SEVENTH FRAMEWORK PROGRAMME
THEME ENERGY.2009.3.2.2
Biowaste as feedstock for 2nd generation

VALORGAS

Project acronym	:	**VALORGAS**
Project full title	:	**Valorisation of food waste to biogas**
Grant agreement no.:		241334

D5.6: Evaluation of the role of small-scale low cost biogas upgrading and bottling systems as a means of contributing to local transportation needs in India and EU

Due date of deliverable: Month 39

Actual submission date: Month 42

Project start date: 01/03/2010 Duration: 42 months

Lead contractor for this deliverable

Foundation for Innovation and Technology Transfer (IIT)

Revision [0]

D5.6 Evaluation of the role of small-scale low cost biogas upgrading and bottling systems as a means of contributing to local transportation needs in India and EU

Lead contractor for this deliverable
Foundation for Innovation and Technology Transfer (IIT)

Authors

Virendra K Vijay [a] (Part A - India)
Rimika Madan Kapoor [a] (Part A - India)
Prasad Kaparaju [b] (Part B - Europe)

[a] Centre for Rural Development and Technology, Foundation for Innovation and Technology Transfer, Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016(India)
[b] Department of Biological and Environmental Science,P.O.Box35,FI-40014 University of Jyväskylä, Finland

Advisor
Prof R. R Gaur-IIT Delhi (Part A-India)

Contributors
Amit Aggarwal - IIT Delhi (Part A - India)
Vinay Mathad - IIT Delhi (Part A - India)

D5.6 Evaluation of the role of small-scale low cost biogas upgrading and bottling systems as a means of contributing to local transportation needs in India and EU

Contents

Part A: India

Overview for Part A

Upgraded biogas refers to the gas produced by cleaning and purification of biogas from the anaerobic digestion of organic materials, such as animal manure, wastewater/sewage, livestock manure, food wastes and yard debris. After removing carbon dioxide (CO_2), H_2S and other gases, the remaining methane (CH_4) becomes equivalent to natural gas and can be used in all applications where natural gas is used. There is growing interest in the use of biogas as a vehicle fuel around the world. In many European countries, such as Sweden, Switzerland and Germany, upgraded biogas is being used as a transport fuel. But in these cases the scale of production of biogas may be quite large and instead of bottling the gas after upgrading, it is often injected into the natural gas grid.

Energy has a major economic and political role as an important resource in developed and developing countries. Energy consumption is also increasing at a fast rate in developing countries. In a vast agrarian country like India with 70% of the total population residing in rural areas, there is high dependence on fossil fuels like petrol, diesel and coal (Ambulkar and Shekhar, 2006). The natural gas grid is only available in some urban parts of the country. Only 51 cities and towns are covered under City Gas Distribution (CGD), as a part of which piped natural gas for cooking and compressed natural gas (CNG) for the transport sector are supplied (Corbeau, A.S.,2010). Due to this uneven distribution in the country, a technology needs to be developed to serve as a source of energy and to mitigate the energy supply crisis. Therefore, there is an urgent need to explore alternative options for fuels which are renewable, cheap and easily available in rural as well as urban areas.

Biogas produced from anaerobic digestion of organic feedstock can be an important contributor to an alternative, more environmentally benign, energy system. Biogas is a highly versatile fuel which can be utilised in cooking and transport as well as for heat and electricity generation. Biogas upgrading and bottling widens the scope of waste management along with delivering an energy efficient fuel. India, being an agrarian country, has widespread availability of organic wastes. This report explores the resources available for producing biogas at a scale which is viable for small-scale biogas upgrading and bottling. It approximates the maximum amount of biogas that could be produced from organic resources in India, and discusses how small-scale bottling systems could be used for vehicular applications by exploring the potential, technology requirements, vehicle availability and infrastructure status and requirement. The report presents the underutilised status of upgrading and bottling of biogas as compared to the achievable potential in India. An assessment of the current and future potential opportunities for producing and bottling biogas for transportation use in India is also presented. This analysis provides an all-round review of the possible sources of biogas, technologies for upgrading and bottling, economic analyses of these technologies, end users, entrepreneurial options and the scope of utilisation of bottled biogas as a vehicle and cooking fuel in India. This report covers the barriers to promotion of the technology and the strategies to be followed for development of the industry. An evaluation has been made of the lack of policies and subsidies to overcome the socio-techno-economic barriers in the utilisation of upgraded and bottled biogas along with the analysis of the different strategies/scenarios for bottled biogas distribution and utilisation as a cooking and transport fuel in India.

The report provides a thorough review of the widespread availability of the potential feedstock for biogas upgrading and bottling. There is a huge potential for the installation of medium to large-size biogas plants in the country depending upon the availability of the feedstock. ***The potential can be translated to an aggregated estimated capacity of approximately 48383 million m^3 of biogas generation annually***. The contribution of upgraded biogas in the transportation and cooking sector as a percentage of total petroleum fuels consumption for the year 2011-2012 has also been estimated and is approximately 86.8 % and 83.4%, respectively. Current and future scenarios for upgrading and bottling of biogas in India are evaluated and assessed. This part of the report concludes with a series of recommendations to support further development of transportation, starting with support for basic investments in research and development, technologies for small-scale upgrading and bottling, policy supports and subsidies etc.

A1 Introduction

Biogas produced from anaerobic digestion of organic feedstock is potentially an important future contributor as a vehicle fuel after upgrading and bottling. Upgraded biogas is a highly versatile fuel which can be utilised for transport and cooking fuel requirements. Besides environmental benefits, bottling of biogas results in the diversification of energy utilisation options. The widespread availability of organic waste like animal/agro-wastes, human waste, wastes from agro-based industries (paper and pulp production, sugarcane processing, distilleries and food-processing industries) indicates that biogas production, upgradation and bottling becomes a feasible option for efficient management of waste. These wastes need to be treated to provide better environmental conditions and to reduce the methane emissions that contribute to climate change. In addition to gaseous fuel, biogas plants provide nutrient-rich organic digestates which support the soil fertility required for sustainable production and improved productivity. Thus, there is a huge potential benefit from the installation of biogas plants in the country. Presently biogas is mainly used for cooking and lighting purposes in rural areas. The use of biogas in stationary engines for various agricultural operations is already quite popular in India. Its utilisation in automobiles for transportation purposes is also feasible, by enriching and compressing it in cylinders. Due to the rising cost of petroleum products and the environmental concerns associated with them, it has become imperative to make use of local resources as an alternative to petroleum fuels. Therefore, there is a growing interest around the world for the use of biogas as a vehicle fuel. Biogas can be converted to biomethane after upgrading and it becomes equivalent to compressed natural gas. Despite the potential benefits, however, there is a large gap between actual biogas utilisation and the widespread availability of feedstock and this gap is widened further by various barriers and hindrances.

The current utilisation of biogas as a vehicle fuel is quite low as compared to the technically achievable potential. This report evaluates the possible reasons for the under-utilisation of biogas upgrading and bottling technology along with the requirements for policy support to overcome the techno-economic barriers of biogas upgrading and bottling in India.
The potential of biogas, based on physical feedstock availability and technical aspects, is discussed in the following pages; the socio-techno-economic potential, i.e. with technology and market conditions taken into account, is also evaluated. Furthermore, studies examine the influence of different infrastructural conditions on bottled biogas use while taking into

account the geographical locations of both the biogas feedstock and of potential markets. In particular, requirements for policy support and feasibility analysis of different options for bottled biogas distribution and its infrastructure are discussed.

A2 Present scenario, status, potential of biogas production and utilisation in India

A2.1 Status and scenario of biogas production in India

Rapid industrialisation and population increase has resulted in the generation of huge quantity of wastes, both solid and liquid, in industrial sectors such as sugar, pulp and paper, food processing, sugar/starch, distilleries, dairies, tanneries, slaughterhouses, poultry farms etc. Despite requirements for pollution control measures, these wastes are generally dumped on land or discharged into water bodies without adequate treatment, and thus become a major source of environmental pollution and health hazard.

In India, feedstock for biogas production is present in variable quantities at the site. According to the quantity of the feedstock, biogas plants are available in different ranges. The types of biogas plants are summarised below.

- *Household - Domestic / family size/ small scale biogas plants* – These plants are mainly for households having small number of animals. These plants are in the capacity range of 1-20 Nm^3 day^{-1}.
- *Medium size biogas plants* – These biogas plants are for the feedstocks from small dairies, vegetable and fruit markets, poultry farms, hostels, restaurants, etc. These plants are in the capacity range of 85 - 600 Nm^3 day^{-1}. Examples of medium size biogas plants are community and institutional biogas plants. If the waste is collected by a number of people/ households of a local group such as village or residents of a particular housing community and fed in a centralised digester for the biogas production are categorised as *community biogas plants* where as *institutional biogas plants* are those in which people contributing the waste belong to an institution such as hospitals, hostels/ mess.
- *Large-size biogas plants* – These plants are mainly for feedstocks from waste water treatment plants, industries such as distilleries, pulp and paper, sugar, food processing, etc producing waste in large quantities. These are commercial level plants. The capacity range of these plants is above 600 Nm^3 day^{-1}.

Organic wastes are widely available in India, biogas can be produced at different scales. A total of about 4.5 million family biogas plants have been installed all over the country till December 2012, out of the total potential of 12 million family type biogas plants (Energy Statistics, 2013). More than 4000 Community Biogas Plants (CBP), Institutional Biogas Plants (IBP) and Night-soil based Biogas Plants (NBP) had been installed in India till 2004 (Khoiyangbam et al., 2004). There are numerous cattle farms, dairies, and village communities with a large number of cattle which have the potential for producing biogas at a medium to large scale. Large-scale biogas can be produced in industries like distilleries, food processing, pulp and paper etc, and at sewage treatment plants and landfills in urban areas. For small-scale biogas upgrading, family-size biogas plants are not considered here as the amount of biogas produced is only a few cubic meters and is not viable for bottling. Resources like industrial wastes from distilleries, food processing, pulp and paper, waste water treatment plants and landfills etc are also not considered as these produce large volumes of biogas for which large-scale upgrading and bottling becomes viable. Hence, for small-scale biogas upgrading and bottling medium and community level resources are considered like cattle manure, dairy farms, canteens, hostels, community toilets, institutional and community biogas plants etc.

A2.2 Resource availability and potential for biogas production for small-scale upgrading and bottling in India

To harness the organic waste potential for small-scale biogas upgrading and bottling in India medium-size biogas plants can be built according to the availability of waste.

- Medium-size biogas plants in dairies, cattle sheds, poultry farms, piggery farms and animal rearing farms, fruit and vegetable market waste, water-borne biomass such as water hyacinth, algae and variety of such agro wastes.
- Institutional / Community-sized biogas plants intended to recycle biodegradable municipal solid waste (MSW), municipal wastewater, food waste etc of communities and centralised human habitations such as hostels, restaurants, military barracks, hotels, community toilets, etc.
- Medium to Large capacity biogas plants could be used for distilleries, pulp and paper industries and large-scale industries generating biodegradable waste and wastewater, where a high output of biogas can be achieved. Bottling can hence become an economically viable option as bottled gas can be transported in cylinders to nearby filling stations for vehicle fuel.

Table A1. Potential for low cost small-scale upgraded biogas storage, bottling and distribution in developing economies

Type of Biogas Plants	**Range of Biogas Plant Capacity/Size (Assumption)**	**Viability of Biogas Upgrading and Bottling**
Medium-size biogas plants	85 - 600 Nm^3 day^{-1} for small dairies, vegetable markets, poultry farms etc.	• On-site small-scale biogas upgrading and bottling and hence captive utilisation of biogas as vehicle fuel. • Collection and transportation in pressurised tankers to centralised upgrading and bottling station. • Distribution of bottled gas to far off places or filling stations for vehicle fuel applications.
Institutional/ Community-size biogas plants	85 - 600 Nm^3 day^{-1} Hostels, restaurants, military barracks, hotels, community toilets.	• On-site small-scale biogas upgrading and bottling and hence captive utilisation of biogas as vehicle fuel. • Commercial selling of bottle biogas for cooking or transport. • Collection and transportation in pressurised tankers to centralised upgrading and bottling station. • Distribution of bottled gas to far off places or filling stations for vehicle fuel applications.

Type of Biogas Plants	Range of Biogas Plant Capacity/Size (Assumption)	Viability of Biogas Upgrading and Bottling
Medium to Large-size biogas plants	Above 600 Nm^3 day^{-1} for commercial purpose mainly for WWTP, sewage plants, industries such as distilleries, pulp and paper etc.	• On-site upgrading and bottling becomes economically viable. • On-site filling stations can be installed or biogas can be bottled in a cascade of cylinders and transported to the site of utilisation as vehicle fuel.

Biogas upgrading and bottling plants having a capacity of less than 100 m^3 $hour^{-1}$ are considered as small-scale units for upgrading biogas from medium – large size biogas production plants. Since organic feed stock is available in variable quantities in decentralized locations; these can be harnessed to produce biogas and hence upgraded for local fuel needs for cooking and transport. Small-scale biogas upgrading and bottling systems are economically viable for medium – large scale biogas production plants.

A2.2.1 Feedstock availability and potential of medium – community-scale biogas plants in rural areas

a) Animal manure - India has a large livestock population base constituting around 300 million livestock. The livestock population is projected to increase to 322 million by the year 2015 (Rajeswari, K.V., 2009). The quantity of dung will grow from an estimated current total output of 2 million tonnes day^{-1} to over 3 million tonnes day^{-1} in 2022. Uttar Pradesh, Punjab, Haryana, Rajasthan, Gujarat, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu are the major states in India with large numbers of cattle (National Dairy Development Board (NDDB, 2010). Since livestock such as cattle, buffalo, sheep and goats are common in rural areas, animal dung is the most easily available and abundant biomass for fuel, and burning of the dung is common. Rural dispersed small farmers with 1-8 grazing animals versus large commercial farms of 50-1000 animals clustered in pre-urban areas is the structure of farming in India (Harsdoraff, M., 2012). A large majority of cattle is held by rural householders with 1-8 cattle who have family-size biogas plants. Based on the availability of cattle dung alone, from about 304 million cattle till 2012, there is a potential for about 18,240 million m^3 of biogas generation annually (Bamboriya, N.D.). Upgrading and bottling of small-scale biogas produced from domestic-size biogas plants is neither energy-efficient nor economically viable, hence the biogas potential from these is not considered in this report.

b) Poultry waste - The poultry population in India is 649 million till 2012 as reported by National Dairy Development Board (NDDB, 2012). India's poultry industry is the fifth largest in the world in egg production and the fastest growing industrial sector. The states of Andhra Pradesh, Maharashtra, Tamil Nadu, Punjab and Karnataka together contribute more than 50% of the poultry farms in the country. At present, there are more than 700 hatcheries and about 10 major poultry processing plants in India. The increasing number of poultry farms is an important resource for biogas production; the total biogas potential of all the farms in the country is estimated at 438,227 m^3 day^{-1} (Rao et al., 2010). But since the potential of individual farms is not enough to set up independent decentralised biogas plants, clustering of centralised biogas production plants is needed.

c) Crop/agricultural residue - India being an agrarian country, agriculture is the main source of livelihood for the majority of the people. The quantity and quality of biomass obtained from the cultivation of different crops varies significantly. In India no crops are grown specifically for anaerobic digestion to produce biogas. A large amount of biomass is available in the form of crop residues and agricultural waste, however, which can be used for anaerobic digestion. The Ministry of New and Renewable Energy of the Government of India has estimated that about 500 million tonnes of crop residues are generated annually in India (MNRE, 2009). Generally, agricultural waste obtained from cultivation is disposed of by burning in open areas or by dumping in the field itself until the next crop season. The biomass generated is also used as fodder to feed animals, and as firewood (Gupta, 2012). The remaining biomass may be available for bioenergy generation, and is estimated as 278.71 million tonnes $year^{-1}$. The biogas potential of crop residues and agricultural waste is estimated as 45.8 million m^3 day^{-1} or 16717 million m^3 $year^{-1}$ (Rao et al., 2010).

d) Community biogas plants/dairies/clusters of small dairies

Dairy and dairy clusters – Indian dairying is characterised by very small individual producers owning 1-3 milk animals. Today, around 75 million smallholders are engaged in low productive dairying activities especially in semi urban and rural areas. Dairy operations in India can be classified on the basis of the number of cattle: large, medium, semi-medium, small, marginal, and landless (Global Methane Initiative, 2011). Semi-medium, medium, and large operations account for only 40% of the Indian dairy herd (National Dairy Development Board (NDDB, 2010). Hence, a large amount of cattle dung can be collected from dairies and dairy clusters for biogas productions. Dung from dairies is easily to collect for biogas digester feeding. Therefore, medium to community-size production of biogas becomes a viable option in dairies. The biogas generation potential from small, medium and large dairies is 14792 million m^3 $year^{-1}$ (Table A2).

