Synthesis

State of the art and potential of biomethane vehicle fuel

Joint study by ADEME, AFGNV, ATEE Club Biogaz, GDF SUEZ, IFP, MEEDDAT

This document presents approaches to producing biomethane vehicle fuel and the resources involved. The potential of each type of resource and the production costs are described in this report. Lastly, the contribution of this gaseous biofuel to reducing greenhouse gas emissions is evaluated.

Biogas is a mixture consisting basically of methane (CH_4) and carbon dioxide (CO_2) produced by the anaerobic fermentation (in the absence of air) of organic matter. Anaerobic fermentation is a natural process that causes such phenomena as will-o'-the-wisps.

Two kinds of organic matter (or biomass) can be used to produce gaseous biofuels:

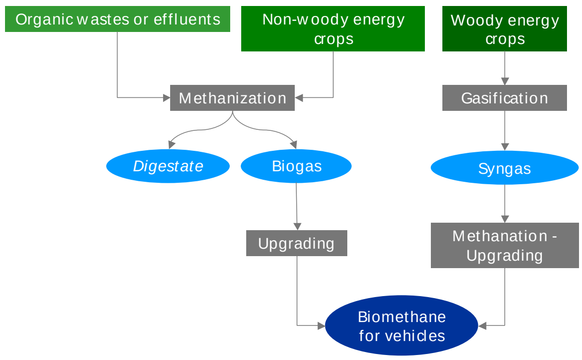
- solid wastes or effluents, from forests, from the residential sector or the industry; characterized by the fact that they are undesirable matters associated with desired productions by industrial, residential or agricultural process.
- energy crops.

1. How is biomethane vehicle fuel produced?

Biomethane is biogas that has been purified to resemble natural gas (heating value, composition). It can be used as a gaseous biofuel, in which case it is called **biomethane vehicle fuel**. It is used exactly like natural gas, and to supply a vehicle must be compressed to 200 bar by a compression station.

Several ways of producing biomethane:

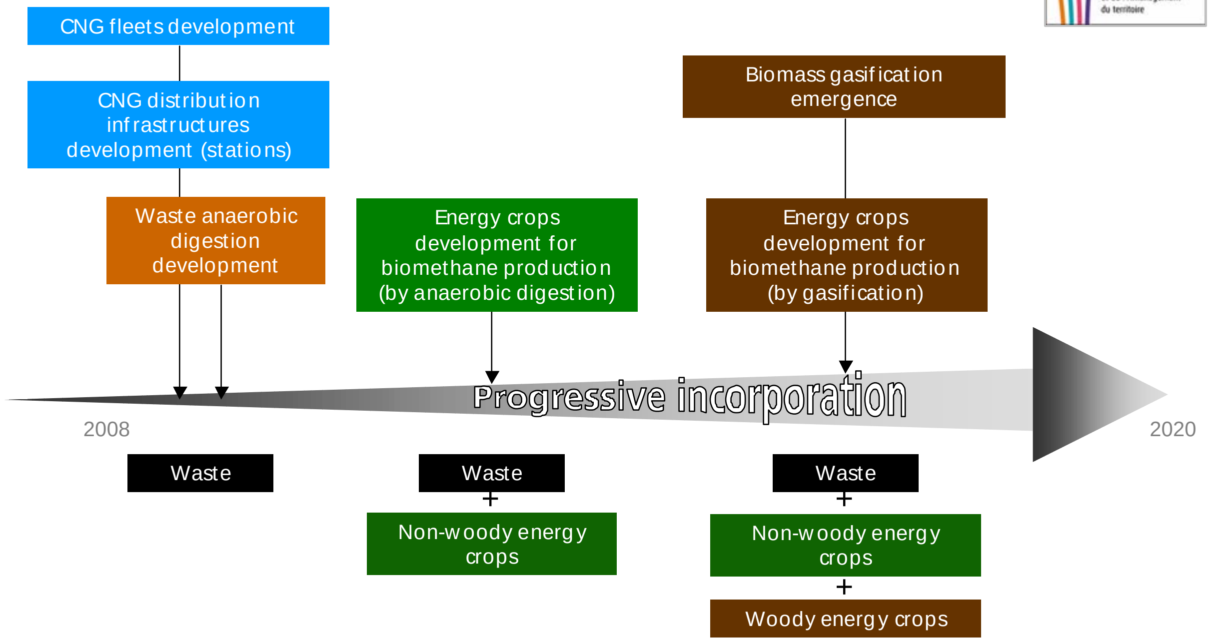
- **In the short term**, use is made of **wastes or effluents of organic origin.** This approach is already well developed in many European countries. In France, the approach has undergone rapid development in the last few years.
- **In the medium term**, it may be possible to produce biomethane from **energy crops**.
- **In the longer term**, the **gasification** of biomass derived from lignocellulosic resources is also foreseeable.



