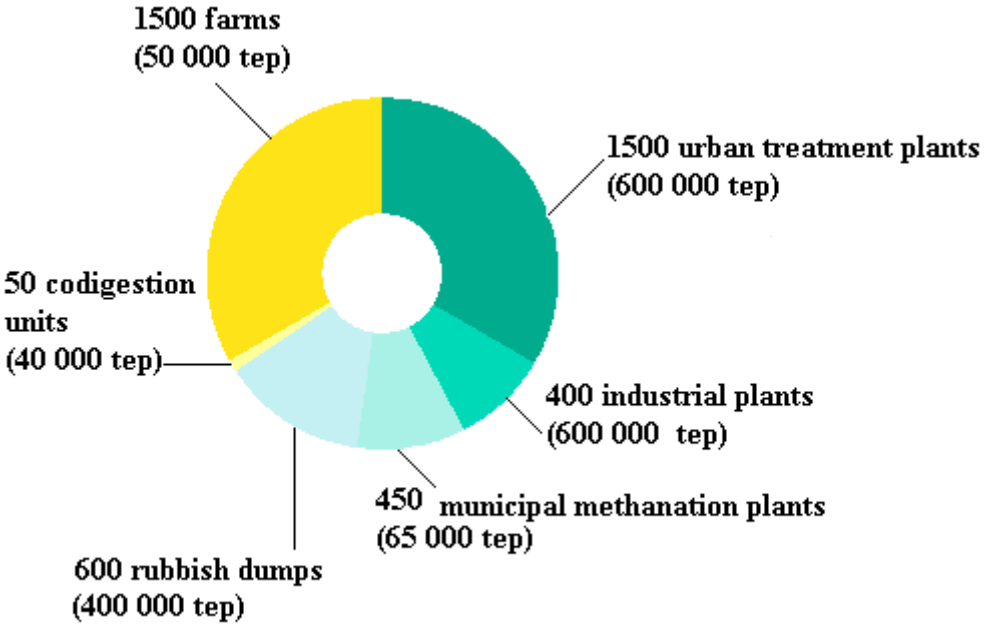


Fig.4. Number of installations per biogas deposit in Europe (in 2000)
Source: EurObserv´ER

Who produces most part of the biogas?

UK and Germany are the two leading countries in producing biogas. They have mostly developed the farms and landfills biogas plants.

France, Switzerland, Italy, Netherlands, Sweden, Spain and Denmark form the second group, which has not only developed farms plants, but also municipal metahnisation and dumps plants.

A deeper study of the leading countries will be done into the next part.

Country	Production of biogas in 2000 (ktep)
UK	897
Germany	525
France	167
Italy	143
Netherlands	143
Sweden	120
Spain	101
Denmark	72
Switzerland	58
Belgium	48
Austria	36
Ireland	24
Finland	17
Portugal	7
Luxembourg	2
Greece	2
TOTAL EU	**2304**

Source: EurObserv´ER, Annual balance sheet, April 2002

Fig.5. Estimation of gross annual production of biogas in Europe in 2002

The European Commission is targeting 1000 megawatts of installations at the conclusion of the *Campaign for Take Off* (end of 2003) and 15 million tep of biogas production in 2010[*see ANNEX 2*]. As of present the first threshold and benchmark have already been passed. On the other hand, the 2010 incentive is going to be much more difficult to attain.

What is the biogas production compared to the other energies?

Biogas is a renewable energy that does part of the biomass family. The scheme below shows that the renewable energies are a small part of the total energy production of Europe (9%). In that small figure, the biomass represents 45 % of the energy production in 2002.

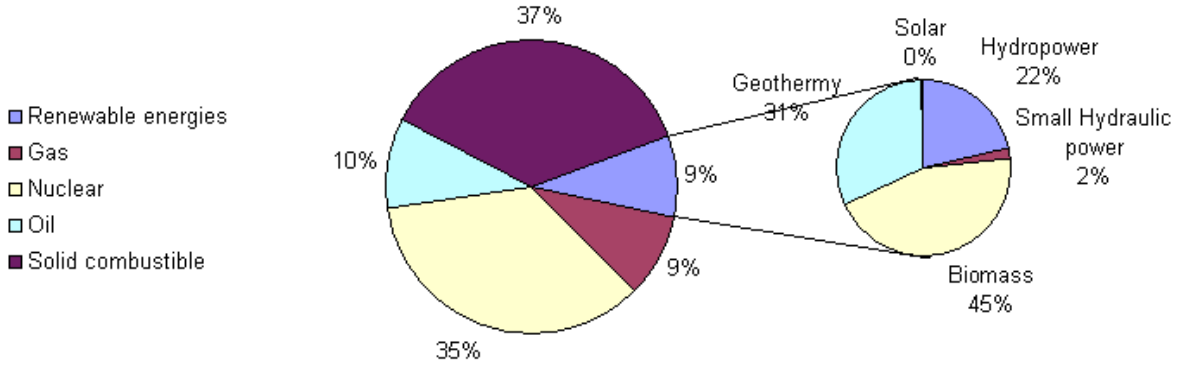


Fig. 6. Part of the biomass in the total energy production of Europe
Source: www.eubionet.vtt.fi

We can go deeper by doing an analysis of the countries producing this biomass:
- Finland, with timber provides more than 10% of energy thanks to biomass
- Austria, Denmark and Netherlands can produce about 3% of their energy consumption thanks to biogas

UNIT %	Hydraulic power	Wind energy	Biomass	Geothermal	**Total**	**2010 Incentives**
Germany	3,2	0,8	0,9	-	4,8	12,5
Austria	64,6	0,1	3,0	-	67,7	78,1
Belgium	0,5	0,0	0,6	-	1,1	6,0
Denmark	0,1	6,8	3,5	-	10,4	29,0
Spain	17,4	1,1	0,8	-	19,3	29,4
Finland	21,4	0,0	10,7	-	32,2	35,0
France	12,3	0,0	0,4	-	12,7	21,0
Greece	8,0	0,2	-	-	8,2	20,1
Ireland	4,4	0,8	0,4	-	5,6	13,2
Italy	15,9	0,1	0,5	1,6	18,1	25,0
Luxembourg	9,1	0,8	3,4	-	13,4	5,7
Pays-Bas	0,1	0,7	3,4	-	4,3	12,0
Portugal	33,3	0,2	2,6	0,1	36,3	45,6
UK	1,5	0,2	0,8	-	2,5	10,0
Sweden	47,0	0,2	1,8	-	48,9	60,0
Total EU	**12,3**	**0,5**	**1,2**	**0,2**	**14,2**	**22,1**

Fig. 8. Renewable energy production in Europe (2000) and 2010 incentives (transport, heating)
Source: Eurobionet

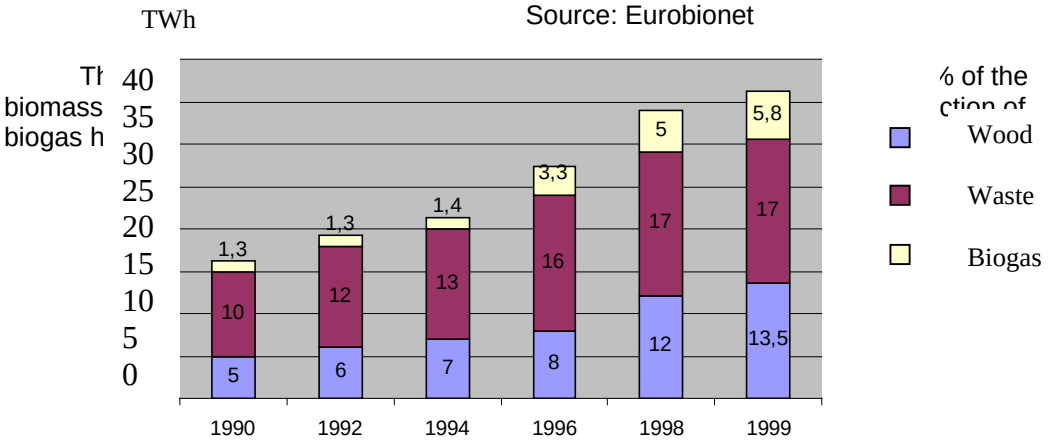


Fig.9. Breakdown of biomass into Wood, Waste and Biogas. EU 90-99
Source: European bioenergy networks

It is admitted that the European production of biogas is increasing, all the more about the European potential is large and still poorly exploited.