Community biogas plants – the majority of the cattle dung biogas plants in India are small-scale household level plants. Since only prosperous villagers have an adequate number of cattle, however, most small farmers and landless labour and artisans in the villages cannot have biogas plants. The common needs of the villagers such as organic fertilisers in large quantities, lighting and water supply cannot be met from privately owned individual biogas plants, which are used mostly for cooking and the sludge for fertilising the fields. At present, the number of community biogas plants established in villages to cater to the cooking fuel, organic fertiliser or electricity requirements of the village is very small. These plants are placed in urban communities where different households contribute waste cattle dung or food waste/MSW, benefit from the gas produced for cooking and lighting purposes, and share the system. Larger biogas plants can also be found in institutional buildings like schools, hospitals, jails and monasteries. Many of the community and institutional biogas plants are in remote areas and scattered around the country.

A2.2.2 Feedstock availability and potential of medium – community scale biogas plants in urban areas

Vegetable market waste - Another substrate for biomethanation in medium-size biogas plants is vegetable market yard waste (mandi waste). At present, collection, transportation and disposal of vegetable/fruit market waste is a problem for most cities and towns. If this waste could be segregated and digested in a biogas digester, both biogas and fertiliser could be produced. In addition to this, the management of public health problems arising out of such waste could be dealt with effectively. All cities in India, districts and tehsils have vegetable markets which produce plenty of vegetable waste irrespective of the size of the market. In large cities and towns it could be to the extent of a few hundred tonnes. An estimated production of fruits and vegetables in India is 150 million tones and the total waste generated is 50 million tones per annum. i.e., 30% of the estimated production of Fruits and Vegetables (Velmurugan et al., 2011). One tonne of vegetable waste yields around 80 m^3 of biogas per day; hence from the total vegetable market waste generated the biogas production potential is about 4000 million m^3 $year^{-1}$ (Lal, 2011).

a) **Food waste/canteen waste** - Food waste is an untapped energy source that mostly ends up rotting in landfills, thereby releasing greenhouse gases into the atmosphere. Food waste is difficult to treat or recycle since it has high moisture content and is mixed with other wastes during collection. The growing number of hotels, canteens, restaurants, and townships in India are facing problems related to waste disposal: currently this waste is disposed of into sewers, dumped in low-lying areas/dump sites/landfill sites. A lot of food waste is generated during weddings in India. Wedding halls/community halls generate waste which can be utilised for biogas production in the medium scale. A leading newspaper in India (Times of India) quoted "A survey shows that annually, Bangalore alone wastes 943 tonnes of high calorie, high quality food during weddings. About 84,960 marriages are held at 531 kalyana mantapas (marriage halls) in Bangalore every year". Community/Institutional biogas plants can be built to harness the potential of the high quality calorie rich food waste (Vyas. H, TOI, Oct. 2012). Considering that 30% of population resides in urban areas where the probability of waste collection is at a maximum, and that 1 m^3 of biogas is generated from 6 kg of food waste, the total biogas generation potential can be estimated as 5780 million m^3 $year^{-1}$.

b) **Human waste/community toilets** - According to estimates by Energy Alternatives India (EAI), about 0.12 million tonnes of faecal sludge is generated in India per day. Recycling and use of human excreta for biogas generation is an important way to get rid of health hazards from human excreta, besides promoting use of biogas for cooking, lighting and electricity generation. Biogas digesters when attached to public toilet complexes recycle human waste into biogas. Environment-friendly compost toilets have been implemented in more than 1.2 million houses all over India (Patak. B, 2006) Besides using biogas for different purposes, biogas plant effluent can also be used as manure or discharged safely into any river or water body without causing pollution. Thus biogas technology from human wastes has multiple benefits – sanitation, bioenergy and manure. Based on the 'Sulabh Model' design, 200 biogas plants of 35 to 60 m^3 capacity have been constructed by Sulabh in different states of the country so far, along with community toilets: if facilities for bathing and washing clothes could also be provided, maintaining cleanliness all around, people would like to use them and also pay for the use (Patak. B, 2006). Sulabh International has constructed and is maintaining over 8000 public toilet complexes spread all over India, out of which 200 are linked with biogas plants (Effluent Treatment System SISSO, 2013). Biogas produced from human excreta is channelised and used for different purposes e.g. cooking, lighting, warming oneself during winter, heating water and electricity generation. The engine to covert biogas to electricity is run 100% on biogas.

d) **Industrial Waste** - major industries which are generating biological waste are considered. These includes distillery, dairy, pulp and paper, sugar, tannery, slaughter houses, cattle form waste, maize starch and tapioca starch.

Distilleries: Currently, about 60 million m^3 $year^{-1}$ of spent wash is generated from distilleries in India. The 325 distilleries in India produce 4.02 million m^3 $year^{-1}$ of alcohol. It is estimated that from the spent wash available in the country, the total volume of biogas generation potential is 1507 million m^3 $year^{-1}$ (Global Methane Initiative, 2011).

Dairy Industrial Waste - The dairy industry involves various operations which include silo washing, can and crate washing, plant washing, tanker washing, milk processing, and other dairy products. The biogas production potential of all 342 dairy units is estimated to be 219,409 m^3 day^{-1} or 80 million m^3 $year^{-1}$ (Rao et al., 2010).

Pulp and Paper industry - The pulp and paper industry is one of the key industrial sectors contributing to the Indian economy. There are 759 paper mills in India (Kulkarni H. D, 2013). It is estimated that a paper mill having a capacity of 17 metric tonne per day paper production, generates an approximate 1.02 metric tonne per day of pulp waste (Dasgupta and Das, 2002). The biogas generation potential from the anaerobic treatment of black liquor from all the pulp and paper units in India is around 412,278 m^3 day^{-1} or 153 million m^3 $year^{-1}$ (Rao et al., 2010).

Sugar Industry - India is the second largest producer of sugarcane after Brazil. Sugar factories have been established in large cane-growing states like Uttar Pradesh, Maharashtra, Tamil Nadu, Karnataka, Punjab and Gujarat. Sugar production in India is around 18.5 million tonnes $year^{-1}$. Sugar factory operations generate bagasse as a solid waste and other process wastes include wastewater and press mud. There were 571 sugarcane processing plants in India as of March 31, 2005 (Global Methane Initiative, 2011). Sugar industries generate about 1000 litres of wastewater for every tonne of sugar cane crushed. The biogas generation potential of utilising press mud is 2.9 million m^3 day^{-1} and from waste water obtained from sugar factories is 0.6 million m^3 day^{-1}. Hence, the total biogas production is estimated to be 1277 million m^3 $year^{-1}$ (Global Methane Initiative, 2011).

Slaughterhouse Waste – India has 3600 slaughterhouses, 9 modern abattoirs and 171 meat processing units licensed under the Meat Products order. The major meat production centres are located in Aurangabad, Nanded, Mumbai and Satara in Maharastra, Goa, Medak district in Andhra Pradesh, Derabassi in Punjab, Aligarh, Unnao and Ghaziabad in up and Cochin in Kerala. The biogas potential of the wastewater from the slaughterhouses is estimated as 1,494,225 m^3 day^{-1} or 548 million m^3 $year^{-1}$ (Rao et al., 2010).

e) **Municipal waste -** Total sewage generation from urban centres in India is around 38 billion litres day^{-1}. Sewage sludge generation in India is increasing at a faster rate as more and more sewage treatment plants (STP) are developed. In India, wastewater disposal systems are usually managed by local bodies. Estimates suggest that there is a potential of about 226 MW from sewage sludge - from treated and untreated sewage together (EAI, Sewage Sludge). The total municipal solid waste produced in India is 97,173 tonnes day^{-1} with a biogas generation potential of 9.23 million m^3 day^{-1} (Rao et al., 2010) or 3369 million m^3 $year^{-1}$ as shown in Table A2. Hence, instead of using large-scale wastewater or sewage treatment systems for a city or a town for biogas generation, small to medium-scale treatment systems can be installed for housing societies and housing clusters, and biogas can be generated at a medium scale to serve the housing society or cluster.

As discussed above there is a huge potential for biogas production and hence biogas upgrading and bottling. There is also a need to treat these wastes to improve environmental conditions and reduce methane emissions that can cause climate change. In addition to gaseous fuel, biogas plants can provide high quality organic manure with nutrients which improves soil fertility for sustainable production and improved productivity. Thus, there is a huge potential for the installation of medium size biogas plants in the country. ***The potential can be translated to an aggregated estimated capacity of approximately 48382.5 million m^3 of biogas generation annually***. Estimation of the total biogas generation potential is summarised in Table A2.

Table A2. Estimation of Biogas Production Potential from Organic Feedstock for Medium/Large Scale Biogas Plants for Biogas Upgrading and Bottling in India

Feedstock	Biogas Generation Potential	Source	Remarks
Animal Manure (Cattle Dung)	18240 million m^3 $year^{-1}$	Bamboriya, N.D.	The number of family size biogas plants which will utilise the dung are estimated to be 12 million and produce 3448 million m^3 of biogas
	There is a potential for 12 million family-size biogas plants which can produce 3448 million m^3 $year^{-1}$	Rao et al., 2010	Small scale biogas plants are not included in the biogas generation potential estimate.
	18240 (total) – 3448 = 14792 million m^3 $year^{-1}$		This potential is from small, medium and large dairies (Dairies and Dairy Clusters)
Poultry waste	438,227 m^3 day^{-1} = 160 million m^3 $year^{-1}$	Rao et al., 2010	
Crop residue and agro-waste	45.8 million m^3 day^{-1} = 16717 million m^3 $year^{-1}$	Rao et al., 2010	
Vegetable market waste	4000 million m^3 $year^{-1}$	Lal, 2011	One tonne of vegetable waste yields around 80 m^3 of biogas generation per day and 50 million tonnes of vegetable waste is generated annually.
Food waste/canteen waste	1270 million population*0.3 * 0.25 kg food waste $person^{-1}$ = 95 million kg food waste = 5780 million m^3 $year^{-1}$	India on line, 2013; Banks, 2009	Based on 30% of population reside in urban areas and 1 m^3 of biogas from 6 kg of food waste
Municipal waste	9.23 million m^3 day^{-1} = 3369 million m^3 $year^{-1}$	Rao et al., 2010	

Feedstock	Biogas Generation Potential	Source	Remarks
Distilleries	1507 million m^3 $year^{-1}$	Global Methane Initiative, 2011	
Dairy Industrial Waste	219409 m^3 day^{-1} = 80 million m^3 $year^{-1}$	Rao et al., 2010	Biogas production from wastewater from various processes (silo washing, can and crate washing, plant washing, tanker washing, milk processing, other dairy products)
Pulp and paper industry	412,278 m^3 day^{-1} = 153 million m^3 $year^{-1}$	Rao et al., 2010 Parivesh, N.D.	
Sugar Industries	0.6 million m^3 day^{-1} (wastewater) + 2.9 million m^3 day^{-1} (press mud) = 1277 million m^3 $year^{-1}$	Global Methane Initiative, 2011. NMP, 2007.	
Slaughter houses	1,494,225 m^3 day^{-1} = 548 million m^3 $year^{-1}$	Rao et al., 2010	
Total Raw Biogas Potential	**48383 million m^3 $year^{-1}$**		Estimated raw biogas production potential in India

A2.3 Scenario of organic / biodegradable waste utilisation and management methods in India

Rapid industrialisation and population increase in India has led to the generation of thousands of tonnes of organic waste. Lack of resources and the technical expertise necessary to deal with the disposal and management of organic/biodegradable waste are major issues in India. The management of organic waste is going through a critical phase, due to the lack of knowledge, and unavailability of suitable facilities to segregate, collect, treat and dispose. Table A3 gives the present scenario of organic feedstock utilisation and management in India. The most popular modes of organic waste utilisation are composting and landfilling. If appropriate technologies and systems are made available then the organic / biodegradable wastes can be processed for efficient waste to energy recovery options. In general organic waste, e.g. cattle dung and food waste, is used for compost production and liquid organic wastes e.g. wastewater from distilleries and pulp and paper industries, are either disposed of to the sewer or used for power generation by producing biogas.

Table A3. Scenario of organic feedstock utilisation/ management in India

Feedstock	Scale of Biogas Production Potential	Current waste management methods									
		Drain	Landfill	Compost	Feed for animals	Cakes for cooking	Incineration	Spread in Fields	Biogas Generation		
									Cooking	Electricity production	Biomethane
Cattle Dung	Medium – community scale			√		√			√	√	
Poultry Manure	Medium – community scale	√							√	√	
Crop Residue	Medium scale						√	√		√	
Dairies/Dairy clusters	Medium scale			√		√					
Vegetable Market wastes	Medium – community scale		√	√	√				√	√	
Food waste/Canteen wastes	Medium scale		√		√				√	√	
Human waste	Medium scale	√							√	√	
Municipal waste (Solid and liquid)	Medium – Large scale									√	

A2.4 Different modes of biogas utilisation

Raw biogas is a low-grade fuel as it has a low percentage of methane. It can be utilised on the site of production itself or nearby for cooking with biogas cook stoves and for electricity production by using it in dual fuel or 100% biogas engines. If raw biogas needs to be utilised at a distance from the production site then it must be stored in biogas balloons and taken to the site of utilisation or it can be transported through pipelines. Upgrading biogas widens the scope for its utilisation. When produced in centralised plants in large quantities, upgraded biogas can be injected directly into the natural gas grid. In developing countries, since there is a large potential of small to medium-size decentralised biogas plants, hence upgrading of biogas and its injection into the natural gas grid is not possible due to limitations in quantity and quality and cost constraints.

A2.4.1 Cooking

Domestic and commercial cooking are the two possibilities for using biogas.

Domestic cooking - For domestic and community cooking biogas upgrading and bottling is not necessary. Biogas produced from family-sized biogas plants is used for cooking for household use. At a small scale (household level), cooking is the most cost economic method of biogas utilisation. Biogas cookstoves are easily available in the market. If biogas is produced at medium or community level, then community cooking becomes a feasible option for biogas utilisation where central or community kitchens are available for cooking meals for people in marriage halls, hostels etc. Cooking preferably can be done near the site of biogas production plant because lying of the pipelines is not cost effective. Community cooking using biogas is being done in India in some hospitals, hotels and hostel messes. Upgraded and bottled biogas can be used as a domestic cooking fuel in remote and far off areas without considering the economics.

Commercial cooking – When biogas is available at a medium to large scale, biogas upgradation and bottling becomes a feasible option for utilisation. Raw biogas after upgrading can be bottled and then sold as commercial cooking fuel in place of LPG. Bottled biogas becomes a viable cost economic option as compared to domestic cooking gas and there is no need for changing the receptacles of LPG. Bottled biogas can be directly used instead of LPG. The payback period of biogas upgrading systems for cooking is low as compared to other applications: hence it is advantageous for the project developers.

Figure A1. Bottled biogas used as a cooking fuel in Tohana, Haryana (Source: Author)

A2.4.2 Electricity/power production

Electricity can be produced from biogas by using duel fuel or 100% biogas engines which are readily available in the market at different scales of production. Electricity can be produced at small scale (less than 100 kW) and large scale (MW). For electricity production, upgrading is not required as raw biogas can be directly used in the engines.

For small-scale electricity production, Indian manufactured engines are easily available. These have low efficiency, and the cost economics of electricity production from biogas are not beneficial. At this scale, electricity is used for captive use. If more electricity is available and the producer wants to sell the electricity as retail, then the economics of the plants are worsened further because of the price of retail electricity, hence it is not beneficial to sell it as retail. Also, as the load at the customer's size varies, gas consumption in the engine does not vary in proportion to the load, hence the economics of the plant fails.

Large-scale electricity production engines available in India are usually foreign made. At the sites where biogas is produced at a large scale (for example distilleries, sugar mills etc.), large-scale electricity production (MW) is most economically feasible for captive use. If excess electricity is available, then export to the grid also becomes a possibility. But grid export gives poor economic returns because of the low feed in tariffs and tax incentives. Finding a market for electricity is not easy because the system becomes uneconomical for the seller. Also the fee (tariff) for grid export is too small to make the system economically viable. Along with economic liabilities, the operator has to sign a contract with the state electricity board and the buyer.

For electricity production, bottled biogas can be used in biogas engines instead of raw biogas in remote areas where no electricity grid or other fuel like diesel is available. Bottled biogas can be easily transported to such areas using a cascade of cylinders and can facilitate electricity production. The economics of electricity production from bottled biogas are unsatisfactory, but it can be harnessed as a high grade fuel in remote areas.

A2.4.3 Upgraded bottled biogas for vehicular use

Another option for utilising raw biogas is by converting it into a more energy efficient fuel commonly called bio CNG/biomethane. Biogas upgrading and bottling is not so prevalent because it is a new concept in biogas utilisation. Biogas when produced from medium – community-scale biogas plants can be upgraded by small-scale bottling plants and sold as transportation fuel instead of CNG. It is economically viable for cases where above 500 m^3 day^{-1} of raw biogas is available. Biogas upgrading and bottling facilitates easy storage and transportation of upgraded biogas away from the site of production. The advantage of using bottled biogas for vehicles is that it can be directly used in CNG vehicles, and natural gas infrastructure can be used wherever available. For selling bottled gas in vehicles there is a need to monitor the quality and quantity of gas. The payback period of small-scale bottling systems for producing biogas for vehicular use is high as discussed in the following sections. It is easy, however, to find a market for vehicular fuel. As a vehicle fuel bottled biogas can be dispensed into vehicles using simple dispensing/filling stations instead of the highly sophisticated infrastructure required for large-scale biogas/natural gas from the gas grid.