Since the quality of biomethane is similar to that of natural gas, the incorporation of biomethane in NGV[1], in any proportions, is possible with no modification either of the vehicles running on natural gas or of the associated distribution infrastructure. **These two fuels are perfectly complementary, insofar as biomethane constitutes a renewable input to NGV, but it will be able to grow only if the NGV approach itself is well established**.

Investments in NGV (engine technology, larger number of stations) therefore contribute to the gradual development of biomethane vehicle fuel.

[1] NGV: Natural Gas for Vehicles



<u>Biomethane from organic wastes: a fast-growing, attractive renewable fuel</u>

On the industrial scale, two types of biogas production can be mentioned:

- storage installations for non-hazardous wastes: biogas is produced by the spontaneous breakdown of the fermentable fraction of buried household and similar wastes. In the conventional management mode, the production of biogas can last approximately 20 - 30 years.
- anaerobic digestion in a digester: this basic process has been implemented on an industrial scale using digestion technology. After undesirable compounds have been removed, the organic matter is put into a reactor, or "digester", kept at temperatures of the order of 35°C or 50-55°C depending on the process; the residence time can be close to twenty days. In addition to biogas, this also produces a digestate that can be treated and composted to yield a useful organic product.

Because it is renewable, biogas contributes to reducing greenhouse gas emissions. It can be converted into heat, electricity, and/or, if correctly purified, a gaseous biofuel.

Biomethane vehicle fuel is highly developed in Sweden and Switzerland. In France, it is still an emerging approach. As an example, the Lille Métropole project treats 108,000 metric tons of biowastes with a view to producing enough biomethane to supply about a hundred buses. The process had already been tried and tested, over a 10-year period, by the demonstration operation of the Lille-Marquette purification station, where biogas derived from the anaerobic digestion of urban sludges served, after purification, to fuel 4 buses.

<u>Biomethane derived from energy crops: a debated approach</u>

In addition to the biomethane potential associated with fermentable wastes, a large potential could be developed in the medium term by using farmland to grow dedicated crops that could be converted to methane, provided that this does not compete with the production of food, or with the production of other types of energy or materials from the same resource.

It must be emphasized that anaerobic digestion has a specific strength, the digestate, an organic by-product that can be used to fertilize farmland dedicated to energy crops, replacing chemical fertilizers.

The anaerobic digestion of energy crops is highly developed in Germany, thanks to tax breaks; however, the crop most used is corn, which, alongside its strong methane potential, has some drawbacks: irrigation needs, rising prices, etc. It is therefore essential to identify plants that will make it possible to produce biomethane vehicle fuel more sustainably (alfalfa, sorghum, etc.).