Forecast[4]

To follow the EU Commission incentives (*White paper*), the biogas production must have a big growth in the next years [*see ANNEX 3*].

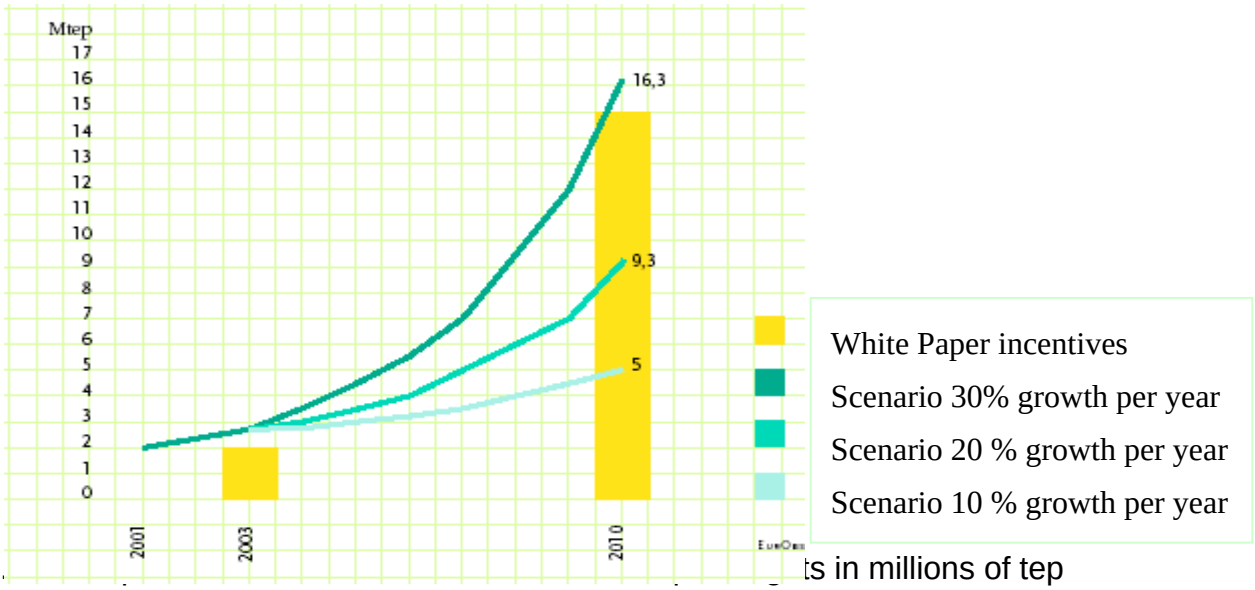
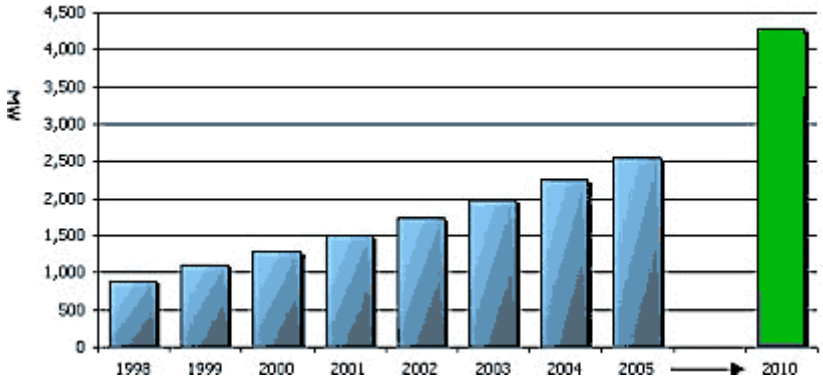


Fig. ts in millions of tep
Source: EurObserv´ER

Frost & Sullivan have studied the obstacles, drivers and trends of the European market of biogas. Their calculations and forecasts addressing the period 1998 to 2010 are shown below.



[4] From: Ian French "*Biogas: Untapped and Under-Developed - The European Market*", 2002

Fig.11. Forecast of the biogas production in Europe (2001)
Source: Frost & Sullivan

The rise in capacity is not sufficient to reach the EU's projected biogas-based electricity production of 38.4TWh by 2010. Frost & Sullivan forecasts just 21.8TWh (based on a load factor of 60 percents) thus showing a shortfall in the EU's expected generation of 16.6TWh. The difference between the two figures can be attributed to the general lack of favourable installation and generating incentives put forward by governments across Europe.

- **Biogas consumption**

Only 50% of the biogas production are used; indeed Europe still burns off in flare stacks a big part of its biogas production. The first use of biogas is producing heat for internal consumption (28%) and injecting electricity/gas into the grid (19%). 3 % of the upgraded production is used as cogeneration raw material and at least 1% are used for producing biogas fuel for vehicles.

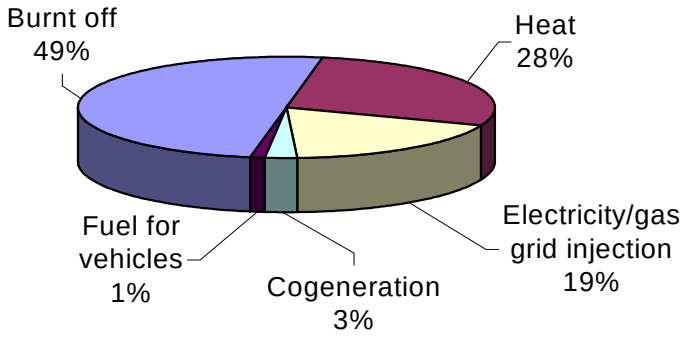


Fig. 12. Biogas use in Europe
Source: Biogas Barometer December 2002

- **Biogas used as fuel for vehicles**

As we just saw on the former graph, the biogas used as fuel for vehicles represents the smallest part of the production. The detailed study of the different projects existing in Europe is explained in the following part. However trends and common characteristics can be developed in this paragraph.

The majority of the biogas produced as vehicle fuel comes from municipal dumps and sewage and the size of the cities never drops down to 50 000 inhabitants. Some examples show that biogas fuel can be produced from cities which count about 20 000 inhabitants, but it’s because of their big industrial activity (ex: Eslöv, Sweden).

This upgrading solution is often chosen when the municipal dump or treatment plant already produces biogas for its own consumption (heat, electricity). Moreover the towns who decided to develop such a solution are already turned to friendly-environmental actions.

The first use of this biogas-fuel is for municipal equipment: buses, collection trucks, municipal car fleet. A relevant indicator of the reliability of this solution is when the private users begin to own their biogas car.