Despite the potential benefits of the small-scale bottling system, there exists a significant gap between the achievable potential and the realisable potential. Standards for upgraded biogas composition have been finalised by Bureau of Indian Standards (BIS) in the year 2013. Presently, there is a high initial cost of the system associated with the technology, low central financial assistance, and small profit. In India, the promotion of this technology is quite slow because of these various barriers. Stringent rules for the adoption of upgraded and bottling biogas technology are present in India. The manufacturer has to obtain permission from the Petroleum Explosives Safety Organisation (PESO), the Ministry of Industry, the Central Pollution Control Board and the Ministry of Environment. The procedure for taking grants, permissions and regulations is time consuming and tedious.

A3 Evaluation of market demand potential of upgraded and bottled biogas as a replacement of existing petroleum fuels for cooking and vehicular applications in India

The major application areas for the scope of utilisation of bottled biogas in rural and urban parts of India are:

a) **Cooking**: Domestic (replacement of household LPG cylinders, Kerosene Oil)
: Commercial (replacement of commercial LPG cylinders in for use in hotels, bakeries, canteens, etc)

b) **Industrial**: For use in production and manufacturing process, captive power

c) **Automotive Sector**: For use as fuel in automobiles, cars, two/three wheelers, commercial vehicles (as a replacement of motor spirit - petrol and high speed diesel)

The major petroleum fuels used for the above applications are LPG, Kerosene, Diesel and Petrol. These can be easily replaced by upgraded and bottled biogas.

1) **LPG** – Liquefied Petroleum Gas: LPG is prepared by refining petroleum or 'wet' natural gas, and is almost entirely derived from fossil fuel sources. It is a flammable mixture of hydrocarbon gases used as a fuel in cooking and vehicles. When specifically used as a vehicle fuel it is often referred to as autogas. For cooking purposes LPG cookstoves can be easily replaced by biogas cookstoves, which are readily available. Bottled biogas can replace LPG (autogas) which is used in vehicles by making simple modifications in the LPG kit installed in the vehicle.

2) **SKO** – Superior Kerosene Oil: Kerosene is a combustible hydrocarbon liquid. Kerosene oil is widely used for lighting/ cooking in rural areas of developing countries where electricity is not available or is too costly for widespread use. The kerosene burners can be easily replaced by biogas cookstoves.

3) **MS** – Motor Spirit- Gasoline or petrol, light, volatile mixture of hydrocarbons for use in the internal-combustion engine and as an organic solvent, obtained primarily by fractional distillation and 'cracking' of petroleum, but also obtained from natural gas.

4) **HSD** – High Speed Diesel: HSD is normally used as a fuel for high speed diesel engines.

5) **Natural Gas -** a naturally occurring hydrocarbon gas mixture consisting primarily of methane, but commonly includes varying amounts of other higher alkanes and a lesser percentage of carbon dioxide, nitrogen, and hydrogen sulphide. Natural gas is an energy source often used for heating, cooking, power generation and as a vehicle fuel.

Upgraded and bottled biogas can replace MS, HSD and NG which are used in vehicles as a fuel by installing CNG kit in the vehicle. The consumption pattern of the above mentioned petroleum fuels from 2007 - 2012 in India are shown in Tables A4 – A6.

Table A4. Major End Use of Petroleum Products

Petroleum Product	End Use
LPG	Cooking- Domestic/ commercial, also used for industrial applications, now also used as a transport fuel
SKO	Majorly for lighting and cooking
MS	Also known as motor gas, gasoline, petrol. Used as a vehicle fuel in passenger cars, taxis, two wheelers.
HSD	In transport sector in vehicle fuel- buses, cars, tractors etc., for power generation - as a fuel for pumpsets, gensets etc.
NG	The major demand for natural gas comes from the power sector, fertiliser, captive use/LPG shrinkage, industrial fuel, and petrochemicals manufacturing, as a domestic cooking fuel, vehicle fuel. Natural gas is currently the source of half of the LPG produced in the country.

Table A5. Consumption Pattern of Major Petroleum Products in India

(Thousand tonnes)	2007-2008	2008- 2009	2009-2010	2010-2011	2011-2012
LPG	12165	12344	13135	14331	15358
SKO	9365	9303	9304	8928	8229
MS	10332	11258	12818	14194	14992
HSD	47669	51710	56242	60071	64742
NG(million cubic meters)	30579	32989	46506	51429	45905

(Source: Indian Petroleum and Natural Gas Statistics, 2011-2012)

Table A6. Trend in Sector wise Consumption of Major Petroleum Products in terms of Energy from 2007-2012 (million MJ)

	Year	Domestic	Industrial	Transport	Power Generation	Others
LPG	2007-2008	516193	0	0	0	45830.4
	2008-2009	421429	0	0	0	78863.4
	2009-2010	525017	40286	10397	0	31138.8
	2010-2011	571448	45507	10349	0	34788.6
	2011-2012	615338	48279	10348.8	0	35574
SKO	2007-2008	400331	0	0	0	8919.09
	2008-2009	398933	0	0	0	7607.71
	2009-2010	397623	0	0	0	8962.11
	2010-2011	381064	0	0	0	9089.42
	2011-2012	351486	0	0	0	8121.25

	Year	Domestic	Industrial	Transport	Power Generation	Others
MS	2007-2008	0	0	456158	0	0
	2008-2009	0	0	497041	0	0
	2009-2010	0	0	565915	0	0
	2010-2011	0	0	626665	0	0
	2011-2012	0	0	661897	0	0
HSD	2007-2008	0	0	38310	4204.2	2002486
	2008-2009	0	0	227027	14414	1976918
	2009-2010	0	0	230159	12999	2169625
	2010-2011	0	0	232346	7121.4	2337578
	2011-2012	0	0	224281	7207.2	2545943
NG	2007-2008	15603	117038	46632	423949	473786
	2008-2009	1338.4	208223	54063	443884	454379
	2009-2010	3592.5	106293	64735	752486	710858
	2010-2011	8664.2	81606	43039	965569	712475
	2011-2012	1021.39	56986.7	32895.9	716138	809754.1

(Source: Indian Petroleum and Natural Gas Statistics, 2011-2012)

The total biogas generation potential from dairy farms, municipal solid waste, crop residue and agricultural waste, vegetable market, food waste, community toilets, wastewater sludge, industrial waste which includes distilleries, dairy plants, pulp and paper, poultry, slaughter houses, sugar industries excluding wastewater is ***approximately 48383 million m^3 of biogas generation annually***. The raw biogas if upgraded and bottled can be utilised as a vehicle fuel or as a cooking fuel for commercial purposes.

Table A7. Conversion of Raw Biogas to Upgraded Biogas on Mass Basis and Energy Basis

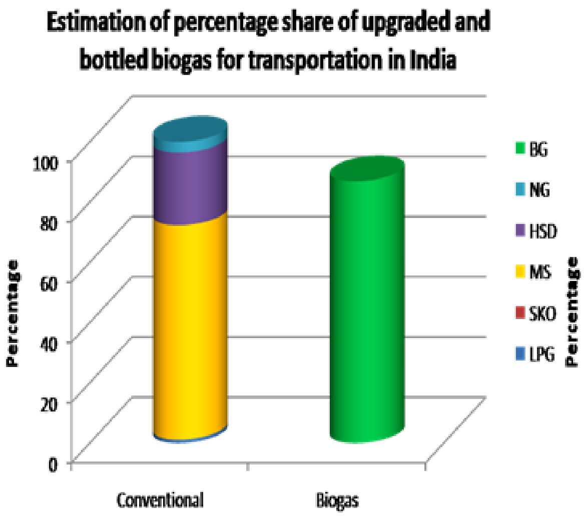
Biogas output form	Amount	Unit	Remarks
Total raw biogas potential	48382.5	Million m^3 $year^{-1}$	Considering the total raw biogas potential from the available organic feed stocks in India as evaluated in Table A2
Total upgraded biogas potential	18946.59	Million kg $year^{-1}$	Considering 55 % methane in raw biogas and density of upgraded biogas as 0.712 kg m^{-3} (Subramanian et al., 2013),
Total energy potential of biogas	807503.5	Million $MJyear^{-1}$	Considering calorific value of upgraded biogas(biomethane) as 42.6 Mega Joules kg^{-1} (Subramanian et al., 2013),

Table A8 shows the consumption of the major petroleum products during the financial year 2011- 2012 in terms of energy in two major sectors, i.e. cooking and transportation. The contribution of upgraded biogas in terms of energy in the cooking and transportation sector as a percentage of the total petroleum fuels consumption can be evaluated.

As calculated above by referencing the source Indian Petroleum and Natural Gas Statistics - 2011-2012 data and the references quoted in the text above, the contributions of upgraded biogas in the transportation and cooking sector as a percentage of total petroleum fuels consumption for the year 2011-2012 are approximately 86.8 % and 83.4% respectively as shown in Figure A2.

Table A8. Consumption of Petroleum Fuels during the Year 2011-2012

Consumption of petroleum fuels during 2011-2012 in terms of energy (Million MJ)				
Fuel	Conventional Fuels for Transportation	Conventional Fuels for Cooking	Upgraded Biogas Potential in India	Remarks
LPG	10349	615338		CV of LPG = 46.2 $MJkg^{-1}$ (Staffell, 2011)
SKO	0	351486		CV of SKO = 46.2 $MJkg^{-1}$ (Staffell, 2011)
MS	661897	0		CV of MS = 46.2 $MJkg^{-1}$ (Staffell, 2011)
HSD	224281	0		CV of HSD = 46.2 $MJkg^{-1}$ (Staffell, 2011)
NG	32896	1021		CV of NG = 46.2 $MJkg^{-1}$ (Staffell, 2011)
Total	929423	967845	807503	



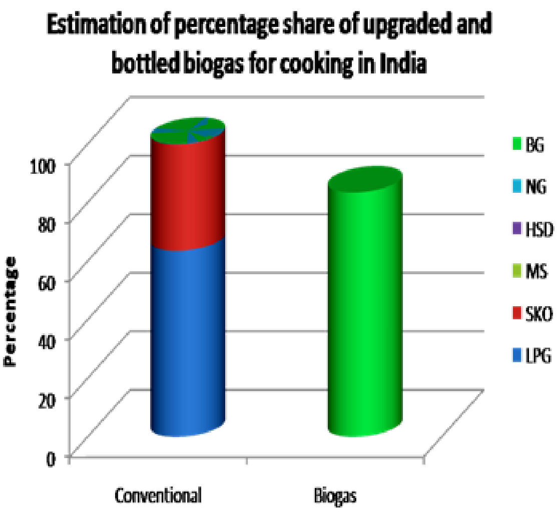
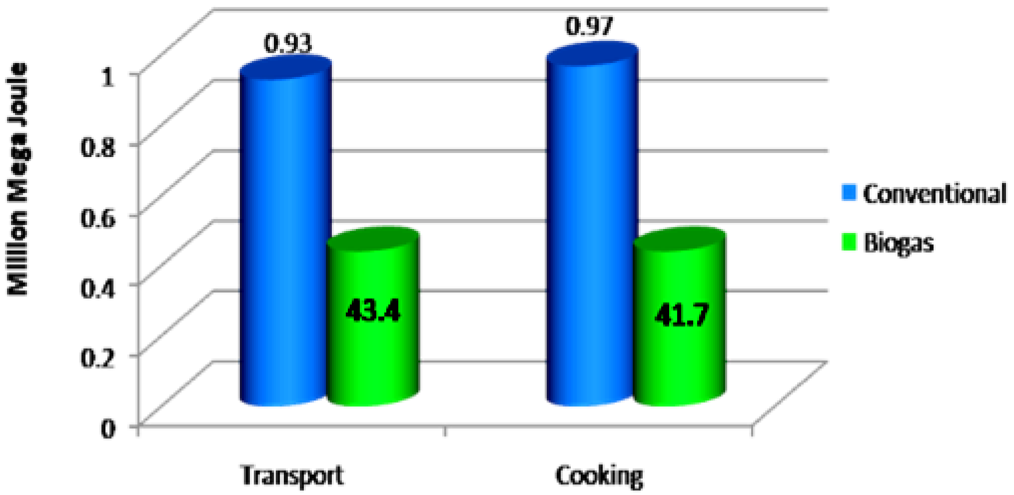


Figure A2. Contribution of upgraded biogas in the transportation and cooking sector as a percentage of total petroleum fuels consumption for the year 2011-2012 (*Estimate based on the source Indian Petroleum and Natural Gas Statistics - 2011-2012 data and the references quoted in the text above)*

In some places upgraded biogas will be used for vehicular applications and in some places for cooking, depending upon the market requirement and availability of the entrepreneur. Hence, a scenario is presented for utilisation of upgraded and bottled biogas in the transportation and cooking sectors in India assuming a 50% contribution of bottled biogas in each sector. Based on the Indian Petroleum and Natural Gas Statistics - 2011-2012 data and the references quoted in the text above, it is estimated that if 50 % of the total upgraded biogas contributes to the transport sector then around 43.4% of the total transport sector demand can be fulfilled, and similarly around 41.7 % of the energy demand can be fulfilled in the cooking sector as shown in Figure A3.



The data are based on petroleum fuel consumption in transport & cooking sectors in the year 2011-2012

Figure A3. Scenario for utilisation of bottled biogas in transportation and cooking sector in India assuming 50% contribution in each of the two sectors (*Estimate based on the source Indian Petroleum and Natural Gas Statistics - 2011-2012 data and the references quoted in the text above)*

A4 Adaptability of upgraded biogas in natural gas grid and vehicles in India

With a large number of Indian cities implementing the natural gas vehicle programme, consumption has increased rapidly within the past decade. As per the Ministry of Petroleum, Government of India, India has an estimated current demand for natural gas of around 57.32 billion m^3 $year^{-1}$, which is made up of around 45.58 billion m^3 $year^{-1}$ from domestic supplies and the rest from imported LNG (Jain and Sen, 2011). India's future demand for gas could reach 113.61 billion m^3 $year^{-1}$ by 2015 and 135 billion m^3 $year^{-1}$ by 2025, depending on how the gas market develops (Roychowdhury, 2010). India currently has around 12,000 km of natural gas pipeline. Most of these gas pipelines are in the northern and western regions and much development is needed in southern, eastern and central regions. The network density is low when compared with some of the more developed natural gas markets.

Presently, the transportation sector in India, with around 1.1 million natural gas vehicles, consumes less than 2% of the total natural gas consumption (MPNG, 2012)). It is expected that within the next decade the number of natural gas vehicles will increase to over 5.8 million. It is also expected that the natural gas pipeline network will increase to 15,000 km and implementation of city gas distribution networks will cover around 150 to 200 cities by 2014. This would further increase the share of natural gas imports to India (Roychowdhury, 2010).

There are over 860 CNG service stations providing a blend of CNG and upgraded biogas (biomethane) to over 90,000 natural gas vehicles in some developed countries like Sweden and Germany; two of these stations only sell upgraded biogas (Power, 2011). Such development is yet to begin in India, as no commercial upgraded biogas facilities are currently in operation.

Hence, the potential of organic waste that can be translated to an optimistic aggregated estimated capacity of raw biogas production is 54 million m^3 $year^{-1}$ or 24 million kg $year^{-1}$ of upgraded biogas (NB: This is just an approximation of the total organic waste available in India based on the waste data and rough calculations). Bottled biogas can be easily dispensed through the present available natural gas infrastructure in the country. Hence, small-scale biogas bottling systems would help in contributing to the natural gas demand in India for the local transportation market.

A5 Assessment of possible scenarios for the adoption of upgraded biogas in India

Bottled biogas can be utilised in two different scenarios: 1) Captive/in-house use and 2) Selling of bottled biogas as a fuel either for cooking or for vehicles. The following section depicts some potential scenarios for harnessing this technology. Upgraded and bottled biogas can be utilised as a transport fuel or can be used as a replacement of cooking fuel - LPG. Bottling facilitates easy transportation of biogas to remote places. If the barriers in the promotion of this technology are overcome and support is provided to entrepreneurs in the form of tax incentives, policies and subsidies, then this technology has all the benefits of fulfilling energy demands, reducing dependence on fossil fuels and waste management in rural, urban as well as in remote areas.

Scenario I: Captive/In-house use

This scenario represents the various models where biogas production, upgrading and bottling is done in the same place. This type of scenario is possible in locations like cattle sheds, fruit and vegetable markets, sewage treatment plants, community toilets and housing societies etc.