In the longer term, production by gasification

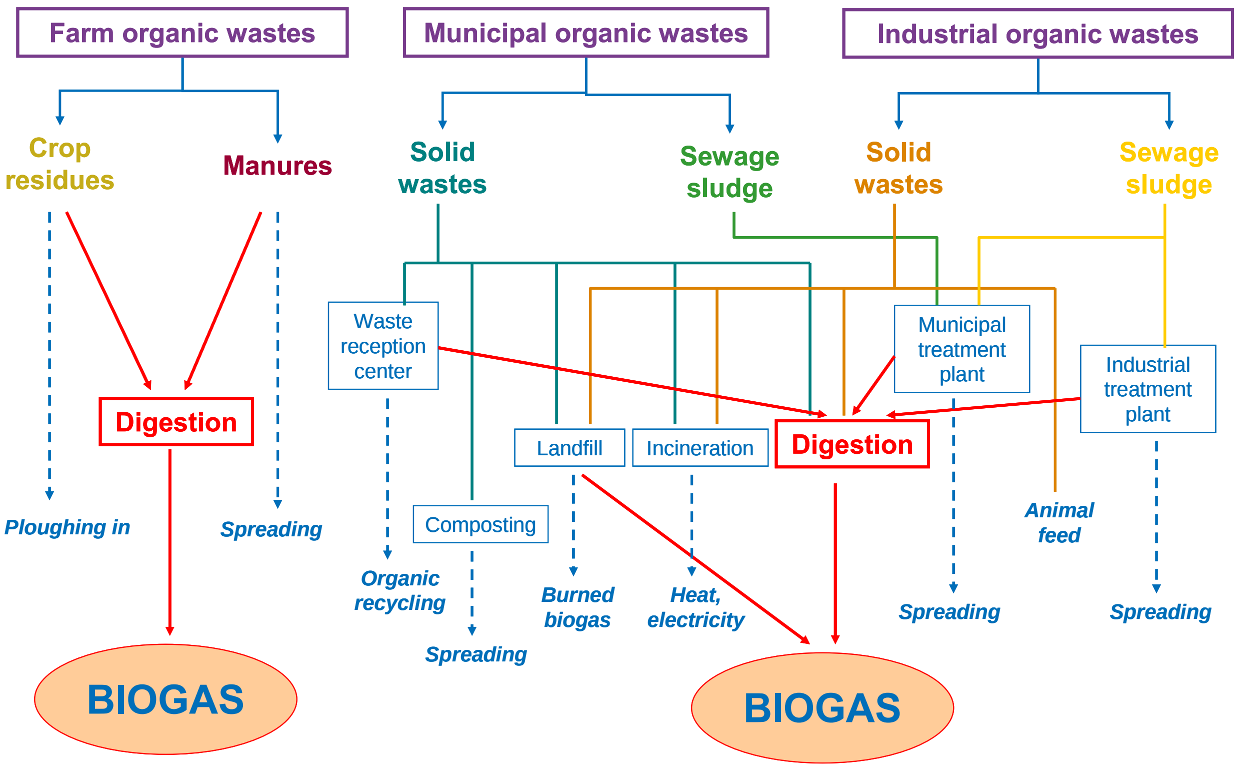
Gaseous biofuel can also be produced from ligno-cellulosic biomass by a first gasification step, followed by a methanation step.
This process produces Substitute Natural Gas (SNG). Today, gasification and methanation are technologically understood, but must be adapted to biomass; the SNG production technology is still in the demonstration stage. This approach, complementary to the production of second-generation liquid biofuels, uses a different biomass from that used for anaerobic digestion (more ligneous and less damp). In the long term, it would therefore make it possible to attain a gaseous biofuel potential even larger than that made up of organic wastes alone.

It can be expected to occupy a favorable position among second-generation biofuels thanks to high-energy yields, higher than 60%. The sizes of facilities producing biomethane vehicle fuel using this approach could be adapted to local supply of biomass and easy local use of the co-produced heat.

2. Biomethane vehicle fuel production potential

The fermentable wastes needed to supply the production of biomethane can come from three main sectors: agriculture (harvest residues, breeding effluents), municipalities (a share of household and green wastes, sewage treatment sludges, etc.), and industry (transformation process wastes, scrubbing waters, etc.).

Some of these wastes can be recycled (paper and cardboard in particular), while others can be used as an input of organic matter to farmland (burial of straw, spreading), and also be used for energy production (combustion of landfill gases, incineration, anaerobic digestion).



Based on the existing recovery processes for each of the wastes, it is possible to define:

- a "total potential" of biogas production from all fermentable wastes produced, without taking into account current recovery approaches,
- a biogas "potential without recovery" (or minimum potential), produced from wastes already recovered as biomethane plus wastes not currently recovered (surplus straw, flared landfill gas, wastes incinerated without energy production, etc.),
- a biogas "potential without recovery of material" (or intermediate potential), excluding wastes currently recycled for the recovery of materials (industrial uses, fertilizer). This last potential assumes a determination first to reduce waste production, then to recover energy from the wastes not otherwise recycled.