Another essential point that permits to build up demand is to target on the selling price of the biogas. Actually it is imperative to fix a biogas price lower than the cheapest fuel (normally diesel fuel). Some likely projects collapsed because of a too small difference of price between fuel and biogas (ex: Christchurch, New Zealand).

It is essential to notice that the majority of the biogas-fuel projects have been started during the 90´s; so they are all ongoing projects, which rely on the current policies and enhances.

The main reasons for developing such a solution are:

- stopping wasting the biogas potential into flare stacks
- saving money by selling biogas-fuel
- saving money by purchasing biogas-fuel instead of diesel fuel
- avoiding polluting emissions
- avoiding noise pollution

Nowadays there are about 12 European cities that run biogas vehicles. The policies and the environmental commitment of the state support those projects. That's why the most advanced countries in the use of biogas-fuel are Sweden and Switzerland.

2.2- Biogas upgrading in some European countries[5]

Austria:

Austria is a country with a large excess of pig and cattle manure: the animal production sets free about 300 000 tons of methane per year. The Federal State, the Ministry of Agriculture and the Ministry of environment support the creation of biogas plants.

About 100 plants, mainly farm scale, are now operating in Austria. It also exists about 20 large-scale biogas plants, which digests separate collected waste and sewage sludge.

[5] According to Dr. W. Tentscher "*Biogas in the internal market of gas, Compensation for biogas injected into the gas grid*", June 2002

However most of the separately collected bio-waste from the municipal collection is composted. None of the biogas plants are connected to the gas grid.

The aim of the Federal authorities is to install additional landfill gas collection systems. The problem is to use the collected gas, as the majority of the sites are rather small and located sparsely populated areas.

Denmark:

In Denmark, you can find three categories of biogas plants:

- 20 community biogas plants (600-8000m^3), delivering electricity to the grid and heat to the town. 60% of the raw material come from manure and 40% from industrial waste.
- 8 large and primitive biogas farm using manure to produce biogas for cogeneration.
- 18 small-scale biogas farms which produce electricity by cogeneration.
- a few municipal plants that digest sewage sludge and waste. The resulting biogas is mainly used for combined heat and power generation, and the digested biomass is redistributed to a wide range of crops at farms, as nutritionally fertiliser.

From January 1st 2000, a renewable energy reform was introduced in Denmark and the tariff conditions for biogas became less favourable by the introduction of a green certificate.

Finland:

Biogas production is almost non-existent; there is no problem with excess manure, and the cost of transports would be very high in a centralised biogas plant situation.

The main barriers for implementation of biogas technologies are: the current Finnish legislation that allows cheaper ways of treating manure, the low price level for electricity and the high costs of biogas production because of the dispersed location farms.

Germany[6]:

Germany is the second biggest producer of biogas in Europe, and the production is mostly due to biogas farms. In Germany, at least 1600 decentralised agricultural biogas plants existed at the end of the year 2002. National German legislation and promoting programs create good conditions to erect and run biogas plants. As the production of biogas is well running, the parliament requested to prepare a law on compensation for biogas injected into the gas grid.

In September 2001, the German Biogas Association estimated the potential for biogas and gas from biomass in the order of substituting 20 to 30 % of the actual German natural gas consumption.

[6] M.Harasek, "*Evaluation of the potential of biogas upgrading*", 1999 and ADEME, "*From biogas to Energy, an European ovevrview*", 2002

France:

Even if France has the biggest biogas production, its potential is exploited parsimoniously. At the opposite of the previous countries, France doesn't produce biogas from agriculture and manure. 185 municipal dumps and landfills are existing, whereas there are just 10 farm digesters. There are also 66 bio-industries biogas plant that run for producing biogas.

The biggest part of the biogas production is burnt into flakes or used as heat and electricity for the own consumption of the treatment station.

Several projects of introducing biogas into the natural gas grid have been studied, but they didn't fetch up (mostly because of the French gas monopoly of GDF, which wasn't expected to make money with biogas).

However, some biogas-fuel projects have been developed and France is a pioneer in the use of biogas for vehicles.

Italy:

Five centralised biogas plants are built in Italy, and more than 150 farm scale plants. There is no program on biogas in Italy, but the Electric Company of Italy is obliged to buy the electricity produced from biogas, at almost 80% more than the electricity price for end users.

The legal problems concerning the reutilization of the treated water is considered to be the main barrier to the biogas development.

Netherlands:

There are about 20 landfills treatment plants existing in the Netherlands and 5 sites using bio-waste produce biogas injected into the natural gas grid. However there is no use of biogas as vehicle fuel, even if the biogas is tax exempted.

Switzerland:

Switzerland has constantly multiplied its biogas producing capacity thanks to the industrial wastewater, the municipal organic waste and landfills and the agriculture. 11 anaerobic digestion plants of organic solid waste are implanted and the biggest part of the biogas is used for electricity and heat production. On 4 installations, the biogas is cleaned, compressed and injected into the natural gas network or sold as fuel for vehicles. Biogas is tax exempted.

The number of biogas farms has decreased evenly during the last years, but on the other hand, electricity production has significantly increased. Actually, since 1995, the new installations were implanted in larger farms, and replaced the small and old ones. On those sites the biogas is used to produce electricity and heat.

Sweden:

Sweden is one of the most developed European countries in the recycling and re-use of the biogas. The raw biogas comes from more than 20 sites, mainly sewage treatment plants, and it is commonly used as vehicle fuel. Half of the NGV-fleet is operated with biogas (about 1500 vehicles).

One plant in Lalhom, where a small natural gas grid exists, injects upgraded gas into the network.

But Sweden has problems with inefficient utilisation of manure nutriments, resulting in leaching to lakes along the western cost.

United Kingdom[7]:

UK is the first producer of biogas of Europe and the major part of its production comes from waste storage centres. During the end of the 90´s, the biogas sector especially benefited from the “Non Fossil Fuel Obligation” programmes that made possible to put 330 MWe into service at the end of the year 1999.

Moreover it exists more than 40 farm scale plants from where the biogas is used for cogeneration. The major part of the British biogas plants produces electricity thanks to a regulation that provides a premium electricity price to schemes ranging from landfill gas, food processing waste and municipal waste.

[7] According to Teodorita al Seadi “ *Biogas in Europe, a general overview*”, 1999,

2.3- Biogas as vehicle fuel in Europe

- **14 cities use biogas as fuel**

In 2003, 5 European countries have enhanced the biogas-fuel production:

- **Sweden** with **9** cities operating with biogas (Eslöv, Stockholm, Trollätthan, Uppsala, Helsingborg, Göteborg, Linköping, Kalmar, Jönköping and Kristianstad)
- **France** with **1** city (Lille) and two abandoned projects (Tours, Chambery)
- **Italy** with **1** city (Roma)
- **Iceland**, with **1** city (Reykjavik)
- **Switzerland** with several cities and lands using a mix of biogas and natural gas (Zurich region).