Model a: Biogas upgrading and bottling in rural areas (Cattle sheds)

The scope of implementation of this technology in rural areas is immense as apart from the small-scale – individual household biogas plants, rural areas have cattle sheds (dairies) which generate wastes at different scales which in turn have a potential of producing medium to large scale biogas. Biogas upgrading and bottling systems can become a feasible option where there is a potential of producing above 500 m^3 day^{-1} of biogas. There is a large scope for biogas upgrading and bottling in dairies as waste can be converted into bottled biogas there. Small-scale bottling systems can be installed in cattle sheds. This bottled biogas can be used as a transportation fuel in the captive vehicles like vans, tractors etc of the cattle sheds. Apart from this, if a suitable market is found outside the farm, then the bottled biogas can be transported in a cascade of cylinders to nearby dispensing stations, where dedicated systems are available for metering and monitoring the quality of the gas for selling it as a vehicle fuel instead of CNG cylinders. Bottled biogas can also be sold as a vehicle fuel in villages by deploying a compressing, dispensing and metering system. Hence it can be sold as a vehicle fuel for the private vehicles or tractors of villagers.

Model b: Biogas upgrading and bottling in communities like restaurants, hostels, fruit and vegetable markets, community toilets.

Biogas upgrading and bottling can become a feasible option in urban or rural areas where community biogas plants (Figure A4) can be employed, like community toilets, fruit and vegetable markets and marriage halls etc. Biogas can be upgraded and bottled at the site of production and can be used as vehicle fuel for the captive vehicles of the communities like trucks, lorries and auto rickshaws. Bottled biogas can also be used as a replacement for LPG in cooking, for example in marriage halls. As in scenario I(a), if a suitable market is found outside the community, then the bottled biogas can be transported and sold as a vehicle fuel to replace CNG cylinders or by direct dispensing and metering.

Figure A4. Community biogas plant (Source: http://balajibiopower.com/)

Model c: Biogas upgrading and bottling in urban areas serving housing societies/housing clusters, industries producing organic effluents (medium-scale biogas production)

In urban areas organic wastes are available in abundance in sewers and landfills. Apart from this, wastes from fruit and vegetable markets, restaurants and hotels are also available, which are presently sold as piggery feed or dumped in landfills. These municipal wastes can be used for medium-scale biogas generation and small-scale biogas upgrading and bottling systems can be installed at these sites. This biogas after upgrading and bottling can be dispensed into private vehicles or those of the housing societies/housing clusters or filled in a cascade of cylinders and transported to centralised dispensing stations.

Scenario II: Selling of upgraded biogas as a fuel

Another option for implementing biogas upgrading and bottling system as an entrepreneurship model in rural areas is in dairy clusters, village clusters and clusters of housing societies in urban areas. If wastes from different dairies can be collected and transported to a centralised site for biogas production, upgrading and bottling then bottled biogas can be used for vehicle fuel. Another option for offsite upgrading and bottling is a mobile biogas upgrading unit. Such a unit can serve a cluster of biogas plants in villages or in urban areas a housing cluster where a biogas upgrading and bottling system is not present.

Model a: Biogas upgrading and bottling at a location away from the site of production of waste (collection of waste from different locations and transportation to a centralised site for biogas production and upgrading)

Another option for waste collection is from village clusters/dairy clusters in rural areas. In urban areas, waste can be collected from dedicated waste production sites for example housing societies, restaurants, hostel messes, sewers etc. Centralised collection systems can be installed in which people dispose of waste in a centralised place. From here the waste is mixed and shredded and fed into digesters known as community biogas plants or medium/large-scale biogas plants, depending upon the scale of production of biogas (Exnora Green Pammal News, 2010). Upgraded bottled biogas can be produced at the biogas production site using small-scale upgrading technologies, and can be sold to local people at nominal prices. This model is shown in Figure A5. The upgraded bottled biogas can be filled in a cascade of biogas cylinders for transportation to remote rural areas and or in cylinders dispensing into a vehicle. This bottled biogas can be used as a transportation fuel for the captive vehicles of the community. Apart from this, if a suitable market is found outside the community, then the bottled biogas can be transported and used as in Scenario I (a).

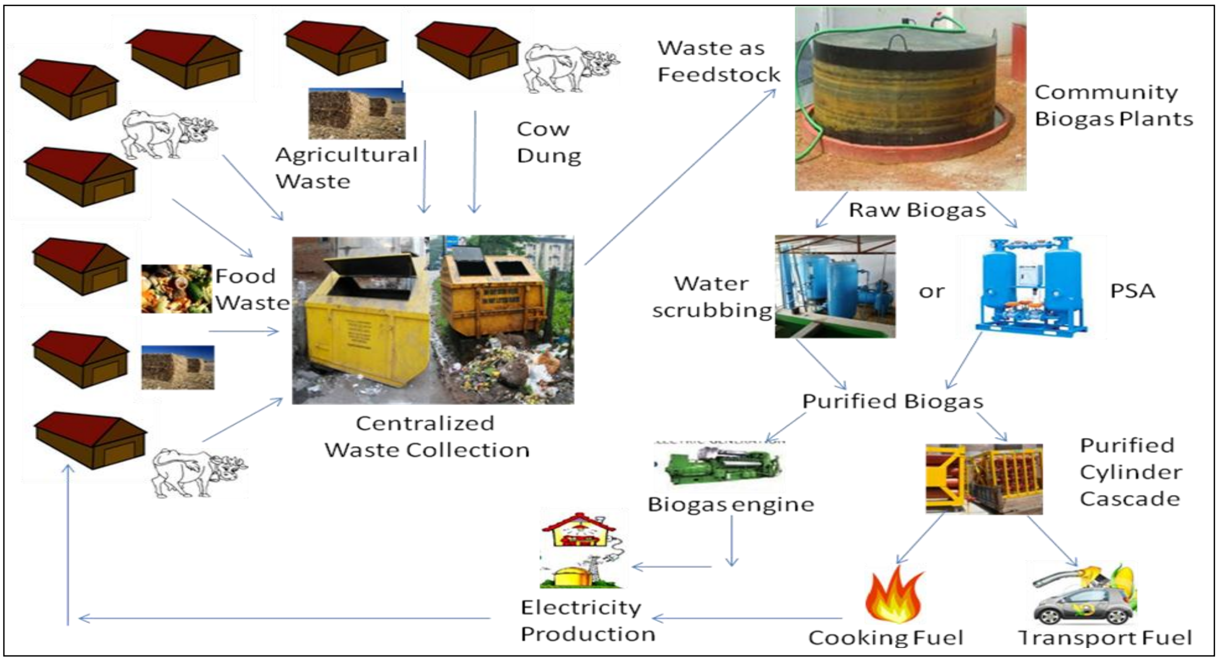


Figure A5. Schematic diagram of Biogas Entrepreneurship Model I (Source: Author)

Model b: Onsite upgrading and bottling of biogas from various plants using mobile unit

Another option for upgrading and bottling is a mobile biogas upgrading unit serving a cluster of biogas plants in villages or in urban areas a cluster of housing where there is no biogas upgrading and bottling system. The biogas producer can hire the mobile upgrading unit and hence biogas can be upgraded at the production site without implanting an upgrading and bottling unit. The cost of the upgrading and bottling plant is saved by the biogas producer. In this option the mobile upgrading unit is mounted on a trolley attached to a vehicle. The unit can service more than one biogas plant within a cluster. The trolley-mounted machine as shown in Figure A6 can be transported to digesters in different locations where raw biogas is produced. The raw biogas can be upgraded and used to fill CNG cylinders for storage at high pressure which are then transported to the nearby dispensing stations, giving an uninterrupted supply of upgraded biogas (Leonard et al., 2006). The scenario can be site-specific depending on the local situation. After bottling, biogas can be used as a transportation fuel for the captive vehicles of the village or community. Apart from this, if a suitable market is found outside the community, then the bottled biogas can be transported and used as in Scenario I (a).

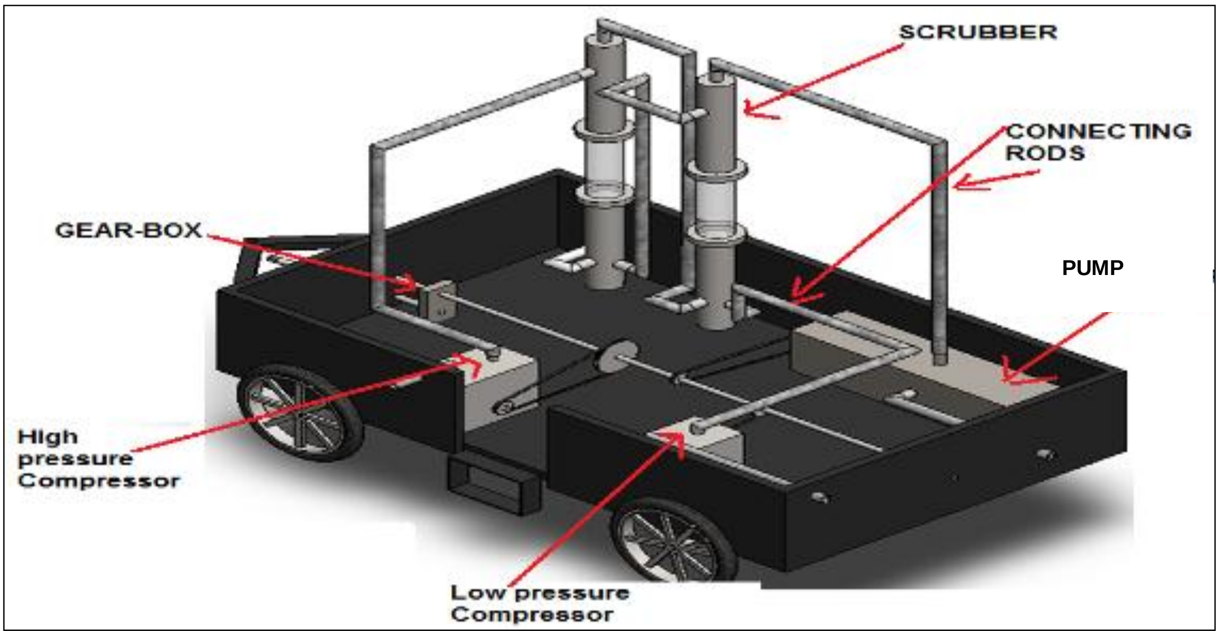


Figure A6. View of the mobile unit (Source: Author)

Model c: Setting up of upgradation and bottling plant at the site of waste generation (for example, large cattle sheds, dairies, large vegetable and market yards, residential colonies) and selling of upgraded biogas locally for cooking and transportation purpose.

Another scope for implementation of biogas upgrading and bottling plants for commercial purposes is at sites where a large quantity of organic waste is generated having a potential to produce biogas at a medium to large scale: for example, large cattle sheds, dairies, large vegetable and market yards, industries such as sugar mills, pulp and paper, distilleries, residential colonies in urban areas. Biogas upgrading and bottling systems can become a feasible option where there is a potential of producing above 500 m^3 day^{-1} of biogas. The upgraded and bottled biogas can be sold as a fuel to local vendors for cooking in nearby restaurants, hotels, hostels etc. If a small dispensing system along with metering device is installed then the upgraded biogas can be sold as a transport fuel for local vehicles. Apart from this, if a suitable market is found at far of places, then the bottled biogas can be transported in a cascade of cylinders to the site of utilisation.

Urban areas are densely populated and have large scope for small-scale biogas upgrading and bottling systems. If residential colonies societies etc can be grouped in 20,000-25,000 households, then waste from these households can be collected at a centralised place. Biogas can be produced, upgraded and bottled for consumers for applications like cooking, as a replacement for LPG, or as a vehicle fuel for private vehicles of the residents of the societies. For example, if on average one household gives 250 g day^{-1} of biodegradable waste, then a small community of 25000 households will be able to generate approximately 6.5 tonnes day^{-}

[1]. This quantity of waste can generate approximately 500 Nm^3 day^{-1} of biogas, which is sufficient for running a small-scale biogas upgrading system in entrepreneurial mode. Bottled biogas can be used either in community kitchens in the housing society or as a vehicle fuel in community vehicles like laundry vans etc. Such systems are a need of the time and in future may become a reality everywhere.

A6 Adoption feasibility of upgraded and bottled biogas in India

A6.1 Availability of components for low cost small-scale biogas upgrading and bottling in India

i. Upgrading Units

Biogas upgrading or purification processes involve removal of contaminants in the raw biogas stream. Carbon dioxide, H_2S and moisture are absorbed or scrubbed, leaving more methane per unit volume of gas. There are four main methods of biogas upgrading: water washing, pressure swing absorption, cryogenic, and chemical scrubbing. These technologies can deliver a gas containing up to 98% methane. The most widely used technologies for biogas upgrading are water scrubbing, PSA, organic physical and chemical scrubbing. Of these technologies, water scrubbing and PSA are considered to be most appropriate at a small scale due to their low cost and simple maintenance (Kapdi et al., 2005). All technologies have their own advantages and disadvantages and the various published reviews and reports show that each technology is situation-specific. The optimal choice of the economically viable technology is strongly dependent on the quality and quantity of the raw biogas to be upgraded, the desired upgraded biogas quality, the final utilisation of the gas and the local situation and scenario at the plant site. The choice is upon the discretion of the entrepreneur and future operator. Existing biogas upgrading systems are suitable and optimised for biogas upgrading and bottling and hence demand high capital investment costs. In most cases, with increasing gas prices and current systems of grants/subsidies, upgrading systems above 500 Nm^3 day^{-1} can be economically viable.

ii. High Pressure Compressors

For dispensing into vehicles, upgraded biogas needs to be compressed at 200 bar and stored in cylinders. Natural gas compressors for large-scale applications are multi-stage compressors which are readily available in the market. Not many applications are available in the market for compressing biogas from small-scale upgrading units. For small capacity high pressure applications, diaphragm-type compressors are preferred and a few reputable companies are manufacturing high pressure compressors for small-scale applications, for example Bauer Compressors Pvt. Ltd, Indian Compressors Ltd, Coltri (Nuvair compressed gas solutions), DMC Ltd, Shanghai etc. These foreign make compressors are expensive due to the taxes, duties and excise levied on import. Another problem with imported compressors is that if any fault occurs then neither the technical manpower nor the mechanical parts are available in India. Some Indian companies have started manufacturing small-scale natural gas compressors. They are relatively cheap as compared to the foreign make compressors but reliability of these compressors is still a question under consideration.

iii. Gas Storage and Distribution Units

After compressing the upgraded biogas, it needs to be stored in dedicated cylinders. Since after upgrading it becomes equivalent to natural gas, CNG cylinders are most compatible for this application. For efficient transportation and storage of upgraded biogas, CNG cylinders are easily available in the market. Upgraded biogas can be stored at 200 bar in these cylinders. Bottled gas can be transported using cascade of cylinders to dispensing stations or where ever required. These are available in different capacitates in the market. In India, there are certain legalisations and regulations on the use of CNG cylinders for upgraded biogas. CNG cylinders are a viable option for storage but special permissions have to be taken from relevant authorities like PESO etc.

Different distribution scenarios can be adopted for utilisation, storage and transportation of bottled biogas for vehicular use.

a) On site utilisation/captive use:

If biogas is upgraded and bottled at a small scale and is to be used on the site of itself for filling captive vehicles then the two cylinder cascade system can be used to dispense the gas directly in the vehicles. For this, there is no need for dedicated systems for monitoring the quantity of gas being dispensed in the system.

Figure A7. 2-cylinder cascade system for on-site dispensing of upgraded biogas at IIT Delhi *b) Trolleys of cascade of cylinders:*

If upgraded and bottled biogas is to be transported to small dispensing stations nearby, for example to the local village vehicles, then small trolleys with CNG cylinders can be used to transport the bottled biogas manually as shown in Figure A8. This can be also an option when there is a centralised station for dispensing the biogas in a village then collection of bottled gas from decentralised small-scale biogas upgrading and bottling units and transported to the dispensing stations via these trollies.

(a) Trailer

(b) Three cylinder cascade trolley

Figure A8. Trolley Carrier for the transport of cylinder cascades to the buyer

c) Transportation using trucks of cylinder cascades for long distances:

In a truck-based bottled gas distribution strategy, the locally produced bottled gas is first collected in bottles/CNG cylinders from decentralised small-scale biogas upgrading and bottling units and then the cascades can be transported with trucks anywhere (Figure A9). This facilitates long distance distribution. The cascade of cylinders can be transported to urban areas where sophisticated and dedicated stations for monitoring the quality and quantity of gas are present for dispensing the gas in vehicles. Another option is that the trucks can transport the upgraded biogas to remote locations to cater to local transportation needs.

In scenarios II(b) and (c), the role of small-scale upgrading and bottling units can be evaluated for contributing to local transportation needs. In both the cases, the gas produced at various decentralised small-scale biogas upgrading and bottling units can be collected and transported to dispensing stations placed centrally. With such scenarios, the high investment cost associated with sophisticated infrastructure for monitoring the quality and quantity of the gas and dispensing the gas in vehicles are not incurred by the project developers/entrepreneurs. Hence, only the costs of upgrading and bottling unit have to be borne by the entrepreneur.