Various annual raw biogas production potentials in France

		Total potential Mtoe biogas	Potential without recovery of materials Mtoe biogas	Potential without recovery Mtoe biogas
Urban wastes	Solids	2,08	1,56	1,24
	Effluents	0,21	0,21	0,18
	Total urban	**2,29**	**1,77**	**1,42**
Industrial wastes	Solids	2,85	0,26	0,25
	Effluents	0,35	0,35	0,33
	Total industrial	**3,20**	**0,61**	**0,58**
Agricultural wastes		**10,7**	**≤ 10.7**	**5,0**
	TOTAL	**16,2**	**≤13**	**7,0**

Source: IFP calculation from ADEME, Solagro, AND, SITA

Considering the availability of the organic wastes alone, **potential biogas production ranges from 7 to 16 Mtoe** (millions of metric tons oil equivalent). The agricultural sector seems to be by far the leading source of organic wastes, followed by the industrial sector, from the standpoint of waste production, but by municipalities from the standpoint of wastes recoverable as energy (a large share of industrial organic wastes is already recovered for animal feed, compost or recycled).
The intermediate potential without recovery of material comes to nearly 2.4 Mtoe for the residential and industrial sectors, to which can be added an agricultural intermediate potential corresponding to the quantity of biogas produced by the wastes that could actually be substituted by the spreading of digestates coproduced by the anaerobic digestion. Assuming that the spreading of the digestates would eliminate all need to spread effluents and plough in straws, this agricultural intermediate potential would be close to the total potential. The intermediate potential, all sectors combined, would then be close to 13 Mtoe.

This potential must be qualified due to technical and economic obstacles likely to limit the development of biomethane production: not all of these resources are necessarily usable from an economic standpoint, and the investment necessary to produce fuel-grade biogas is not justified in all cases.
It should be noted first of all that the distribution of the resource varies depending on the sector. The agricultural sector has a very sparse resource in a rural setting, while the industrial and urban sectors can provide concentrated large volumes of wastes and convenient transport networks. This consideration might make the industrial and residential sectors predominant in terms of the resources that could be used from a technical and economic standpoint.

To evaluate a biogas production potential by 2015-2020, a first estimate, based on existing and planned digesters alone and on probable developments of anaerobic digestion by sector, indicates a total capacity of 1.4 Mtoe of biogas.
To this potential may be added a landfill production, calculated based on assumptions concerning the mean rate of biogas recovery of all landfills and on the rate of energy extraction from the recovered biogas. This production amounts to 0.87 Mtoe of biogas by 2020 (Solagro, 2008)**. The total biogas production capacity is therefore 2.3 Mtoe.**

In a second step, taking into account the minimum digestion installation size for profitable purification of the biogas for use as a vehicle fuel reduces the potential by nearly 15%, leaving a **final technical and economic potential of 1.9 Mtoe of biomethane vehicle fuel** (or bioNGV).

This threshold size depends on the substrate used and the profitability of a purification unit may only be evaluated for specific projects. Nevertheless, macro-economic assumptions may be used for a global evaluation, that are detailed in the following table.

Sector	Total capacity	Comments	Biogas fuel production capacity (Mtoe)	Comments
Agricultural	0.46	Target of the French Grenelle Environment Round Table for 2013	0.34	75% of agricultural biogas (344 ktoe) could be produced in collective facilities large enough to make the production of BioNGV profitable.
Urban	1.09		0.86	
of which landfill gas	*0.87*	In an optimized system, 90% of the methane collected in landfills in 2020 could be converted into energy.	*0.78*	90% of landfills would be large enough to make BioNGV production profitable (> 50,000 population equivalent). However, limits on the CH4 content of landfill gases, which can vary significantly.
of which methanizers	*0.22*	23 household waste methanizer projects are announced (63 ktoe), while the equipment of urban sewage treatment plants could double, according to the ADEME (154 ktoe)	*0.08*	All household waste methanizers (63 ktoe) and 6% of urban sewage treatment plant methanizers (at least 12.7 ktoe) would be large enough to make BioNGV production profitable.
Industrial	0.73	Existing and planned: 0.73 Mtoe	0.73	100% of the total industrial capacity
TOTAL	2.28		1.93	

Source: IFP calculation from after ADEME, Solagro[2], AND[3],

In addition it should be noted that:

- the mentioned potentials correspond to a "gross" production of biogas and not to a "final" or "net" production; in other words, they don't include autoconsumption of biogas by production plants, that represent around 10% of gross biogas production.
- Evaluations of technico-economical potentials are based on a profitability criterion for BioNGV production, but don't take into account technico-economical performances of other possible valorizations of biogas (power and / or heat).

There is an important gap between biogas production potentials based on available waste resources (7 to 16 Mtoe) and technico-economical potentials based on existing production units, known projects and probable growth linked to actual development measures (2.3 Mtoe, i.e. 14 to 33% of available organic wastes). This is obviously linked to the various calculation methods but also to the time-frame associated to each potential: short or middle term (2015-2020) for technico-economical potentials, due to the low development level of those pathways in France today; longer term for potentials based on the total available resource, corresponding to an important development of biogas production pathways.