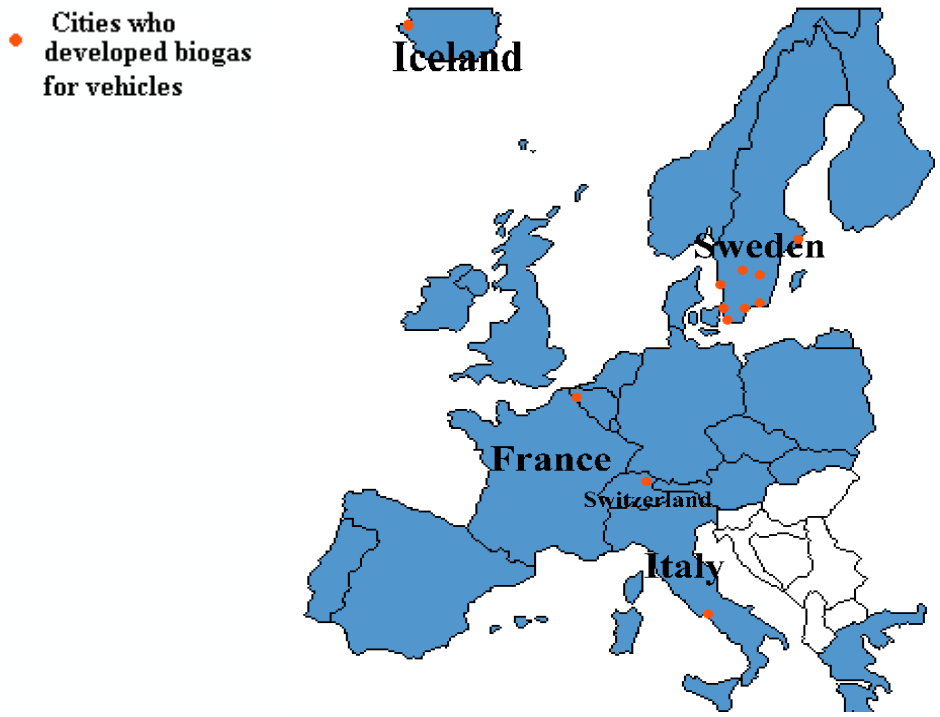


Fig.13. Biogas for vehicles in Europe

A detail of the biogas cities and refuelling stations of Sweden and Switzerland is available in the [*see ANNEX 4*]

- **Biogas distribution and selling costs**

This table is an abstract of all the biogas-fuel actions lead in Europe: the figures and information come from different reports[8] and several contacts[9] mainly working in national energy or biogas institutions. All the data are updated (2002/2003).

CITY[10]	SIZE (inhabitants)	SOURCE	Annual Production	vehicles park	Production cost	SALE
STOCKHOLM	800 000	sewage	1,5 MNm^3 (+ 3 MNm^3)	425 cars 3 lorries	0,7€/m3	0,9 €/m^3 1SEK less than petrol
LILLE	1,2 millions	sewage	1 MNm^3	124 buses	0,75€/m^3	
UPPSALA	200 000	food industries manure	2 MNm^3	46 buses (+2 hybrid buses: electricity/biogas)		0,85 €/m^3
ZURICH	1,2 millions		Natural gas +biogas	9 trucks only biogas 600 light vehicles		
ROMA	2,8 millions	sewage dump	3,5 MNm^3	12 lorries		
REYKJAVIK	170 000	landfill		44 public and private cars		1,1 €/ m^3
LINKÖPING	132 000	food industries organic waste	3 MNm^3	68 buses 200 cars		0,83 €7m^3
GÖTEBORG	600 000		Natural gas [11]+biogas	1490 vehicles		0,81 €/m^3
TROLLHÄTTAN	52 000	sewage food industries	0,6MNm^3/year	100 cars 10 buses 5 lorries	0,2€/m3	0,61 €/m^3
HELSINGBORG	300 000	landfills		60 vehicles		0,88 €/m^3
KRISTIANSTAD	70 000	sewage manure	1,5 MNm^3	22 buses, 2lorries 50 cars		0,66 €/m^3
KALMAR	57 000	Sewage, manure	2,5 MNm^3	35 cars, 5 lorries		0,77€/m^3
JÖNKÖPING	118 500	sewage	1,5 MNm^3	95 cars		0,75€/m^3
ESLÖV	29 000	sewage	0,2 MNm^3	50 cars, 2 buses 2 lorries	0,33€/m3	0,66 €/m^3

[8] www.energie-cites.fr, www.utopia-eu.com, www.zeus-europe.org,
[9] C. da Costa Gomez (Germany), Björn H. Halldórsson (Iceland), E. Poitrat (France)
[10] Ronald Svensson (Trollhättan), L. Rahm (Stockholm), S. Alexandersson (Stockholm), S. Germe (Lille). M.Andersson (Kalmar). F. Eskilsson (Jönköping) Lars Anshelm and Göran Johnsson (Eslöv), Lasse Jansson (Linköping)
[11] BUSINESS REGION GÖTEBORG, "*Biogas Väst*", 2002

Fig.14. Main characteristics of the cities using biogas as fuel

Those biogas realisations will be studied in details in the part 3).

2-4. Natural gas and biogas

As it is the case in Switzerland or in South of Sweden, it happens that the biogas is mixed with natural gas (NG) in order to be injected into the natural gas grid or into the natural gas filling stations. Indeed the methane exiting from the biogas plant (renewable source) has the same characteristics as the natural gas (fossil source), so it can be used in the same conditions. One interest of biogas and natural gas mixing is the existing NG infrastructure, which can support the implantation and use of biogas. Another interest is the large available amount of natural gas, which can increase the biogas distribution when its production is too small. This mixed gas is called Green (South of Sweden) gas or Naturgas (Switzerland).

In this part, we will essentially deal with the Natural Gas used for Vehicles (NGV).

- **NGV is not a barrier to the biogas development?**

There are many strong standard development activities and equipment suppliers so that gas companies are involved in a number of programs with European Commission that foster NGV and alternatives fuels commercialisation. According to experts[12], the development of NGV is not an obstacle for the spread of the biogas use. Several arguments have been advanced:

- the most developed countries in NGV are the states that produced the most biogas-fuel (Sweden, Switzerland and France).
- at the beginning of the biogas-fuel development, an existing gas grid permits a better distribution of the biogas.
- long-term studies show that the natural gas deposits will not be sufficient while biogas will always be available.

However, this is a very controversial part, and negative influence of the natural gas commercialisation can be found:

- the natural gas price is lower than the biogas; it is difficult for the biogas to compete when there is no support from the government or cities.
- the natural gas benefits from high investments that permit it to be developed in the whole country. At the opposite, the biogas is still a local production.
- the natural gas is a fossil fuel still considered as clean fuel in the majority of the countries. In that case is difficult to develop another clean fuel more expensive.

[12] C. Da Costa Gomez (Germany), P. Labeyrie (France)

- **NGV European market**[13]

Italy

With 400 000 vehicles (mostly commuter ones) and 320 refuelling stations (mostly public stations), the Italians have been the historic leaders in the NGV market. Today they are embarking on a significant expansion program to increase both NGV and refuelling station numbers.

Germany

The German market has been the most expansive: from a handful of vehicles in 1994 to some 6000 and over 100 refuelling stations in 2002.

France

The French are expanding their market steadily, mostly due to efforts by GDF[14] who has 3300 vehicles in its own fleet, making it the largest company fleet in Europe. They have created a separate marketing entity call "GNVert"[15] to install refuelling stations (9) and sell Compressed Natural Gas. Nowadays it exists about 1200 buses running on NGV and more than 100 lorries.

Sweden[16]

There has been some motivated projects, especially for a country with only a limited natural gas distribution network. The government is environmentally oriented and is working with local institutions and private industries. Volvo has also been active in leading the development of the NGV market. In 1995, Sweden had just over 100 NGV vehicles, and today they own more than 1500 cars and 22 refuelling stations.

Switzerland

Switzerland permits the mix of biogas and natural gas, called Naturgas. So by developing the natural gas use all over the country, the government countenances the production and distribution of the biogas fuel. Today 520 vehicles are using natural gas/Naturgas and it exists 15 natural gas filling stations and 11 Naturgas ones. A major determinant to the development of the NGV and biogas fuel is a possible decrease of the fiscal tax on those clean fuels. Indeed, Switzerland has got the highest fuel taxes of Europe.