(a) Trailer for transportation of **c**ascade of cylinders

(Source: http://trade.indiamart.com/details.mpoffer=1642656088)

(b) **C**ascade of cylinders for storage and transportation of upgraded and compressed biogas

(Source: http://maxengg.tradeindia.com/cng-storage-cylinders-70720.html)

Figure A9. Trailer system for transport of cylinder cascade

iv. Dispensing Units

For utilising bottled gas in captive vehicles, sophisticated infrastructure like metering devices, filling stations, piping, high capacity compressors and distribution system is not required. But if the bottled gas is to be sold as vehicle fuel, efficient and dedicated systems for dispensing biogas into the vehicle are necessary. A typical CNG pumping station consists of a high capacity CNG storage, a cascade of cylinders, a similar capacity high pressure CNG compressor and a highly sophisticated CNG metering and dispensing system for filling gas in the vehicles as shown as Figure A10. For small-scale applications, for captive use or selling the bottled gas in a community, a dispensing system consisting of a two-cylinder cascade for compressed gas storage, a dispensing nozzle and hose can be used as shown in Figure A11.

(a) A sophisticated biogas dispensing station leased by Chesterfield BioGas Ltd, U.K (Source: http://www.chesterfieldbiogas.co.uk/news/Temporary-CNG-refuelling-station-for-councils-low-carbon-vehicle-trial/7)

(b) Biogas dispensing station with bulk cascade of cylinders in UK (Source: http://www.chesterfieldbiogas.co.uk/news/Chesterfield-BioGas-trailer-fuels-Coca-Cola-Enterprises-supply-vehicles/6)

Figure A10. Highly sophisticated dispensing units for large scale applications in U.K

(a) Upgraded and compressed biogas dispensing nozzle (Source: Author)

(b) A two cylinder CNG cascade (Source: Author)

Figure A11. Details of two cylinder cascade system and dispensing system in IIT Delhi specially designed for small scale upgrading and bottling applications

v. Upgraded gas measurement and composition analysing units

If the bottled gas is to be sold as vehicle fuel, efficient and dedicated systems for dispensing biogas in the vehicle are required. These are costly and require a high amount of investment, while dedicated professionals are required to operate the equipment. In India, dedicated infrastructure like dispensing stations is available for CNG but only in some urban cities. In rural areas, CNG infrastructure is not available and adds to the cost of upgrading and bottling units. Hence, centralised stations for dispensing upgraded and bottled biogas can be installed for village clusters with bottled gas being collected from various locations. Hence, with proper monitoring, quality and quantity checks bottled gas can be used as a transport fuel.

A6.2 Scope of utilisation of upgraded biogas as a transport fuel in India

The scope of utilisation of biomethane as a vehicular fuel in India can be understood by the growth of CNG infrastructure in India. Although natural gas is not yet a major transportation fuel in India, the use of compressed natural gas (CNG) is a key step toward the goal of using upgraded biogas in transportation. Since conversion for biogas use is the same as for natural gas use, upgraded biogas can be easily substituted in the existing natural gas vehicles and infrastructure currently available in the country. For other conventional fuel driven vehicles, licensed NG conversion companies can provide conversion services with certified conversion kits. The original equipment manufacturers (OEMs) are also responding to the growing market for CNG in the country by adapting and indigenising the technology into varied vehicle segments, such as buses, three wheelers, taxis, light commercial vehicles and passenger cars. According to a survey in India in the year 2008, 210,422 passenger cars, 270,320 three wheelers, 14,547 light duty vehicles and 13,949 buses were operated with CNG (Ghosh. A., et al., 2011). The following are the developments in various vehicle segments towards implementing CNG across India, which can also been seen as potential upgraded biogas fuelled vehicles in the near future.

a. Passenger cars

The passenger car industry has been slow to respond. This market is largely driven by after-market conversion. OEMs have shown little interest as there is no regulatory mandate for cars and this market has therefore been slow to develop. Only a couple of models that are popular in the taxi segment were initially made into CNG models by Tata and Maruti Udyog Ltd. Very recently, however, the car industry has begun to show interest in product diversification and the car majors including Toyota, Tata, Maruti Udyog Ltd and General Motors have announced more CNG models. This has been triggered largely by the growing consumer interest in CNG cars and the spurt in after-market conversion that followed the recent hike in petrol and diesel prices.

b. Light Commercial Vehicles

In the light commercial vehicle segments, the three-wheeler market Bajaj Auto Ltd has been the monopoly producer of the CNG four-stroke three wheelers for a long time. Only Scooters' India Ltd produced CNG two-stroke three-wheelers at a small scale. But as two-stroke engines, even if they are on CNG, are banned in the major markets like Delhi, this did not expand. Now a couple of new players have joined in. In the light commercial vehicle category Tatas, Swaraj Mazda and Hindustan Motors have launched CNG models (Becker. D., et al., 2010)

c. City Buses

Nearly the entire CNG bus market has been supplied by two India majors – Ashok Leyland and Tata Motors. In the last few years some more players including Eicher Motor, Swaraj Mazda and Volvo have entered the market. The CNG bus market in India is unique and growing as CNG cities are planning expansion of bus transport as a mobility measure to reduce pollution and congestion. Industry thus needs to innovate and diversify its bus product portfolio. Already Tata Motors and Ashok Leyland have begun to produce low floor specially designed urban CNG buses

A6.2.1 Upgraded biogas as a vehicle fuel in urban areas

At present Delhi alone has more than 200,000 CNG vehicles, and around 30 cities including Mumbai, Pune, Vadodra, Surat, Ankleshwar, Lucknow, Agra, Kanpur, Bareilly, Vijaywada, Hyderabad, Rajamundary, Agartala, Indore and Ujjain have access to CNG. Many cities are now augmenting their bus fleets to enhance local transport services (Roychowdhury A., 2010). The CNG programme has been linked with the public transport augmentation plan that includes both buses and intermediate public transport of autos and taxis. Upgraded biogas can be easily implemented as a transport fuel with these infrastructures. The upgraded biogas generated from small -medium scale bottling and upgrading plants as mentioned above can be supplemented to the natural gas distribution network. Small sewage treatment plants installed at housing clusters across the city will provide a potential source for replacing CNG in vehicles for local transportation.

Example: Based on the model in Scenario II (b) of residential colonies, housing societies etc coming together in groups of 20,000-25,000 households, these could produce 500 Nm^3 day^{-1} of biogas, which after upgrading will be equal to 220 kg of upgraded biogas. This amount of bottled biogas will be sufficient to run approximately 80 – 85 four-wheeled vehicles like cars, etc. (NB This is an approximation based on the available waste data and basic calculations)

A6.2.2 Upgraded biogas as a vehicle fuel in rural areas

In rural areas of India tractors/trolleys and light goods vehicles constitute the major proportion of vehicles. The Indian tractor industry is the largest in the world, currently constituting up to one third of global production. With increasing agricultural GDP, sales of tractors in rural India have also increased dramatically within the past decade. But due to lack of CNG infrastructure in rural sectors, no CNG fitted vehicles are currently available. The OEMs of tractors and trolleys are not presently keen on manufacturing CNG operated tractors/trolleys for rural areas. Due to the higher availability of biomass from cattle and poultry manure and agriculture waste residues in rural areas, however, there is a huge potential for generation of upgraded biogas to cater for local transportation needs. A local dedicated biogas upgrading and dispensing unit can be developed where raw biogas obtained from nearby farms can be upgraded, bottled and dispensed into vehicles and tractors/trolleys. The OEM manufactured CNG buses and light duty vehicles for urban areas can be purchased and easily utilised in rural areas. The existing gasoline-operated vehicles can be converted through certified conversion kits to operate with upgraded biogas under bi-fuel mode. Due to these developments tractor manufacturers can also look towards adapting the CNG technology into their vehicles to be utilised along with upgraded biogas.

Example: In many rural areas, the majority of households have cattle. If a village has 1000 families with cattle, then the total number of cattle may be around 3000. If 250 g of waste is considered per person, then approximately 250 kg of waste will be available. If other organic waste in the village is considered, like agricultural waste, water hyacinth etc, then an approximation of the total waste can be made at around 31000 kg. This will produce around 3000 m^3 day^{-1} of biogas; after upgrading with a yield of about 60%, 1300 kg of upgraded biogas can be obtained. This amount of upgraded biogas is sufficient to run 460 vehicles like tractors, trollies, four wheelers etc. (This is an approximation based on the available waste data and basic calculations).

A6.3 Scope of utilisation of upgraded biogas as a cooking fuel in India

The scope of utilisation of upgraded biogas as a cooking fuel is tremendous in rural as well as in urban areas. There is a huge market for cooking fuel in India apart from utilising the upgraded biogas for captive use. In India, upgraded biogas as a cooking fuel can be adopted as a cooking fuel in rural small scale restaurants called dhabas, highway restaurants, hotels, and restaurants in urban areas, community kitchens in temples and marriage halls, roadside eating joints etc as shown in Figure A12. In commercial eating places cooking fuel is used in the form of commercial LPG cylinders which are comparatively expensive. These can be easily replaced by upgraded and bottled biogas. Upgraded and bottled biogas is cheap as compared to commercial LPG. If upgraded and bottled biogas is made available at these places, the buyer will happily accept to replace commercial LPG with upgraded biogas due to economics.

(a) Roadside eating joints in India
(Source : www.digital-photography-school.com/forum/photojournalism-sys/113809-roadside-food-joints-indian-roads.html)

Figure A12 Scope of adoption of upgraded and bottled biogas in India

(b) Commercial cooking in India
(Source:http://travelerfolio.com/bukhara-itc-maurya-new-delhi/,
http://www.flickriver.com/photos/robinthom/sets/721576210 03902466/)

(c) Community cooking in India

Cooking in the kitchen at Shirdi Temple, Pune (Soure:http://solarcooking.wikia.com/wiki/India)

Community cooking in marriage halls in rural area (Source: www.flickr.com/photos/lokraj/2283335329/)

Figure A12 ctd Scope of adoption of upgraded and bottled biogas in India

A7 Success stories of biogas upgrading and bottling in India

The need to replace fossil fuels in vehicles and move towards energy self-reliance in India has been realised. The Ministry of New and Renewable Energy (MNRE) has taken a new initiative for bottling of biogas to demonstrate an integrated technology package in entrepreneurial mode on medium-size mixed feed biogas-fertiliser plants (BGFP) for generation, upgrading/enrichment, bottling and piped distribution of biogas. Installation of such plants aims at meeting stationary and motive power, cooling, refrigeration and electricity needs in addition to cooking and heating requirements. Under the demonstration phase, the MNRE had a provision for a central financial assistance of 30 to 50 % of the cost (excluding cost of land) for a limited number of such projects for implementation following an entrepreneurial mode on built, own and operate basis (MNRE, 2011)

A7.1 Status of biogas upgrading and bottling plants in India

During the year 2008-09, an initiative was taken on installation of medium-size (200-1000 m^3 day^{-1}) BGFP for generation, upgrading/enrichment, bottling and piped distribution of biogas under the RDD&D policy of MNRE. Installation of such plants aimed at production of Compressed Biogas (CBG) of CNG quality to be used as vehicular fuel, in addition to meeting stationary and motive power and electricity generation needs in a decentralised manner by the establishment of a sustainable business model in this sector. Under the demonstration phase, the MNRE provided central financial assistance for 15 BGFP projects with aggregate capacity of 11,200 m^3 day^{-1} in 8 States, namely Gujarat, Karnataka, Punjab, Chhatisgarh, Haryana, Maharastra, Rajasthan and Bihar (MNRE, 2011).

i. 500 Nm^3 day^{-1} plant at Nasik, Maharashtra – upgraded biogas as a fuel for captive vehicle

A 500 Nm^3 day^{-1} capacity BGFP project for generation, upgrading and bottling of biogas was sanctioned by the MNRE with central financial assistance during the year 2009-10 to Ashoka Biogreen Pvt Ltd at village Talwade, District Nasik, Maharashtra. The biogas bottling plant was commissioned on 16 March 2011 after obtaining a license for filling and storage of compressed biogas in CNG cylinders. The upgraded biogas is filled in two cylinder cascades of 20 cylinders each (80 L capacity) using a high pressure compressor of 5 Nm^3 hour^{-1}. Upgraded biogas is primarily used to generate electricity to provide power for the entire plant. 5 KW CNG Kirloskar generators are installed for this purpose. The cylinders are filled to 150 bar only, as per the licence conditions. For experimental purposes, Ashoka Biogreen runs a CNG vehicle (TATA Magic) within its premises from the gas generated on the site, since at present there are no regulations and authorisations for running vehicles on upgraded biogas in India.

(a) Water scrubbing and PSA system

(b) Gas Analyser System

Figure A13. 500 Nm^3 day^{-1} plant at Nasik, Maharashtra

ii. 600 Nm^3 day^{-1} plant at Mukstar, Punjab – upgraded and bottled biogas used as commercial cooking fuel

Another project sanctioned by MNRE during the year 2009-10 was to Anand Energy for a 600 Nm^3 day^{-1} plant for generation, upgrading and bottling of biogas. The plant is located at Mukstar, Punjab and has started operation after having received the consent to operate from Punjab Pollution Control Board and a licence for filling and storage of compressed biogas in CNG cylinders. The biogas is produced using upflow anaerobic sludge blanket (UASB) digesters and the biogas upgrading technology is water scrubbing as shown in Figure A14. A cylinder cascade is used for storage of compressed biogas at 15 MPa. The plant produces upgraded biogas with a methane content of around 95%. The upgraded gas is filled in cylinder cascades using a high pressure compressor and is sold to meet the cooking demand of the hotel industry nearby.

(a) Biogas Plant (b) Upgrading Plant

Figure A14. Biogas and upgrading plant at Mukstar (Punjab)

iii. 600 Nm^3 day^{-1} plant at Tohana, Haryana - upgraded and bottled biogas used as commercial cooking fuel

The biogas fertiliser plant at Tohana, Haryana is owned by M/S Shashi Energies (Figure A15). They procure 14 tonnes day^{-1} cattle dung from the nearby villages and cattle farms. This dung is mixed with digester slurry and fed into a continuously-stirred (CSTR) type digester. The 600 Nm3 day^{-1} production of raw biogas from the digester is stored in a balloon of 200 m^3. The raw biogas is then fed into the low pressure water scrubbing tower operated at 0.8 bar. The capacity of the water scrubbing tower is 50 m^3 hour^{-1}. Upgraded biogas is compressed using a three-stage high pressure compressor and filled and stored in cascade of CNG cylinders. These cylinders are sold and used to replace commercial LPG cylinders in nearby hotels and restaurants.

(a) and (b) 50 m^3 $hour^{-1}$ Low Pressure Water Scrubbing Tower

(c) Bottling of upgraded biogas in CNG cylinder cascade

(d) Bottled biogas being used for cooking

Figure A15. Plant at Tohana, Haryana

A7.2 Performance evaluation of vehicle running on upgraded biogas as a fuel

In India, the government is taking initiatives towards implementing utilisation of biogas as a vehicular fuel for local transportation in the future. The MNRE has sanctioned a project entitled 'Comparative Evaluation of Performance and Mass Emissions of an automotive passenger vehicle with Enriched Biogas' to IIT Delhi to test for the feasibility of utilising biogas in Indian driving conditions. In this project a CNG automotive passenger vehicle was purchased to perform tests to evaluate performance and emissions using upgraded biogas as fuel. The fuel quality is maintained as per the suggested BIS standards with the help of the water scrubbing system developed at IIT Delhi

(a) and (b) CNG automotive passenger vehicle sponsored by MNRE,GOI

(c) and (d) Trial runs of biogas as a transport fuel in natural gas vehicle

Figure A16. IIT Delhi project on evaluation of biogas vehicle

A8 Economic analysis of small scale biogas upgrading and bottling plant

Biogas can be utilised in a number of different manners. Raw biogas as a cooking fuel is a trusted technology. Similarly, upgraded biogas (compressed biogas-CBG) can be utilised as a cooking fuel and as a vehicle fuel as discussed in the previous sections. The following Table A9 provides a comparative analysis of the economic benefits of small-scale biogas bottling for use as a vehicle fuel or for cooking fuel. In the current market the option of cooking fuel is more economically favourable.