As a comparison, first-generation liquid biofuels currently comprise 1.16 Mtoe of biodiesel in diesel oil and 0.03 Mtoe of ethanol and 0.66 Mtoe of ETBE in gasoline. This amounts to a global level of 3.59% by LHV[4] in road fuels consumed in France in 2007. The production potential of biogas fuel derived from organic wastes, by 2020, is therefore comparable to the current annual consumption of liquid biofuels on an energy basis.

Biomethane derived from dedicated plant resources such as wood and energy crops has, like all 2^{d} generation biofuels using lignocellulosic resources, a much larger production potential. Surplus wood not currently recovered but technically usable (thus excluding mountainous area and mineral requirements of soils) could by itself produce nearly 1.3 Mtoe of synthetic biodiesel or ethanol or1.8 Mtoe of synthetic biomethane. Considering the whole capitalised amount of wood which is not entirely collected in France, these potentials amount to respectively 3 Mtoe and 4.4 Mtoe. It is important to notice that these higher values correspond to quite long term potentials since it implies to access to biomass amounts which are more difficult to collect (slope area notably)." Other energy crops, on marginal farmland, could also produce large quantities of fuels, but it is still currently difficult to evaluate the development level of these crops and the shares allocated to the different types of biofuel.

2 C.Couturier, January 2008, "Waste Landfilling in Europe: Energy Recovery and Greenhouse Gas Mitigation"

3 AND International, 2004, "La marché de la méthanisation en France"

4 LHV: Lower Heating Value

3. From biogas to biomethane vehicle fuel

The biomethane vehicle fuel production chain is divided into four main steps:

- **production** of the raw biogas,
- **purification** of this biogas to turn it into biomethane,
- the **metering**, **odorization**, and **checking** of the biomethane quality,
- **storage** of the biomethane vehicle fuel, its distribution, and its compression to 200 bar.

Various purification processes

Biogas purification is used both to eliminate undesirable compounds and to increase the heating value of the biogas (in particular by eliminating CO_2, which is inert in energy terms). It generally comprises at least three steps:

- **decarbonation**: carbon dioxide is the second largest component of biogas, after methane. Its elimination reduces the risk of corrosion and increases the heating value of the biogas. This treatment can be performed by adsorption, by scrubbing (water or another solvent), or through membrane processes;
- **desulfurization**: H_2S is toxic and, in the presence of water, highly corrosive, even at a low concentration. It can be separated in particular by scrubbing and/or by adsorption on impregnated activated carbon;
- **dehydration**: water is the leading corrosion risk factor. To reach water contents as low as in NGV, it is possible to use the following processes: adsorption on activated alumina, silica gel or a molecular sieve, or scrubbing with a hydrophilic solvent (this last option tends to be reserved to very high gas flowrates).

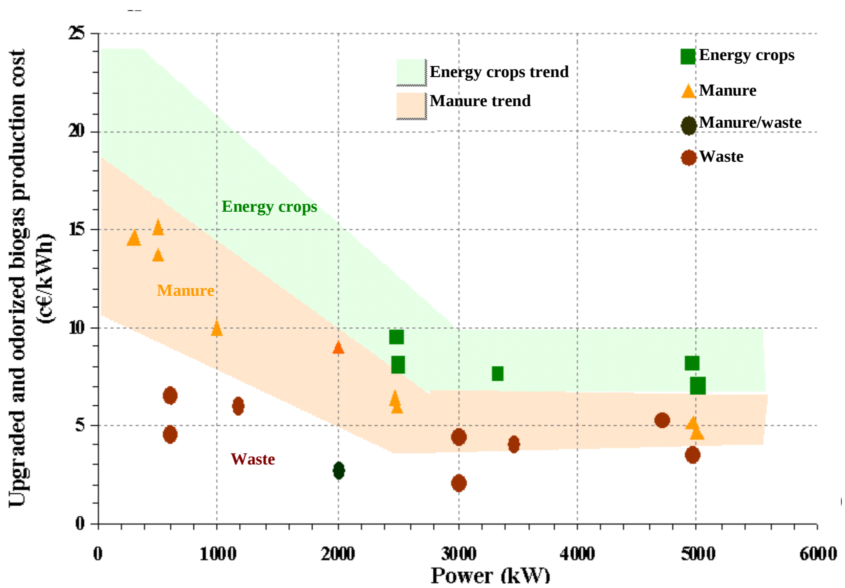
If necessary, these treatments can be completed by the elimination of problematic trace elements, in particular heavy metals (generally by adsorption).