- **Trends and growth of the CNG use**

The European Commission declaration about the promotion of the renewable fuel use in transports fix the following incentives:

[13] "*European NGV marketing: Technology, Marketing & Policies*", 2000, ENGVA (updated with current figures)
[14] Gaz de France, national gas Company
[15] GNVert = green natural gas
[16] S. Wallman, "*Introduction of bi-fuel (CNG/biogas) cars in Gothenburg region*", 2002

	Biofuels	*NGV + biogas*	*H_2*	*TOTAL*
2005	2%	-	-	2%
2010	6%	2%	-	8%
2015	7%	5%	2%	14%
2020	8%	10%	5%	23%

Fig.15. Incentives of the renewable part of the vehicles fleet in Europe
Source: www.e-mobile.ch

Today, the natural gas is considered as a clean fuel in most countries of Europe, and customers are increasingly attracted by this clean (but non-renewable) energy. Therefore, the number of natural gas vehicles exploded in Europe those last 5 years (the Italian case is apart), and the policies are getting more profitable to the use of natural gas.

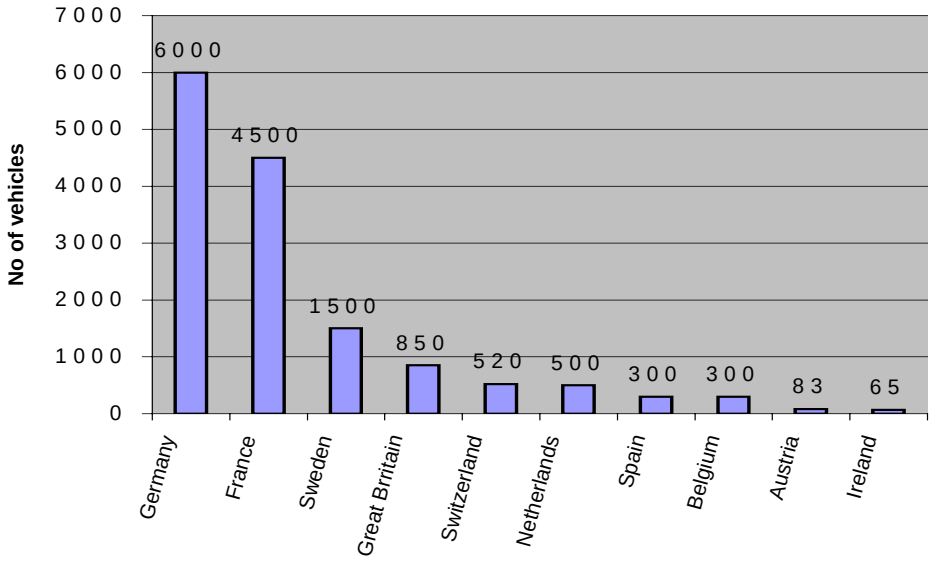


Fig.16. From zero NGV in the 90´s to a steady rise in 2000 (Europe, except Italy)
Source: European NGV update, ENGVA

- **NGV policies necessary to the biogas development**[17]

As the biogas is mostly used in the NGV grid when refuelling the vehicles, the NGV policies are necessary to support the biogas development.

NGV are definitively receiving widespread attention from the European Commission in the form of subsidies for demonstration programmes. Tax policy is a major issue, but most of tax legislation will originate at the national level, despite what occurs in the EU. Some national NGV programmes have begun to move the market toward the natural gas (Germany, UK, Sweden, Switzerland and France).

Belgium

[17] EUROPEAN COMMISSION, "*National incentives and barriers to clean mobility*", 2003
ENGVA, "*European Commission proposes alternative fuel policy*", 2001

There is no excise tax (value added tax) on natural gas as vehicle fuel.

Germany

Starting in 1996 and lasting trough the end of 2009, the tax on natural gas as vehicle fuel will be reduced by twice per megawatt hour. Moreover the price at the station is twice lower than petrol and the included tax is six times lower than for the diesel fuel.

Netherlands

Prior to 1995 the road tax was higher for gaseous fuel vehicles. Now the road tax for NGV has decreased to the same level as gasoline and diesel fuel.

Sweden

From 1995, natural gas fuel has been granted an exemption from the ordinary tax level: the current tax on diesel is 2,5/3 SEK per litre, 4,15 SEK per litre of gasoline and 0,8 SEK per equivalent litre of natural gas.

Switzerland[18]

They strongly believe that NGV and biogas are the best way to provide clean transport energy. Nevertheless, Switzerland practises the highest European tax on the gaseous fuels and does not permit a wise development of those clean energies.

United Kingdom

At the beginning, the excise duty for natural gas was more than 400% of the EU minimum. From 1995 to 2000, the tax has been reduced by 45% while increasing duty on diesel and petrol.

France and Ireland

Only gas companies, cities and some private societies own GNV fleets, that's why natural gas tax does not really exist. However, the natural gas is cheaper than common fuel, and the spread of this energy is getting larger thanks to some reduction costs (purchase of the vehicle, no vehicle tax).

- **Comparison between NGV and biogas**

The NGV is known as a better environmental-friendly fuel as the diesel. Indeed, its emissions of NOx and CO_2 are lower and NGV can reduce smog-forming emissions compared to petrol vehicles as much as: 76% for carbon monoxide, 84% for nitrogen oxides and non-methane hydrocarbons by 88%. It can virtually eliminate emissions of benzene and particles, known human carcinogens. It is however important to note that tailpipe emissions account for only 45-50% of vehicle emissions. The other losses are from fuel evaporation in the engine compartment and from emissions lost during the refuelling process. NGV have no evaporative losses and nearly immeasurable losses at the fuel pump. Another added feature is noise: natural gas at 130 octane reduces noise pollution, a major benefit for drivers, passenger, and the population where the busses operate.

g/km	CO	HC*	NOx	CO_2	Particles
diesel	*0,2*	*0,4*	*9,73*	*1053*	*0,1*
Natural gas	**0,4**	**0,6**	**1,1**	**524**	**0,022**

[18] P.Petipierre, "*Gasmobil, une initiative de l´industrie gazière Suisse pour le développement du GNV*", 2003

biogas	**0,08**	**0,35**	**5,44**	**223**	**0,015**

*HC: hydrocarbons

Fig.17. Comparison of gaseous emissions for heavy vehicles (bus)
Source: TRAFFIC & PUBLIC TRANSPORT AUTHORITY, *Biogas technology and biogas use in Sweden,* November 2000, City of Gothenburg

As it is shown in the table, the biogas used as vehicle fuel presents better characteristics than the natural gas. Some disturbance still appears for the NOx emissions, but they stay below the EU norms. Concerning CO_2, hydrocarbons and CO emissions, the biogas is far better than the NGV.

For those environmental-friendly reasons, biogas has got more trumps than the natural gas, especially in those times of pollution revaluation. NGV benefits from an existing grid, which permits an easier distribution of this fuel. But thanks to the evolution of national policies, the biogas should take advantage of this natural gas network and its development.

3) Biogas vehicle realisations

3-1. Ongoing projects all over Europe

- **Stockholm realisations[19]**

The Stockholm Water Company is using surplus biogas from its Bromma wastewater treatment plant to provide an environmentally friendly alternative to diesel and petrol for city-owned and private vehicles.

Stockholm's Bromma wastewater treatment plant treats 50 Mm^3/year of sewage from nearly 250 000 people. During the treatment process, 23 000 tonnes of digested sludge and approximately 3.5 Mm^3 of biogas are produced. 3.1 Mm^3 of this biogas is used for heating, while 0.4 Mm^3 is burned off. The Stockholm Water Company felt this surplus biogas could be used as fuel for city vehicles.