Table A9. Analysis of small scale bottling plant with 50 % central financial assistance from the Government of India

Biogas Plant		
	Waste Required Water requirement in Biogas Plant: Biogas Production	~10 tonnes day^{-1} cattle dung ~ 10 tonnes day^{-1} 500 Nm^3 day^{-1}
A.	**Cost of biogas plant:**	**Rs. 50 lakhs = 5 million INR (€ 58,145.00)**
Biogas Upgrading and Bottling System (25 m^3 hour^{-1})		
	Upgraded Gas Quantity Upgraded Gas Composition	~200 kg day^{-1} CH_4: ≥ 90 %, CO_2: ≤ 4, H_2S: ≤ 20 ppm, Moisture: ≤ 0.02 gm/m^3
	Cost of biogas upgrading system	**Rs. 20 Lakhs = 2 million INR (€23,258.00)**
	Cost of biogas bottling system	**Rs. 30 Lakhs = 3 million INR (€34887.00), (including high pressure compressor system, cylinders for gas storage and gas dispensing system)**
B.	**Cost of biogas upgrading and bottling system**	**Rs. 50 Lakhs = 5 million INR (€ 58,145.00)**
Slurry Management System		
	Slurry Production	~17 tonnes of liquid slurry
C.	**Cost of management:**	**Rs. 10 Lakhs = 1 million INR (€11,629.00)**
D.	**Other Costs:** Land preparation, Civil work, Vehicles, Trolleys etc.	**Rs. 15 Lakhs = 1.5 million INR (€17,443.50)**
Total Initial Cost of Project (A+ B+ C+D)		**Rs.175 Lakhs = 17.5 million INR (€ 2,03,507.50)**
Revenue: if upgraded biogas is sold as a vehicle fuel		
	Upgraded Gas: as vehicle fuel Slurry: Total Revenue	(Rs. 45 kg) * (200 kg) = Rs. 9000 day^{-1} (Rs. 2 kg^{-1}) * (6000 kg) = Rs. 12000 day^{-1} Rs. 21000 day^{-1}
E.	**Annual Revenue:**	**(Rs. 21000 day^{-1}) * (330 day) = Rs. 70 Lakhs = 7 million INR (€ 81403.00)**
	Cost of Cow Dung	(Rs. 250 tonne^{-1}) * (10 tonnes day^{-1}) = Rs. 2500 day^{-1}
	Annual cost of dung	(Rs. 2500 day^{-1}) * (330) = ~ Rs. 8.25 Lakhs

	Annual cost of water and electricity	Rs. 10 Lakhs = 1 million INR (€ 11629.00)
	Annual cost of Manpower	Rs. 6 Lakhs = 0.6 million INR (€ 6977.40)
	Annual Maintenance cost	Rs. 3 Lakhs = 0.3 million INR (€ 3488.70)
F.	**Total Recurring cost**	**Rs. 27.5 Lakhs = 2.75 million INR (€ 31979.75)**
	Annual Profit:	**Rs. 42.5 Lakhs = 4.25 million INR (€49423.25)**
	Subsidy	Rs. 87.5 Lakhs = 8.75 million INR (€ 101753.75)
	Beneficiary Expenditure	Rs. 87.5 Lakhs = 8.75 million INR (€ 101753.75)
Revenue: if upgraded biogas is sold as a cooking fuel		
	Upgraded Gas: as cooking fuel Commercial gas cost @ 70 kg	(Rs. 70 kg^{-1}) * (200 kg) = Rs. 14000 day^{-1}
	Slurry:	(Rs. 2 kg^{-1}) * (6000 kg) = Rs. 12000 day^{-1}
	Total Revenue	Rs. 26,000 day^{-1}
G.	**Annual Revenue:**	**(Rs. 26,000 day^{-1}) * (330 day) = Rs. 86 Lakhs = 8.6 million INR (€100009.40)**
	Total Recurring cost	**Rs. 27.5 Lakhs = 2.75 million INR (€ 31979.75)**
	Annual Profit:	**Rs. 58.5 Lakhs = 5.85 million INR (€ 68029.65)**
	Central Financial Assistance	Rs. 87.5 Lakhs = 8.75 million INR (€ 101753.75)
	Beneficiary Expenditure	Rs. 87.5 Lakhs = 8.75 million INR (€ 101753.75)

The following assumptions are made:
Land cost is not considered for the economic analysis,
Exchange rate: 1 Euro = 85.98 INR on 19th September, 2013,
(http://www.xe.com/currencycharts/?from=EUR&to=INR&view=1D)
Bottling system cost includes cost of 50 CNG cylinders.
The above cost calculations provide only a very rough idea for the complete biogas production, upgrading and bottling project and are for the discussion purposes only, while the actual figures vary on case to case basis.

A9 Barriers to the adoption of small-scale biogas upgrading and bottling industry

Despite the feedstock potential, easy adoption feasibility and the various benefits of using bottled biogas as a transport fuel in India, the development of this industry is quite slow. There are many reasons for this debility in the growth of this industry. It is evident that there is a conducive situation for the adaption of biogas upgrading and bottling as a transport fuel in India as stated above. The main barriers in the promotion of bottling can be attributed to many factors as listed below. Stringent rules, regulations and policies, lack of awareness, high initial investment cost and scale of the technology, etc contribute to the slow adoption of this technology sector, but the main factor is the non-existence of standards, policies and tariffs particularly for bottled biogas adoption for vehicular use. Unfortunately there is insufficient promotion of the available technology for biogas utilisation. The main barriers to the promotion of biogas bottling as a transport fuel in India are listed and discussed below.

i. *Policies and regulations*

The high investment required to start an industry requires financial support; this may be in form of capital grants or low interest loans. The major issue for this industry is that at the current level of high initial investment and 50% subsidy, the payback period for biogas bottling plants is too high when the bottled biogas is for vehicle use. The profit margin is also small at the present level of central financial assistance and subsidies (see e.g. Table A9)

As noted in section A6, during 2008-2009 the MNRE undertook an initiative to demonstrate an integrated technology package on medium-size (200-1000 Nm^3 day^{-1}) BGFP for generation, upgrading, bottling and piped distribution of biogas. A 50% subsidy of the total project cost for compressed biogas plant (biogas bottling) was granted by the Ministry of New and Renewable Energy. The available term loan was up to 30% from financing institutions with a 20% entrepreneur's share (MNRE, 2011). Installation of such plants aimed at production of Compressed Biogas (CBG) of the quality of Compressed Natural Gas (CNG) to be used as vehicle fuel in addition to meeting other needs. The upgraded biogas, compressed at 200 bar pressure and filled into CNG cylinders for various applications, should be in accordance with the approval given by Petroleum Explosive and Safety Organisation (PESO) India (Annual Report, PESO, 2011). The Compressed Biogas project is eligible to obtain Carbon Emissions Reduction certificates for methane avoidance and replacing fossil fuels (compression and utilisation of methane gas vehicle fuel).

ii. *Biogas standards*

In most of the developed countries, standards and policies for use of upgraded biogas in vehicles as a transport fuel exist or are in the formulation stage. In India, the Bureau of Indian Standards has formulated standards for upgraded biogas use in stationary engines and in vehicles. But these standards can only be implemented if the other legal authorisations are fulfilled for utilisation of biogas in vehicles or as a transport fuel. Standards for biomethane composition have been developed through the Bureau of Indian Standards (BIS) and published in the year 2013 (IS 16087: 2013; for further details please refer to the Bureau of Indian Standards). This standard prescribes the requirements and the methods of sampling and test for the biogas (biomethane) applications in stationary engines, automotive and thermal applications and supply through piped network. The purpose of these standards and policies is to provide general guidelines for upgraded biogas composition and its filling into CNG cylinders. In the biomethane standards, the composition of upgraded biogas suitable for filling in CNG cylinders (at 200 bar) is as shown in Table A10 (Source BIS Standard 16087: 2013 – Biogas(Biomethane)-Specification).

Table A10. Standards for biogas composition in India (Source BIS Standard 16087: 2013 – Biogas (Biomethane) Specification)

Biogas Component	Percentage
CH_4, %, Min	90
Moisture, mg m^{-3}, Max	16
H_2S, mg m^{-3}, Max	30.3
$CO_2+N_2+O_2$, %,	10
CO_2, %, Max (v/v) (when intended for filling in cylinders)	4.0
O_2, %, Max (v/v)	0.5

iii. *Legal authorisations*

Presently there are no existing norms for the use of high pressure compressed biogas for bottling and use in vehicles. Legal authorisations from Petroleum Explosives Safety Organisation (PESO), Ministry of Environment and Forest, the Ministry of Industry and the Central Pollution Control Board (CPCB) must be fulfilled for biogas bottling and its use in vehicles. As there is no single window clearance, therefore, the procedure is time consuming.

iv. *Feedstock availability*

As mentioned above, large quantities of organic wastes are available in India. For effective utilisation, systems should be developed in such a way so as to harness the complete potential of the available wastes. But due to the lack of awareness, unorganised collection and transportation of wastes, limited financial support and low tariffs these are not utilised to the maximum of the available potential.

v. *Cost of small-scale biogas upgrading and bottling*

The operation and maintenance costs of biogas upgrading and bottling project are quite significant. These consist of labour, feedstock, and fixed cost etc:
- Purchase, collection and transportation of the feedstock;
- Water supply for cleaning and mixing the feedstock;
- Supervision and maintenance of the plant;
- Drying, processing, storage and disposal of the slurry;
- Production of bio fertiliser
- Biogas upgrading and bottling unit
- Gas distribution and utilisation, supply chain management;

The running cost of a biogas upgrading plant include professional management is important. Currently, limited experience exists in reliable cost calculation for biogas upgrading plants in India.

vi. *Lack of technical knowledge and support*

There is a limited technical expertise in small-scale upgrading and bottling technology in India. There are a few technology providers and this is particularly the case with respect to small scale upgrading and high pressure applications, with the consequences already noted in section A5.1. This is a major technology barrier for widespread dissemination of small-scale biogas bottling systems in India.

vii. *Barriers in the collection, segregation and transportation of the waste*

There is widespread availability of organic wastes in India, but one barrier in the promotion of this technology is the lack of proper technologies and strategies for the collection, segregation and transportation of biodegradable waste. If proper systems are developed for waste management and feeding it into digesters then the project can become viable for implementation of biogas upgrading and bottling plants.

viii. *Lack of awareness*

There is a need of spreading awareness about the role of this technology for waste management, energy security and biofertilisers. The main bottlenecks in financing of biogas bottling plants in India are the lack of knowledge about biogas projects in general from the side of the financing decision-makers. There is lack of human resource development programmes for project developers on the project financing, technical knowledge and economics of small-scale gas bottling system in India.

A10 Feedback from small-scale biogas upgrading and bottling project entrepreneurs

An international dissemination workshop was conducted 'Promotion of small Scale Biogas Upgrading and Bottling in India & EU' during August 22-24, 2013. Stakeholders for biogas upgrading and bottling technologies participated in the programme. Among the participants, were biogas entrepreneurs, policy makers, project developers, promoters, researchers, etc. Deliberations took place during the technical sessions (Technical Session – I:Biogas Upgradation & Bottling Technology in India and EU- An Overview, Technical Session – II: Technologies for Small Scale Biogas Upgradation & Bottling, Technical Session – III: Success Stories of Biogas Upgradation & Bottling in India & European Union, Technical Session – III: Biogas production, Applications & Regulations and Open Session).Biogas investors/operators are subjected to bottlenecks for the development of commercial biogas bottling projects in India.

Technological

1. Unavailability of reliable technology providers of small-scale biogas bottling for transportation use India,
2. For small scale biogas upgrading mainly water scrubbing and PSA are best suitable as discussed in the report earlier. But till date there are very few small scale technology providers available in India.
3. High pressure systems are not available for small scale in India, they have to be imported from outside.

Policies

4. Presently, there are no separate norms for bottled biogas (biomethane) in India; hence legal authorisations from the agencies like PESO, CPCB etc have to be satisfied on the composition of upgraded biogas and use of pressurised gas in cylinders for vehicular use or as a replacement of LPG in cooking.
5. There should be policies specially for upgraded biogas (biomethane) for use in vehicles as a transport fuel like CNG.

Financial

6. It is very difficult to get any bank loan in India, specifically for the implementation of biogas projects,
7. Poor financing opportunities for biogas projects and the difficulty to get sufficient technical competence on such funding opportunities;
8. Legal authorisations and documentation for example PESO and Ministry of Road Transport, etc is time consuming and tedious;
9. Central financial assistance is not effective enough to provide a profitable return;

A11 Suggestions for successful development of the small-scale biogas bottling industry

During the workshop for the promotion of biogas bottling systems in India and Europe, the following recommendations were suggested:

a) Appropriate grants should be made available to support the initiation of this industry.
b) Special allowances and incentives for the promotion of biogas bottling projects should be made.
c) Bank loans and central subsidies should be provided for the promotion of biogas upgrading and bottling plants.
d) Financial support, standards and allowances for the use of natural gas infrastructure should be provided for upgraded biogas.
e) Formulation of upgraded biogas policies for use in vehicles as a transport fuel like CNG.
f) The government should provide turn-key job fee linked with free maintenance warranty,
g) Central Financial Support (CFA) should be provided to support biogas bottling.
h) The R&D efforts should be strengthened by having close collaboration between the existing biogas upgrading and bottling plants and R&D centres for initiating additional activities like CO_2 bottling, organic manure recovery, etc.
i) Single window clearance system should be created for the biogas upgrading and bottling plant.
j) There should be a need to develop entrepreneurship model in the rural areas for promoting small scale enrichment and bottling of biogas. This will help to generate employment opportunities to rural people.
k) While most of the states are promoting organic farming, the state govt. can tie up with the existing biogas upgrading and bottling plant unit for creating better market for the bio digested slurry.
l) The govt. incentives should be based on the size of the system, end user category and type of application and the incentives should be released after the minimum guarantee period of application.

m) Biogas upgrading and bottling system including the biogas digesters, reactors, purification units, gas composition, emission and list of equipments should be standardised for better comparison and evaluation. Separate standards for cooking, power generation and vehicular application etc.
n) The interest subsidy can be extended to biogas upgrading and bottling plant commercialisation as available for the solar gadgets.
o) Training, workshops and dissemination activities for users, manufacturers and entrepreneurs.
p) It has also been suggested that norms should be eased for small-scale biogas bottling systems.
q) Additional incentives should be provided for application of biogas bottling systems in rural areas.
r) Development of a system for manure management.
s) Instead of dual fuel engine 100% biogas based power generating system should be included for further support and incentives of the government
t) Make biogas for transport competitive as compared to fossil fuels (introduction of CO_2 tax and lowering of excise duties). Upgraded biogas for transport competes with fossil natural gas as the vehicle technology is similar. Governments should look for ways to improve this competitiveness for the end users, for example by introducing a general CO_2 tax, etc.
u) Public transportation should be promoted to run on biomethane, and there should be provision of incentives for biogas taxis and buses. Also for the promotion of biogas use for transportation, blending of upgraded biogas and CNG should be allowed. Dedicated bus fleets to run on upgraded and bottled biogas with steady and regionally bound fuel consumption are a perfect first step to introduce upgraded biogas and filling stations to should be promoted in India.
v) Introduction of green certificates should be encouraged for the producers of bottled biogas. The project developers should receive a certificate for converting waste to energy efficient fuel called biomethane/biomethane. The objective of green certificates is to stimulate the penetration of bottled biogas into the natural gas LPG market. The introduction of such certificates will encourage people to promote and develop this technology.

A12 Roadmap for small-scale biogas upgrading and bottling in India

India should target to achieve the 15% target of renewable energy before 2020 through policy, financial and technological measures. India plans to add 29,800 MW of renewable power generation before the end of the twelfth five-year plan, according to data from the MNRE. These can be the drivers for the biomethane industry and are the rationale for Government support through policy and financial subsidies.

A roadmap directive for both the biogas upgrading and bottling industry and the CNG industry can be broken into 5-year intervals according to the five-year plans of the Indian economy (Table A11). Use of upgraded biogas in vehicles could be operational with supportive tariffs, subsidies and policies. This will facilitate efficient utilisation of organic feedstock and boost the biogas production, upgrading and bottling industry. Targets till 2020 for biogas bottling as a proportion of natural gas should be set taking into account the available potential resources. Appropriate grants should be made available to support the initiation of the biogas bottling industry. To promote biogas bottling industry passenger cars must be manufactured in accordance to run on upgraded biogas. The price structure for retail vehicle gas should have a short payback period to cover any extra cost of infrastructure. A number of incentives should be associated with purchase of new CNG cars, incentives for home refuelling systems. After 2020, the extent and success of the biogas bottling industry coupled with the improvement of air quality in urban centres should be assessed for consideration of further targets.