Production costs

The production cost of purified, odorized, checked and metered biogas, made from energy crops and from liquid manure, is between 8 and 21 €c/kWh, and between 5 and 15 €c/kWh, respectively, and decreases as the power increases. In the case of production from wastes, the cost of the purified biogas is less than 7 €c/kWh; but it is difficult to estimate cost variations according to power.

In France, the price of NGV at the pump is approximately €0.89 /L equivalent diesel, in other words approximately 8 €c/kWh. **It is difficult to define a critical size** for biogas production facilities: the price at the pump includes any taxes on this fuel, which differ from country to country. It also includes the cost of infrastructure to convey the fuel from the production site to the customer's fuel tank.

However, producing biomethane vehicle fuel from wastes is expected to be more profitable than from energy crops. Without any fee for liquid manure, biomethane production projects relying on this resource should also include wastes to make these projects more profitable. Only a case-by-case study can determine the profitability of a biomethane vehicle fuel production project.



The cost of producing biogas that is purified, odorized, checked, and metered varies with the substrates used and the power of the production facility.

The ranges plotted are only a visual representation of the major trends in the variation of the costs of purified biogas according to the substrate used. They are not the actual boundaries.

Expected advances and new technologies

Current research is aimed at making the biomethane vehicle fuel approach more effective:

- by modifying the existing processes in order to improve their environmental performance (for example by reducing methane losses from the facility or by containing any bad odors that may be given off during the production process),
- by developing new purification processes and processes suited to small facilities.

Biomethane vehicle fuel characteristics allow its incorporation in NGV in any proportions, with no need to modify the engines. So a mature NGV sector, with a large national foothold, would foster the development of the biomethane vehicle fuel approach, which could use the infrastructure set up for conventional natural gas.

4. A contribution to limiting greenhouse gas emissions in the transport sector

Biogas, derived from wastes or energy crops (cultivated sustainably), is renewable energy: it can therefore contribute to reducing non-renewable energy consumption and reliance on fossil energy.

Case of biomethane produced from organic wastes

Published studies of the environmental outcome of using biomethane from wastes as a fuel, replacing fossil fuels, highlight the reduction of greenhouse gas emissions achieved accordingly:

- at the use step (combustion of fuel), as CO_2 emissions from biomass wastes (like those from all kinds of biomass) are considered as neutral with respect to the greenhouse effect,
- at the production step, as the anaerobic digestion of organic wastes enables to eliminate CH4 leaks that tend to occur when wastes, animal breeding effluents, etc. are stored.

The extent to which these greenhouse gas emissions are reduced naturally depends on the approach, the type of resource converted, and the conversion process (type of waste, digestate treatment method, type of facility, etc.). Savings are approximately 80% when biomethane vehicle fuel derived from the anaerobic digestion of municipal organic wastes replaces conventional gasoline.

The digestate produced by the anaerobic digestion of organic wastes or energy crops can be used as an organic fertilizer on cropland. Its use has some environmental benefits, such as limiting inputs of chemical fertilizers, thanks in particular to the high mineralization of the nitrogen in the product and the preservation of the fertilizing value of the treated waste. However, in some local contexts, using the digestates may not be environmentally friendly: risk of volatilization of the nitrogen during spreading, low carbon content, etc.

Case of biomethane produced from energy crops

Using energy crops for the production of biomethane motor fuel is also an interesting approach: insofar as it is possible to convert the whole plant, the quantity of net energy produced per hectare is high. Here again, the performance of the approaches depends on what species are cultivated and how they are cultivated (cultivation and harvesting practices, type and amounts of agricultural inputs). However, the literature reports savings in terms of greenhouse gas emissions of approximately 60% compared to fossil fuels[5].

In France, the transport sector accounts for 26% of greenhouse gas emissions and 34% of CO_2 emissions. In this sector, more than 93% of CO_2 emissions are due to road transport. The introduction of biomethane vehicle fuel could therefore yield significant reductions.

[5] Börjesson and Berglund, 2007, Environmental systems analysis of biogas systems – Part 2: The environmental impact of replacing various reference systems, Biomass and Bioenergy 31, 326-344.