Now, the project involves over 500 vehicles mostly owned by the city of Stockholm. These are equipped with dual fuel systems, which make it possible to switch between petrol and biogas power at the touch of a button. The target is to run up to 3000 vehicles in the city on biogas. Each biogas vehicle has a gas tank, which provides a "biogas range" of approximately 200 km beyond the normal "petrol range". Engine power is reduced by about 10% when running on biogas – a negligible figure for vehicles travelling in urban traffic[20]. Biogas is continuously produced in the oxygen free environment of the sludge digestion tank at Bromma and is composed of methane (65%) and carbon dioxide (35%). Before the gas can be used as a fuel, the carbon dioxide, water and other substances are removed and the gas compressed. Purified gas is stored under high pressure from which it can be taken directly to the fuelling station.

The City of Stockholm has, for several years, been working towards making refuse disposal more compatible with environmental needs. This applies to both processes and vehicles. Both LPG and petrol-fuelled refuse lorries have been used in Stockholm's Old Town for the past 10 years, to move 15 tonnes of refuse each day. During 1999, the conventional refuse lorries will be replaced by biogas fuelled vehicles, a considerably quieter and cleaner alternative, which will significantly contribute toward preserving the historic buildings. The first biogas fuelled refuse lorries are part of a collection system. All City of Stockholm refuse lorries will gradually be replaced by biogas fuelled vehicles. The entire fleet, consisting of about twenty vehicles, should be replaced within the next five years. Today, there are existing four filling stations, and another three new are planned for the coming years.

The city of Stockholm was a pioneer in promoting environmentally sound vehicle technology as early as 1994. The current biogas project is now part of the EU's TRENDSETTER project.

[19] S. Alexandersson (City of Stockholm), L. Rham (Stockholm Vatten)
[20] TRENDSETTER, "*Final inception report*", 2003

- **Lille biogas project**[21]

The law on Air and Rational Energy Use of 30th December 1996 permitted to elaborate an Urban mobility Plan for urban areas of more than 100 000 inhabitants, thus endowing the Urban Community of Lille with new responsibility area. In this plan, the Community of Lille set incentives of promoting less polluting energy sources for private cars as well as for public and goods transport.

The Community of Lille responsibilities include looking after the public transport network and managing several waste water treatment plants which, for some of them, produce gas with high methane content.

By the end of 1990, Lille launched a project, the first of its kind in Europe, to provide an energy use to this local renewable source. The aim of this experimental project was to use the biogas produced by the Marquette (in suburb of Lille) sewage plant to power urban buses.

The first incentives of the project were to:
- build a pilot site for the production of biogas
- convert a conventional diesel bus into a biogas one

Up to 1990, 80 % of the 15 000 m^3 of biogas daily produced by the wastewater treatment plant were used internally to supply heat and power to the plant. The rest was burnt off. To avoid wasting the remaining 3000 m^3, Lille decided to clean them to obtain a daily volume of 1200 m^3 of biogas suitable for vehicles.

The biogas cleaning unit was commissioned in June 1995 and a distribution terminal was installed at the Marquette production site. The scrubbing method used is absorption (cf. Fig. 2).

The first biogas bus was introduced in March 1994, the second one in September 1997 and 6 others at the end of 1998. Before the TRENDSETTER project, Lille owned 42 buses that have been completed in 2002 by 62 buses and 20 new ones in 2003[22]. Now they exist 124 buses, and all of them give complete satisfaction, either to the operators or the users. Biogas buses will replace 35% of the fleet with new buses introduced within TRENDSETTER project[23].

[21] From www.energie-cites.org
[22] According to S. Germe, Lille Community
[23] According to "*Setting trends for a sustainable urban mobility*", CIVITAS, 2003

- **Linköping realisations**[24]

The increase of the urban traffic and subsequent rise in air pollution motivated local authority to limit traffic flows in the city centre and to develop public transports. Despite of those measures, the air quality remained poor in several district areas. In order to improve these results, the municipality launched a biogas experimentation for its bus fleet in 1991.

A total of 20 units were integrated into the fleet until 1998, and this first development had been a great success. In 1998, the number of vehicles running on biogas fuel in Linköping amounted to 60 urban buses and 80 light vehicles. Today, 68 buses and 150 biogas cars are running in the Linköping area. 8000 Nm^3 of biogas are supplied daily to make them run.

The organic waste treatment plant is located at Åby Västergård. Waste is mainly composed of organic material from slaughterhouses and animals waste. In order to slow down the digestion process, waste is mixed with manure from farms.

- **Göteborg and Zurich Naturgas fleets**

Göteborg[25]

During the early 90's the City of Göteborg, AB Volvo and Volvo Car Corporation entered into a private public partnership. The objective was to enter into projects to improve and secure efficiency, safety and environmental performance in local and regional road traffic. In 1995 the parties agreed to pursue a project of introducing vehicles run on an alternative, preferably renewable, fuel. After some discussions methane gas as Compressed Natural Gas (CNG) and Compressed Biogas (CBG) were identified as the choice.

Natural gas was already available in Göteborg supplied with a pipeline from Denmark via the City of Malmö. Biogas could be extracted from biomass in the local sewage system.

The Swedish government offers reduced fuel tax and reduced company car taxation and the City of Göteborg offers:

- 2 hours daytime free parking plus night parking on most parking spots.
- priority taxi lanes at 4 locations in central Göteborg including at the railway station for environmentally friendly taxi cars.

There are currently some 1490 vehicles running on CBG and NGV and monthly sales of methane gas are some 450 000 Nm^3 replacing roughly 200 000 litres of petrol and 325 000 litres of diesel fuel.

There are now 7 fuelling stations in Göteborg and a further 9 fuelling stations are planned within the coming two years.

The City of Göteborg has a plan that half of its vehicles shall be environmental friendly by 2003 and that there shall in total be 10 000 environmental friendly vehicles of which 5 000 methane gas vehicles by the end of 2003 in Göteborg.

[24] ALTENER, "*A two-day study tour in Skåne, Sweden*", 2003
[25] TRAFFIC & PUBLIC TRANSPORT AUTHORITY, "*Biogas technology and biogas use in Sweden*", 2000

The Business Region of Göteborg is running a consolidated biogas project together with the Västra Götaland Region government to enable increase of biogas local production and thereby enable the fuelling infrastructure to cover communities which do not have access to natural gas distributed by pipeline.

Zurich[26]

During 1995 and 2000 a programme has been launched in Switzerland to promote the development of new biogas plants. The Swiss program "Energy 2000" aimed to stabilise the consumption of fossil energy and carbon dioxide emissions in the year 2000 to the same level as in 1990. Using biogas as fuel and introducing it into the natural gas grid was an incentive of that project.

On the 16th of June 2003, Switzerland decided to apply a tax relief of 2c€ per litre of gaseous fuel. Moreover the gas industry and the biogas producers signed an agreement whose aim is to promote the use of biogas and natural gas as fuel. This agreement forecasts the biogas injection into the natural gas grid.

At least, prices and buy out conditions are fixed in advance.

Today, the Swiss gas societies have financed and constructed about 30 refuelling stations. The gas-fuel net will complete about 50 stations in 2004 and thanks to the new tax relief, 100 refuelling stations are expecting for 2006. They are approximately 600 light vehicles running on the Swiss roads and 9 trucks powered with only biogas.