Table A11. Roadmap for biogas upgrading and bottling technology use in India

Period	Policy Drivers	Possible Consequences
2012-2017	Small – medium scale biogas upgrading and bottling industry Policies, regulations and appropriate grants to facilitate the development of small – medium scale biogas upgrading and bottling facilities especially for dairies, dairy clusters, vegetable markets and housing clusters/societies. Transport policies and related technologies for biogas vehicles need to be developed and adopted. An appropriate tariff and financial support target for 2017 for biogas bottling and use in vehicles should be set. Central financial support (CFA) should be increased to support biogas bottling. Increased incentives on biogas bottling plants to rural people to promote this industry especially in rural areas. Passenger cars must be manufactured in accordance to run on upgraded biogas. Price structure for retail vehicle gas should at have a short payback period to cover any extra cost of infrastructure A number of incentives should be associated with purchase of new cars to be run on upgraded biogas, incentives for home refuelling and dispensing systems.	Decentralised small – medium scale biogas upgrading and bottling plants in India Widespread decentralised development of maximum number of digesters at significant scale in conjunction with small – medium scale biogas bottling plants especially in rural areas for the development of rural people. Increase in the number of entrepreneurs taking up biogas bottling technology as a venture. Availability of biomethane for vehicle/ cooking use Less dependence of rural people on fossil fuels for transport/ cooking. Increased number of passenger/private vehicles, tractors/trolleys and light goods vehicles and running on upgraded biogas. Increased penetration of natural gas vehicles and associated sophisticated and dedicated stations for dispensing upgraded biogas in vehicles in rural, semi- urban and urban areas.
2017- 2022	Small – medium scale biogas upgrading and bottling industry expansion in India with deep penetration into rural areas. Standards and allowance for the use of natural gas infrastructure for upgraded biogas injection into the grid should be provided.	Small – medium scale biogas upgrading and bottling industry penetration into rural areas with wide spread decentralised plants in India. Growth in the number of biogas digesters and upgrading facilities treating organic waste hence harnessing maximum of the biogas potential of India.

Period	Policy Drivers	Possible Consequences
	Penetration of dedicated upgraded biogas pipelines in rural as well as remote areas. Introduction of green certificates for the producers of bottled biogas. *Gas for vehicle use* Public transportation should be promoted to run on biogas, and there should be provision of incentives for biogas taxis and buses. Dedicated bus fleets to run on upgraded and bottled biogas Decentralised and dedicated biomethane dispensing stations in rural as well as rural areas.	Increased waste management practices for efficient biogas production especially in urban areas for food waste/ MSW and in rural areas for dairies/ vegetable markets etc by deploying community biogas plants. Growth in the number of decentralised biogas upgrading and bottling units. Ease in the availability of biomethane for vehicle/ cooking use Increase in the number of public/private transport vehicles, taxis and commercial vehicles running on upgraded biogas. Availability of decentralised and dedicated biomethane dispensing stations in rural as well as rural areas. Increased penetration of natural gas vehicles and associated sophisticated and dedicated stations for dispensing upgraded biogas in vehicles in rural and urban areas of India.

A13 Conclusions

Bottled biogas is a renewable energy source that can be produced from biodegradable/organic wastes, and hence can help both in waste management and in building a clean and sustainable environment. Centralised biogas upgrading and bottling is an economically viable option for biogas produced at medium to large scales. There is a huge potential for the installation of medium – large scale biogas plants in the country. ***The potential can be translated to an aggregated estimated capacity of approximately 48,383 million m^3 of biogas generation annually***. Based on the Indian Petroleum and Natural Gas Statistics - 2011-2012 data and the references quoted in the text above the contribution of upgraded biogas in the transportation and cooking sector as a percentage of total petroleum fuels consumption for the year 2011-2012 is approximately 86.8 % and 83.4% respectively. In the present report the above mentioned evaluation was made to evaluate the amount of upgraded biogas that can be obtained in urban and rural areas which can substitute for fossil fuels in vehicles as well as for cooking. In this report, various real life situations are analysed where the available organic wastes can be harnessed for biogas production and hence by upgrading and bottling the gas it can be utilised in local vehicles and cooking. If the above mentioned examples are disseminated in urban and rural areas in large numbers, then bottled biogas can help to substitute fossil fuel. Small-scale biogas upgrading and bottling technology is thus a step towards helping in finding a replacement of transport and cooking fuel. However, central financial assistance and other incentives are required to reach the biogas utilisation levels close to the full technical biogas potential of India. There is an urgent need for developing commercially viable systems for different situations. Hence, it is concluded that the present systems available for bottling which are being demonstrated in some developing countries like India are low cost and economically viable. In India IIT Delhi has developed a biogas upgrading and bottling unit using high pressure water scrubbing technology, and based on this development and pilot-scale set ups in the field, the government has undertaken initiatives to provide financial support to any such commercial projects in India. In 2013, Bureau of Indian Standards has brought out national standards for biogas (biomethane) which specifies biogas (biomethane) applications in stationary engines, automotive and thermal applications and supply through piped network. The purpose of these standards and policies is to provide general guidelines for upgraded biogas composition and its filling into CNG cylinders. Therefore, it can be concluded that:

1. The technologies for biogas upgrading should be standardised for minimum methane loss and less energy requirement.
2. Water scrubbing and PSA technologies are the suitable technologies for small scale biogas upgrading and bottling in Indian context.
3. Indigenous high pressure compressors with low gas flow rates (5-50 m^3 $hour^{-1}$) should be developed which could be affordable by the small entrepreneurs.
4. CO_2 recovery systems should also be developed to make the whole system more economically viable.
5. Training, workshops and dissemination activities for users, manufacturers and entrepreneurs.
6. Policies and financial support from the government are necessary for promotion of biogas upgrading in India and other developing countries. Appropriate grants should be made available to support the initiation of this industry. Special allowances and incentives for the promotion of biogas bottling projects should be made.
7. Bank loans and central subsidies should be provided for the promotion of biogas upgrading and bottling plants.
8. Biogas upgrading and bottling plants less than 25 m^3 $hour^{-1}$ are generally not economically viable due to the large capital investment required for plant and machinery.
9. Involvement of more industries/companies is required in this sector to bring down the capital investment in the technology.

Mobile biogas upgrading unit may be useful in rural as well as urban areas for collection of biogas from existing plant and its centralised upgrading and bottling.

References for Part A

Akshay Urja. 2011. Ministry of New and Renewable Energy, 4(6)
Ambulkar, A.R. and Shekdar, A.V. 2006. Prospects of Biomethanation Technology in the Indian Context: A Pragmatic Approach. Resources, Conservation and Recycling, Vol. 40, pp 111–128.
Annual Report. 2010-2011. Petroleum and Safety Organisation (PESO). http://peso.gov.in/PDF/AR2010_11.pdf
Bamboriya, M.L. 2012), Biogas Bottling in India, Akshay Urja, Vol.5, Issue 5.
Bamboriya, M.L. N.D), Biogas Bottling in India – a case study. Available from: http://mnre.gov.in/filemanager/UserFiles/casestudy_biogas_bottling_in_India_mlbambori a.pdf
Banks, C.J. 2009. Optimising anaerobic digestion. Conference on Evaluating the potential for anaerobic digestion to provide energy and soil amendment. University of Reading 25

March 2009. http://www.forestry.gov.uk/pdf/rrps_AD250309_optimising_anaerobic_digestion.pdf/$file/rrps_AD250309_optimising_anaerobic_digestion.pdf

Becker.D., and Nagporewalla. Y. 2010. The Indian Automotive Industry, Evolving Dynamics, KPMG in India.

Corbeau, A. S., 2010), Natural Gas in India, Working Paper, International Energy Agency, France.

Dasgupta, S., and Das, S.K. 2002.Paper pulp waste—A new source of raw material for the synthesis of a porous ceramic composite Bulletin of Materials Science., Vol. 25, No. 5, pp. 381–385.

Effluent Treatment System, Sulabh International Social Service Organization, SISSO, Accessed May, 2013.

Energy Statistics, 2013. Twentieth Issue, Central Statistics Office, National Statistical Organisation,Ministry Of Statistics And Programme Implementation,Government Of India. http://mospi.nic.in/mospi_new/upload/Energy_Statistics_2013.pdf

Fecal Sludge, EAI, Energy Alternatives India. http://www.eai.in/ref/ae/wte/typ/clas/fecal_sludge.html

Ghosh. A., Ray. S and Dewan. S.2011. Indian Passenger Vehicle Industry: Growth Momentum to Continue, ICRA Rating Feature Indian Passenger Vehicle Industry: An ICRA Perspective. www.icra.in

Global Methane Initiative. 2011. Resource Assessment for Livestock and Agro-Industrial Wastes – India. https://www.globalmethane.org/documents/ag_india_res_assessment.pdf

Gupta, H. S. 2012. Crop Residues Management with Conservation Agriculture: Potential, Constraints and Policy Needs. Indian Agricultural Research Institute, New Delhi. http://www.iari.res.in/files/Important_Publications-2012-13.pdf

Harsdoraff, M. 2012. The Economics of Cow Dung Creating Green Jobs in the Dairy Industry in India, Case Study - A Green Value Chain Analysis of the Cow Dung and Dairy Industry in Jabalpur. Green Jobs in Asia Regional Conference, International Labor Organization.

India on line, 2913. http://www.indiaonlinepages.com/population/india-current-population.html

Indian Petroleum and Natural Gas Statistics, 2011-2012, Government of India, Ministry of Petroleum and Natural Gas.

Jain. A and Sen. A. 2011. Natural Gas in India: An Analysis of Policy, Working Paper, Oxford Institute for Energy Studies.

Kapdi, S., Vijay, V.K., Rajesh, S., Prasad, R. 2005). Biogas Scrubbing, Compression and Storage: Perspective and Prospectus in Indian context. Renewable Energy. 30(8), 1195-1202.

Khoiyangbam,R.S., Kumar, S., Jain, M.C.2004. Methane Losses from Gasholder Type Biogas Plants in Relation to Global Warming. Journal of Scientific and Industrila Research, Vol. 63, pp 344-347.

Kulkarni H. D. 2013. Pulp and Paper Industry Raw Material Scenario - ITC Plantation A Case Study, Journal of Indian Pulp and Paper Technical Association, Volume 25, No. 1, Jan.- March – 2013. http://www.ipptaonline.org/Jan-March,%202013/2013_Issue_I_IPPTA_Articel_07.pdf

Lal, B. 2011. Biogas/Energy production from waste (Municipal, Agricultural, Food). Joint presentation BBSRC and Department of Biotechnology Ministry of New and Renewable

Energies, New Delhi, 1011 October 2011. http://www.rcuk.ac.uk/documents/india/Biogas-India.pdf)
Leonard, T., Massie, C. 2006. Mobile biogas Processing System and Method. US Patent Application 2006/0213370. Minneapolis. MN (US).
Mehta, R.2007. Poultry Industry In India, International Conference on Poultry in the 21st Century, Bangkok, Thailand, Nov 5-7, 2007. http://www.fao.org/ag/againfo/home/events/bangkok2007/docs/presentation/3b.India_Case-Study_Mehta.pdf
MNRE 2009.Ministry of New and Renewable Energy Resources, Govt. of India, New Delhi. www.mnre.gov.in/biomassrsources.
MNRE. 2010a. Ministry of New and Renewable Energy http://www.mnre.gov.in/mnre-2010/schemes/decentralised-systems/schems-2/. Accessed December 2011,
MNRE 2010b. Ministry of New and Renewable Energy, http://mnre.gov.in/mnre-2010/related-links/r-d/rd-projects/. Accessed November 2011
MNRE. 2011. Annual Report, Renewable Energy in India and Business Opportunities. Chapter 3, MNRE (Ministry of New and Renewable Energy). Government of India, New Delhi.
MPNG. 2012. Basic Statistics on Indian Petroleum and Natural Gas, 2011-12. Ministry of Petroleum and Natural Gas, (Economic Division), Government of India, New Delhi. petroleum.nic.in/petstat.pdf
NDDB. 2010. National Statistics, Livestock Population in India by Species. National Dairy Development Board. http://www.nddb.org/statistics/population_india_species.html
NDDB. 2012. National Statistics, Livestock Population in India by Species. National Dairy Development Board.http://www.nddb.org/English/Statistics/Pages/Population-India-Species.aspx
NMP. 2007. National Master Plan for Development of Waste-to-Energy in India, Structured Urban and Industrial Database, 2007.
Patak. B. 2006. Operation, Impact and Financing of Sulabh, Human Development Report, Occasional Paper, Human Development Report Office.
Parivesh, N.D. Pulp and Paper Industry. A News Letter from ENVIS Centre – Central Pollution Control Board. http://cpcbenvis.nic.in/newsletter/agro-dec-1994/dec944.htm
Power, G. 2011. Potential of small to medium scale transport biomethane development in Ireland, Proceedings of the Irish Transport Research Network Conference. 31st August – 1st September, University College Cork.
Rajeswari, K.V. 2009. Methane to Markets: Regional workshop on opportunities in livestock and food processing industry sector, The Energy Research Institute (TERI), India.
Rao, V.P., Baral, S.S., Dey,R., Mutnuri. S. 2010. Biogas Generation Potential by Anaerobic Digestion for Sustainable Energy Development in India. Renewable and Sustainable Energy Reviews, Vol.14, pp 2086–2094.
Renewable Energy: Biogas, India Landscape 2012, Athena Infonomics Research http://www.athenainfonomics.in/assets/Renewable%20Energy%20-%20Biogas.pdf
Reports of Indian Sugar Mills Association, 2004.
Roychowdhury, A.2010. CNG programme in India: The Future Challenges, Fact Sheet Series, Centre for Science and Environment. http://www.cseindia.org/userfiles/cngfuture_pdf.pdf
Sewage Sludge, Energy Alternative Initiatives. Accessed April, 2013 http://www.eai.in/ref/ae/wte/typ/clas/sewage.html
Staffell, I.2011. The Energy and Fuel Data Sheet, University of Birmingham, UK

Subramanian, K.A., Mathad, Vinay C., Vijay, V.K., Subbarao, P.M.V.2013. Comparative Evaluation Of Emission And Fuel Economy Of An Automotive Spark Ignition Vehicle Fuelled With Methane Enriched Biogas And CNG Using Chassis Dynamometer, Applied Energy, Vol. 105, May 2013, 17-29

Velmurugan. B. and Ramanujam. R. A. 2011. Anaerobic Digestion of Vegetable Wastes for Biogas Production in a Fed-Batch Reactor. International Journal of Emerging Sciences, Vol. 1, Issue 3,pp 478-486.

Vijay, V.K., Chandra, R., Subbarao, P.M.V., and Kapdi, S.S. 2006) Biogas Purification and Bottling into CNG Cylinders: Producing Biomethane from Biomass for Rural Automotive Applications. The 2nd Joint International Conference on 'Sustainable Energy and Environment, 21-23 November, Bangkok, Thailand. http://balajibiopower.com/

Vyas. H, 2012, Wedding Food Worth Rs 339 Crore Goes Waste, Times Of India, Bangalore, October,12, 2012. http://articles.timesofindia.indiatimes.com/2012-10-12/bangalore/34411336_1_food-wastage-quality-food-marriage-halls

Additional web-based materials

www.indiastat.com, Accessed June 2013.

http://www.indiastat.com/agriculture/2/poultry/220/stats.aspx

http://www.build-a-biogas-plant.com/Community-Biogas.html

http://trade.indiamart.com/details.mpoffer=1642656088

http://maxengg.tradeindia.com/cng-storage-cylinders-70720.html

http://www.chesterfieldbiogas.co.uk/news/Temporary-CNG-refuelling-station-for-councils-low-carbon-vehicle-trial/7

http://www.chesterfieldbiogas.co.uk/news/Chesterfield-BioGas-trailer-fuels-Coca-Cola-Enterprises-supply-vehicles/6

http://travelerfolio.com/bukhara-itc-maurya-new-delhi/,

http://www.flickriver.com/photos/robinthom/sets/72157621003902466/)

www.digital-photography-school.com/forum/photojournalism-sys/113809-roadside-food-joints-indian-roads.html

http://solarcooking.wikia.com/wiki/India

www.flickr.com/photos/lokraj/2283335329/

Part B: Europe

B1 Introduction

This section of the report presents the role of biomethane in local transport in Europe, especially with respect to small-scale producers. First, a general overview of the current situation of biomethane production in Europe is presented. Then, drivers and the factors hindering the use of biomethane in local transport are considered. Finally, various case studies on successful implementation of biomethane as fuel in local transport are presented.

B1.1 Energy in the transport sector in Europe

Transportation is an important sector and plays a vital role in Europe as far as the energy mix and reducing greenhouse gas (GHG) emissions is concerned. Transportation accounts for 30 % of total energy utilisation and is the highest energy-consuming sector in the European Union (EU) (Europe's Energy Portal, 2011). In order to reduce energy consumption and GHG emissions, the EU has introduced several directives and other initiatives including the Renewable Energy Source Directive (RES Directive) (2009/28/EC), the Clean Vehicles Directive (2009/33/EC) and Climate and Energy Package (SEC(2010)650). According to the RES Directive, it is mandatory for each Member State to achieve a 10 % share of renewable energy in the transport sector on its way to achieving 20 % renewable energy in primary energy consumption by the year 2020 (European Union Committee, 2008). Moreover, transport sector is also one of the most difficult sectors in which to reduce GHG emissions and switch to alternative fuels. Most of the vehicles produced today are designed to run on conventional fossil fuel. A sustainable solution for this burgeoning problem would be to transform personal vehicles or large fleets, such as public transportation, to run on renewable fuels.