- **Trollhättan, Helsingborg, Eslöv, Kristianstad, Jönköping and Uppsala biogas fleets**[27]

Trollhättan

The biogas buses experimentation begun in June 1996 in Trollhättan with the introduction of 4 buses. The goal was to replace 12 urban buses, 2 lorries and some municipal light vehicles. Today, 10 buses, 5 lorries and 100 cars are running on biogas in the city.

The biogas is produced at the Arvidstorp waste treatment plant where a former biogas experience had been set. The waste arriving at the plant is composed of 75% of wastewater and 25% of food industry waste. This biogas is sent trough a 3km pipeline to the bus station in the town centre and the buses are generally filled during the night. A quick refuelling is also available during the day.

Eslöv

Eslöv has used natural gas in stationary services for years. Biogas has been produced for an even longer period. The biogas was first used for electricity and heating production.

The main goal of the "Gaslöv" project was to introduce more than 100 vehicles running on biogas until the end of year 2000.

Eslöv City sells the biogas for vehicles to Sydgas. The city delivers the gas in a pipeline at a pressure of maximum 10 bar. Sydgas run the filling station and pay the costs for compressing the gas to 250 bar, storage and filling into cars.

[26] Y. Membrez, "*Les potentialités du biogaz dans l´industrie gazière en Suisse*", 2003
[27] ALTENER, "*A two-day study tour in Skåne, Sweden*", 2003

The biogas produced is suitable as a clean burning fuel for vehicles. Today they are 50 cars, 2 buses and 2 trucks running on biogas in Eslöv.

The biogas plant is set on the Ellinge site, and the production is bigger than the biogas needed for the vehicle consumption. So, when the biogas tank for the filling stations is full, it is diverted into Eslov's heating system. This system has thus minimised storage capacity requirements for the case of excess production. In case of organic supply shortage, an on-site backup system using natural gas can be deployed.

Kristianstad

In Kristianstad, there are two plants where biogas is produced from wastewater treatment and industrial and agricultural waste.

Since the middle of the 80´s, Kristianstad Energy Company has worked towards replacing oil by biofuel and developing a combined power and heating plant in the city.

The biogas is partially used as fuel in public transports and other vehicles within the town environment. At the end of 2002, there were about 95 biogas vehicles in Kristianstad (22 buses. 2 lorries and 50 cars), most of them city buses. In this town, the biogas price is 1,80 SEK (0,20c€) cheaper than the same volume of petrol (1 litre equivalent).

Uppsala

The first biogas buses arrived in 1996 in Uppsala; now there are 46 biogas buses and 2 hybrid (biogas/electricity) buses. Those 2 hybrid buses are very unusual: they are electric vehicles but with a biogas engine.

Helsingborg

The landfill gas collection of Helsingborg was built in 1985; nowadays industrial waste, slaughterhouse secondary products and fatty sludge can also be treated to produce biogas.

Only a minor part of the total gas production (2%) is converted to vehicle fuel and the remainder is sold to external agencies that use it to produce heat and electricity for internal heating systems.

The amount of converted biogas produced at the plant is enough to supply over 60 vehicles a day (including refuse collection lorries). Plans exist to supply vehicle fuel to approximately 50 city buses in 2004.

Jönköping[28]

Jönköping developed its production of biogas from sewage several years ago. Today they produce 150 000 Nm3 of fuel per year (potentially 1,5 MNm3) and can feed 92 vehicles. Half of those vehicles are owned by the municipality, and the rest is divided into private companies and private owners. Only one fuelling station is existing, but there are now discussions about the built of a new plant and 2/3 filling stations for the five next years.

[28] According to F. Eskilsson, Jönköping City

3-2. Small scale biogas developments

- **Reykjavik**[29]

SORPA, a municipal company owned by Reykjavík city and 6 other companies started cleaning landfill gas in year 2000. The plant produces 96-98% clean methane that is used as transportation fuel on 44 cars (as of now). The cars are various types of Volkswagens (Caddy, Caravella, Transporter, DoubleCap, SincleCap, Golf Variant) and Citroen Berlingo. Other car importers have some doubts about the project. The companies behind the initial project where SOPRA, Metan Ltd., Hekla Ltd. (Volkswagen importer) and ESSO in Iceland that set up the first filling station. The biogas production at the landfill has been estimated to fullfill the fuel needs of about 2.500 - 3.000 smaller bi-fuel vehicles (conservative estimate).

- **Roma biogas project**[30]

In the middle of the 90´s, Roma introduced 2 biogas lorries for the waste collection. Today, the city employs 12 lorries that run 7 hours per day and can collect 120 tonnes of waste each day.

The Roma biogas production comes from urban waste and dumps. The biggest part of the biogas is used for electricity production. The rest is used as fuel (called Bio-metano ecologico) and the fuel production is about 3,5 MNm^3 per year. It exists 8 refuelling pumps that can feed lorries in about 10-12 minutes.

- **Kalmar (Sweden)**[31]

The biogas project as fuel vehicles begun in 1996 with the treatment of sewage, manure and industrial waste to produce biogas. The major part of the biogas production is used for the internal heating of the plant. However, Kalmar City has been running 35/40 biogas vehicles for 7 years. But this biogas as vehicle fuel is still a pilot-project, and the amount of biogas vehicles (lorries, cars) have not changed since the beginning of the action. To day the construction of a second refuelling station is under discussion.

[29] According to B. H Halldorsson, Metan Ltd Manager
[30] According to V. Macchi, SICES
[31] According to M. Andersson, Biogas Maintenance at Kalmar

3-3. Investments costs and developments

In this part we will compare the investments costs and results of the most developed fuel-biogas projects. The figures come from municipal articles, the National Energy Agency of Sweden, the project Energie-Cités and some contacts in the concerned cities.

CITY	Annual Production	Investments	Results/ Developments
Stockholm[32]	1,5 MNm^3 (+ 3)* MNm^3	2,8 M€ (+ 3,8 M€)	- New plant under construction - **425** biogas vehicles - 4 existing refuelling stations - 3 refuelling stations under construction
Lille[33]	1 MNm^3	2 M€	- **124** buses - 18 new buses for 2004 - 1 refuelling station under construction
Eslöv[34]	0,2 MNm^3	0,12 M€	- **55** vehicles
Trollhättan[35]	0,8 MNm^3	3,4 M€	- **115** vehicles - 8 more buses, 20 lorries and 100 small cars - 1 refuelling station under construction
Linköping[36]	3 MNm^3	8,4 M€	- **270** vehicles - 1 existing refuelling station - 3 new refuelling stations for 2004 - 1 new biogas plant (corn crops)
Jönköping[37]	0,15 MNm^3	1,5M€	- **92** vehicles - 1 existing fuelling station - 2/3 new fuelling stations for 2009 - 1 new biogas plant for next years
Kristianstad[38]	1,5 MNm^3	4,7 M€	- **95** vehicles - 3 existing refuelling stations - 1refuelling station under construction - plan to buy new buses

* Production and investment for the second biogas plant of Stockholm, under construction

[32] Lars Rahm, Gas Manager at Stockholm Vatten , Sven Alexandersson, Project manager, Miljöbilar i Stockholm
[33] Sabine Germe, Lille Community
[34] Lars Anshelm, city of Eslöv
[35] Ronald Svensson, City of Trollhättan
[36] Lasse Jansson, Informationschef Tekniska Verken
[37] F. Eskilsson, Jönköping Kommune
[38] Lennart Erfors, Kristianstad Kommune, Biogas department

Fig. 18. Investment, results and developments of the main European projects

4) Analysis and recommendations

4.1- Negative and positive results

All the ongoing projects have been set up during the middle of the 90´s and they are still running and being developed. However some biogas-fuel projects have been a failure; it is the case in France with the cities of Chambery and Tours, and in New Zealand with the city of Christchurch.

- **Abandoned projects of vehicle fuel**

Chambery, 102 000 inhabitants

In 1994, the Chambery district decided to upgrade the biogas, produced by the wastewater treatment plant, into fuel for the municipal fleet (15 cars). A private company invested for the city and expected to make benefits from the selling price of the biogas. 12 light vehicles have been transformed into biogas powered cars.

The project collapsed 2 years later because of two main factors:
- the plant was not a technical success; the investors wanted to save money on the technical investment which had a low level of technology (black steel, unaccepted compressor, no gas quality control, no alert system).
- the financial follow-up of the project disappeared; the expensive experimentation coaching has been abandoned, and the low incomes destabilised the investors.

Christchurch, 300 000 inhabitants

In the 80´s, it was decided to upgrade the biogas produced at the wastewater treatment station into fuel for the municipal fleet. 70 light vehicles have been converted into biogas vehicles and the use of biogas as fuel permitted a benefit of 140 000$NZ per year.

This project lasted until 1994, when the municipality decided to convert a part of the biogas into electricity. This decision happened while the city decided to set the price of the diesel at the same level as the biogas. The biogas consumption collapsed and stopped because of:
- a very low diesel price; biogas was not competitive anymore
- a lack of refuelling station

Tours, 300 000 inhabitants

In the 90´s, the Transport department of Tours, in partnership with the wastewater treatment plant, decided to transform 14% of its biogas production into vehicle fuel. They converted 30 communal vehicles (lorries and cars) into bi-fuel engines. The project collapsed quickly due to a non-support of the local authorities. It was not only a question of money but also a lack of real motivation in this new idea (the first one in France).

- **Positive results of the biogas-fuel**

For the majority of the studied projects, the positive results can be measured by the environmental impacts, the inhabitants concerns and the economical viability of the realisations.

Environmental impact

Some cities as Lille or Roma have measured and compared the gaseous emissions of biogas and normal vehicles. All the studies show that using the biogas, as an alternative fuel, is less polluting than the diesel/NGV/petrol vehicles. (cf Fig. 17)

Customers concerns

Some customers' enquiries have been done in the city of Lille and Stockholm. They noticed:

- a reduction of the sound emission (citizens and drivers)
- a best drivability (drivers)
- a reduction of the smelling emissions (citizens)
- that 96% of the citizens who drove a biogas vehicle are satisfied of its performance[39]
- that 2/3 of the Stockholm inhabitants who drove such a car are aware to pay 20 000 SEK extra price to buy it

Economical viability

The economical concern is the weak point of the biogas development; indeed the investment costs are very high and the returning-time is longer than for producing heat or electricity. That is the reason why the majority of those projects benefit grants from EU, state or local authority. However, all the projects presented in this study are now economically viable. Here are the main reasons and conditions to this viability:

- scale effects (flow threshold, plant already producing biogas)
- short distance between production site and refuelling station
- biogas favourable policies (VAT reduction, no extra-taxes, abandon of the fuel tax)
- biogas favourable politics
- in Sweden: grants per km depending on the fuel used
- benefits on environmental taxation
- selling prices of the biogas lower than diesel

[39] I. Blomberg, "*Låneflotta av miljöbilar till företag*", Trendsetter working report, 2003 and www.energi-cites.org

- parking subsidies in some cities (important impact on the user who prefers “direct” actions to save money)

4.2- Guideline to set up a city biogas project

This last part will try to set up in place some common rules which have been found in biogas projects studied in the report. There is not only one way to set up such a project, but 3 points have to be taken in consideration.

- **Technical aspects**

The biogas plant

- its easiest to run such a project when the city already produces biogas and upgrade it as heat or electricity
- the biogas flow must overpass 50 Nm^3/h to make it viable
- the technical investment must be serious and suitable to the production of upgraded biogas (alarm system, quality control, strong material, etc.)

The infrastructure

- the distribution infrastructure must be efficient: natural gas grid or mobile refuelling trucks, or short distance between production site and refuelling stations
- the consumers shall have several refuelling sites in order to avoid waste of time and fuel
- both municipal and private fleets shall be developed at the same time in order to promote quickly the new energy

- **Policies and politics impacts**

Favourable policies

- cities, regions and states who develop such an energy should act in favour of the use of biogas by abandoning or reducing some fuel and vehicle taxes
- some actions as free parking could promote the use of the biogas
- the selling price of the biogas at the refuelling station must be attractive compared to the other fuels. The price difference must be significant.

Favourable politics

The role of the politics and the environmental behaviour of the city is determinant. A city that already demonstrated its environmental-friendly will has good chances to develop the project.

Fix goals

In order to develop the use of biogas, the city must fix environmental, economical and quantity goals. Indeed, it's very important to evaluate the impacts and the success of such a project (polluting emissions, benefits from the sale, excessive purchase, amount of new users, satisfaction enquiries, etc.). This evaluation and the correcting actions cannot be done without fixing goals.

- **Partnerships**

The majority of the projects lead in Europe couldn't have been run without the help of institutional and market partnerships.

European Community grants

With several projects and legislation ongoing regulations, the European Community is the best partner for cities who decide to produce biogas as vehicle fuel. The grants dispensed can easily cover half of the investment costs for the biogas plant (Ex: Lille, Linköping, Trollhättan).

European scale projects

In order to be helped in the different steps of the project, it is useful to be part of an European project as TRENDSETTER. Indeed, the help of such a project permit to fix incentives, to benefit from grants and to have access to others realisations and partners.

Energy producers and distributors

An important point to the development of the project is to have support or agreements with the local or national energy producers and distributors. Indeed, they often have the technology or the existing infrastructure to support the production and distribution of biogas.

Vehicles constructors

Finally, support or agreement with the gas vehicle constructors can make easier the development of the biogas fuel use. Indeed, some cities have been sponsoring by vehicle marks and have had the possibility to convert or buy new cars at least costs.

This short recapitulative underlines that setting up a city biogas project needs a strategic alliance between the actors of the project (politics, producers, distributors). But it is important to have in mind the satisfaction of the consumer that passes trough a good infrastructure, an attractive product and a large communication.

CONCLUSION

Biogas is getting more and more developed across Europe, and thanks to its renewable sources and current EU incentives, it has a real potential of fossil energy replacement. However, still 50 % of the biogas production are burnt into flacks flare, and the rest is used as heat fuel. It has been proven that the best environmental way to use this biogas is the production as vehicle fuel (wastewater upgrading, diesel/petrol economy and replacement, no global warming effects).

This upgrading method is the less employed because of its high investment costs and few-known possibilities. But thanks to European grants, projects and associations, the biogas as vehicle fuel has been developed as pilot projects.

However a common legislation still does not exist about the production, the quality and the distribution of this biogas. That iss why the biogas as vehicle fuel is still depending on the country policies and on the government sensitivity and concerns.

As it is a very new development, the financial output of such a production can not be demonstrated yet (even if the European projects have shown their economical viability). However, the positive environmental impact has already been demonstrated, and the customers who tried biogas vehicles presented a very good opinion on this environmental-friendly fuel.

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ILLUSTRATION TABLE

ANNEXES

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ANNEX 2 Campain for Take Off

ANNEX 3 White paper incentives

ANNEX 4 Biogas as vehicle fuel in Sweden and Switzerland

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This report is produced within the European project Trendsetter.
More reports from the Trendsetter project can be downloaded at www.trendsetter-europe.org:

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