As far as transportation fuels are concerned, biogas is considered as one of the cleanest and carbon dioxide (CO_2)-neutral fuels that could be used in an internal combustion engine. In order to use it as a vehicle fuel, biogas needs to be cleaned and upgraded to a fuel quality in terms of the methane (CH_4) content of 96-98 % (See VALORGAS Project Deliverable D5.1). The upgraded biogas, called biomethane, is a gaseous fuel of biological origin and is very similar to natural gas in composition and characteristics. Therefore, biomethane can be used in natural gas engines without further engine modifications and can also be injected into the natural gas grid. Unlike conventional fuels, combustion of biomethane will only produce CO_2 which is a carbon neutral since the biogas is produced from organic waste. The climate impact is thus minimised by avoiding a net input of CO_2 emissions to the atmosphere. The environmental impact is also reduced by lower emissions of nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon monoxides (CO), hydrocarbons (HC) and particulate matter. Furthermore, biomethane can be transported and stored using more or less the same methods used for natural gas. This availability of distribution and end user infrastructure enhances the prospects for introduction of biomethane as a vehicle fuel for local transport.

B2 Overview of biogas upgrading and utilisation in local transport in Europe

Biogas can be used for generating power and/or heat in a combined heat and power (CHP) plant, in boilers for heat production alone, and can be also be upgraded to biomethane for vehicle use or grid injection. The biomethane is easily storable and is a versatile energy carrier for use in the energy and transport sectors and can be readily integrated into existing renewable systems (Urban, 2013).

Upgrading of biogas to biomethane has increased during the last decade, especially in Europe (Beil and Beyrich, 2013). The produced biomethane offers several advantages over direct utilisation of raw biogas. For instance, heat produced in a CHP plant is not consumed uniformly throughout the year and thus has to be wasted during summer periods. On the other hand, biogas upgrading and use of biomethane for grid injection or vehicle would enable transportation of the high calorific gas to places for complete utilisation e.g. power and heat production and/or local transport use (Beil and Beyrich, 2013). Upgrading thus offers different possibilities to improve the overall efficiency of the biogas utilisation. Moreover, decentralised production and utilisation of the produced biogas is possible especially to meet local needs in remote areas.

Biogas upgrading to biomethane has a history dating back almost a century. In the mid-1930s to mid-1960s, biogas upgrading was initiated in some European countries including Germany, Switzerland and elsewhere (Kugel et al., 1991; Beil and Beyrich, 2013). At that time, upgrading plants were mainly located in wastewater treatment plants. The produced sewage gas was upgraded to biomethane for use in the wastewater treatment plant's own passenger vehicles driven by Otto engines (Kugel et al., 1991) and/or waste collection trucks (Beil and Beyrich, 2013). However, use of biomethane for vehicle fuel was later discontinued in the mid-1960s due to the cheap fossil fuel oil imports, lack of technological development and discontinuation of tax exemption for biogas cars (Kugel et al., 1991).

In the early 1980s, a renewed interest in biogas upgrading and use as vehicle fuel was initiated in Europe (Kugel et al., 1991). Several biogas upgrading plants were built and the produced biomethane had either vehicle fuel or natural gas quality. From 1982 to 1996, the wastewater treatment plant in Moenchengladbach, Germany was upgrading sewage gas to natural gas quality for injection into local gas grid. During this period, approximately 20 million Nm^3 of biomethane of low gas (L-gas) quality was produced in an upgrading plant of 400 m^3 $hour^{-1}$ capacity using water scrubbing technology (Kugel, 1983; Kugel et al., 1991; Schulz, 2004). Similarly, 5 million Nm^3 of biomethane of high gas (H-gas) quality) was produced and injected into the local natural gas grid by a wastewater treatment plant in Stuttgart, Germany during the years 1986-1993 (Schulz, 2004). Chemical scrubber technology with mono-ethanolamine (MEA) was used and the plant had a capacity of 400 m^3 $hour^{-1}$ of raw sewage gas. Between 1987 and 1991, several landfill gas upgrading units were established in the Netherlands (Beil and Beyrich, 2013). All these upgrading plants injected the biomethane into natural gas grids. This is considered as the first reported case of the utilisation of landfill biogas in Europe.

Concurrently, biogas upgrading has been also developing in Sweden and Switzerland (IEA Bioenergy, 2013). In Sweden, biogas has been produced at municipal wastewater treatment plants since the 1960s (SGA, 2011). The primary incentive was to reduce sludge volumes. However, the oil crises of the 1970s changed attitudes, leading to research and development into biogas techniques and the construction of new plants in order to reduce environmental problems and dependency on oil. Industry was the first to act; sugar refineries and pulp mills started to use anaerobic digestion for wastewater purification in the 1970s and 1980s. At this time, several small farm-scale biogas plants were also constructed for treatment of livestock manure. During the 1980s and 1990s, several landfill plants in Sweden also started to collect and utilise biogas. Several new biogas plants have been constructed since the mid-1990s to treat food industry and slaughterhouse wastes, and kitchen wastes from households and restaurants. Similarly, biogas as a transport fuel was also developed in Switzerland. In Zurich alone, 5 plants to treat organic waste arising from homes and restaurants to produce fuel for 1200 cars and trucks (IEA Bioenergy, 2013). Since then Sweden and Switzerland have been the leading European countries in biogas production and upgrading of biogas to biomethane for vehicle use.

Several ambitious projects on upgrading biogas for natural gas grid injection were started in Germany (Beil and Beyrich, 2013; IEA Bioenergy, 2013). Recently, the German government defined targets for the production and sustainable utilisation of biomethane. At the end of 2012, 117 biogas upgrading units were in operation in Germany (IEA Bioenergy, 2013). Figure B1 presents an overview of the development of biogas upgrading in Europe. As on August 2013, there are 234 biogas upgrading plants in operation in Europe (IEA Bioenergy, 2013). The total upgrading capacity is 205 716 Nm^3 $hour^{-1}$ raw biogas (IEA Bioenergy, 2013).

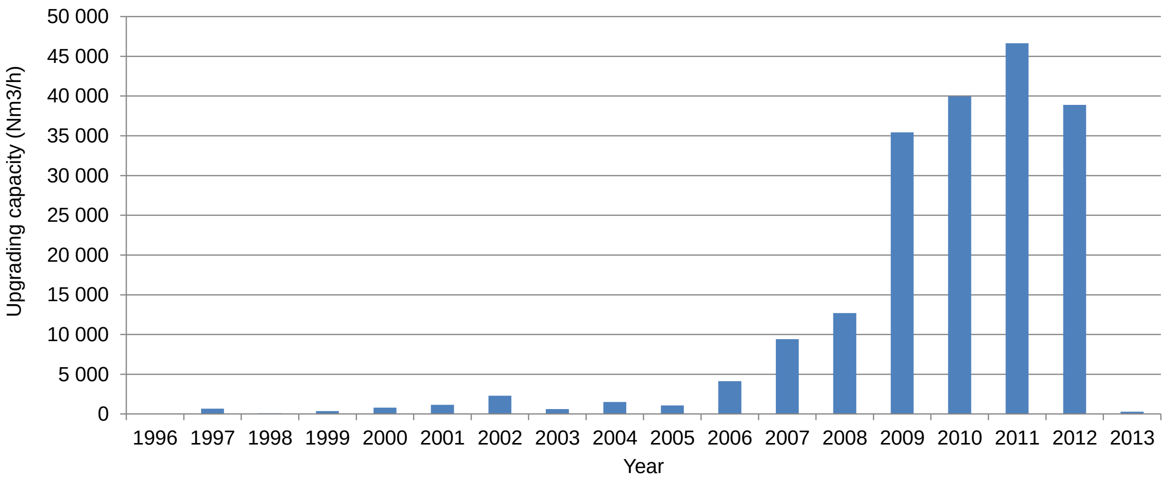


Figure B1. Biogas upgrading capacity in Europe during the period 1996-2013: related to raw biogas (Source: IEA Bioenergy, 2013)

Figure B2 shows the number of natural gas vehicles, filling stations in Europe. Currently, biomethane is widely used as a transport fuel in many European countries (NGVA Europe, 2013). According to Natural Gas Vehicle Association in Europe (NGVA Europe), the probable consumption of biomethane as vehicle fuel in EU-25 is 28.9 TWh $year^{-1}$ in 2013 (NGVA Europe Statistics, 2013). If we include the 10 other European countries and 4 European Free Trade Association (EFTA) countries, then the total biomethane consumption in Europe is 190 TWh $year^{-1}$ in 2013 (NGVA Europe Statistics, 2013). Sweden is a world leader in upgrading and use of biomethane for transport, and has more than 40030 biogas vehicles, including private cars, buses, and even a biogas train and a biogas powered touring car team (Svensson, 2013). However, Italy is the leading European country with highest number of biomethane powered vehicles (782600). The Netherlands is also expanding its use of NGVs with more than 50 compressed natural gas (CNG) filling stations. Countries like Spain, Austria and the UK are also using biomethane in the local transport sector. European cities that developed viable biogas fleets almost ten years ago include Stockholm, Linkoping, Lille, Reykjavik and Rome.

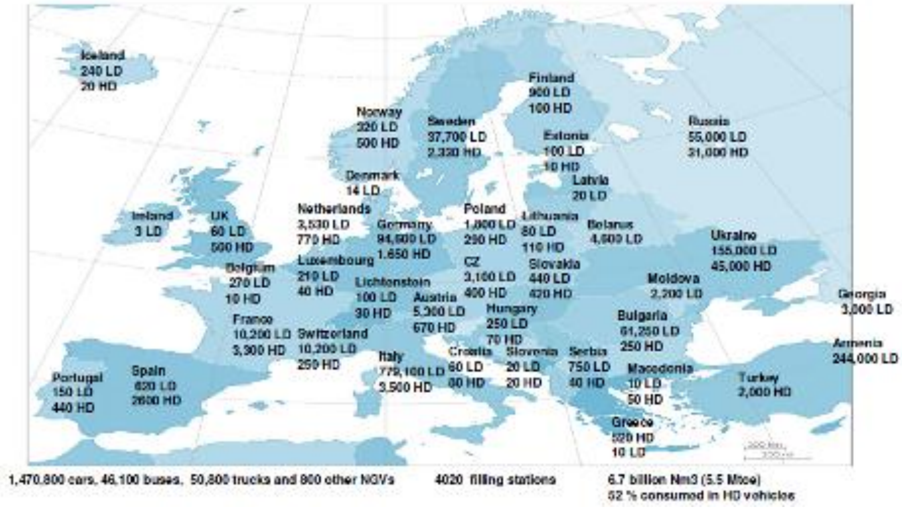


Figure B2. The number of natural gas vehicles in Europe (Source: NGVA Europe, 2013).

B3 Biomethane as vehicle fuel in the EU's local transport

The transport sector is almost completely dependent on fossil fuels, 96% globally (IEA, 2007). Although there are many approaches to counter pollution and GHGs emissions from the energy sector, it is not so for fossil fuel dependent transport sector. In order to reduce GHG emissions and the associated pollution, the transport sector needs to be more efficient, reduce its dependence on fossil fuels and increase the share of renewable fuels. Biomethane is a gaseous high-quality CO_2-neutral renewable that could be easily integrated into the existing natural gas vehicles and distribution network. It is less dependent than natural gas on specific technical development and scale of production and has a greater feedstock flexibility and potential than natural gas (Ahman, 2010). In addition, biomethane is highly miscible and interchangeable with its fossil counterpart natural gas and with no blending limitations and end-user complications, if vehicle fuel quality is achieved. The GHG emissions and carbon footprint of biomethane production and use is much lower than for all other biofuels, excluding renewable electricity (Ahman, 2010). Therefore, small-scale production and use of biomethane in transport sector should be a focus in order to solve the economic and environmental problems associated with the fossil fuel dependent transport sector.

B3.1 Significance and drivers for biomethane use in local transportation in Europe

In this section, the primary energy mix in Europe is presented in order to identify the composition of different energy sources, and the trends of using biomethane as transport fuel is presented. Then, the driving forces of biomethane as a transport fuel are also presented. Most of the literature is based on the Baltic Biogas bus project (see e.g. Baltic Biogas Bus, 2012 http://www.balticbiogasbus.eu/web, last accessed April 2013) and Green Gas Grids project (see e.g. Green Gas Grids, 2013 http://www.greengasgrids.eu/info/downloads.html, last accessed August 2013).

B3.1.1 Primary energy mix and significance of biomethane in Europe

Figure B3 presents the trends in primary energy sources in the European energy mix. Fossil fuels continue to dominate total energy consumption in EU-27. The share of fossil fuels is decreasing, however, from 83% in 1990 to 77% in 2009 (European Environmental Agency, 2011a). On the other hand, the share of renewable energies in Europe has been on an increasing trend: it doubled over the same period, from 4.3% in 1990 to 9% in 2009. During the same period, the share of nuclear energy increased slightly from 12.3% in 1990 to 13.6% in 2009 (European Environmental Agency, 2011a).

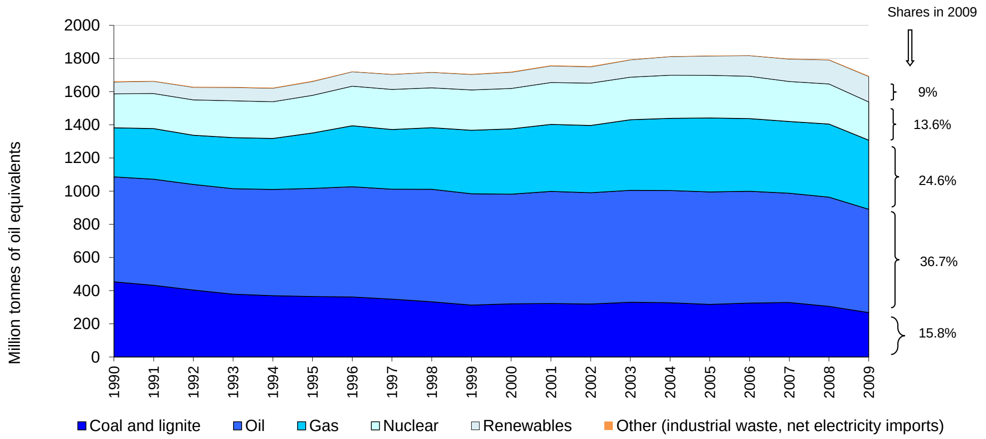


Figure B3. Primary energy consumption by fuel in the EU-27 during 1990-2008. (Source: European Environment Agency, 2011a).

Figure B4 presents the share of renewable energy in EU energy mix in 2008. Of the total renewable energy share of 8.4% in 2008, biomass accounted for 69.7% (European Environmental Agency, 2011b). However, the share of biogas in the European energy mix is a meagre 0.42%. Therefore, its contribution needs to be increased in order for it to be recognised as a sector with a prospective future.

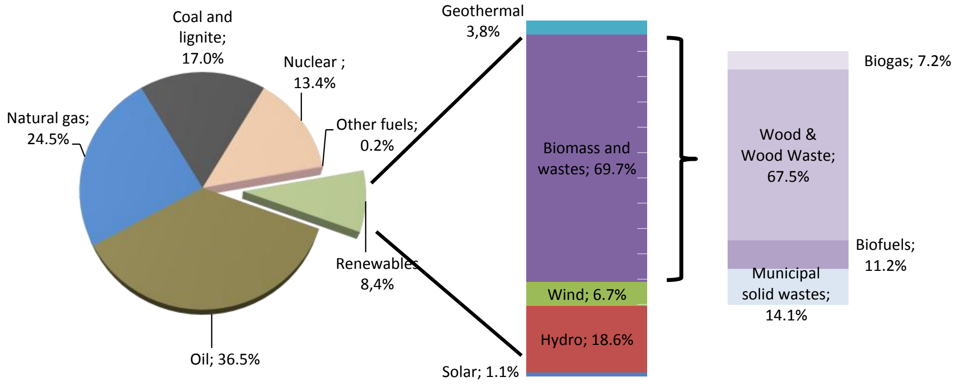


Figure B4. Total primary energy consumption by energy source in 2008 in EU-27 (Source: European Environment Agency, 2011b).

Natural gas holds a substantial share in the European energy mix (Figure B3) and its use has been also growing over the last few decades compared to any other fuel. In the recent years, utilisation of fossil fuel oil has remained more or less the same – if not declined- owing to the increasing market prices, stringent emission standards and environmental concerns. Therefore, it is the natural gas that has been able to bridge the gap between the increasing energy demands and moving towards a sustainable renewable source over the last decade. Biomethane is similar to natural gas in composition as well as characteristics, and hence can readily be used in natural gas vehicles and infrastructure. That means biomethane would be delivered (either through gas grids or in trucks) and refilled using the same methods which are currently being used for natural gas and would be combusted in the same way inside the vehicle engines, same as the ones for natural gas.

B3.1.2. Drivers for biomethane as renewable energy fuel and fuel for local transport

In this section the main drivers for biomethane use as a renewable vehicle fuel and fuel for local transport are discussed. Some of the drivers identified for the successful development, implementation and utilisation of biomethane as transport fuel in Europe are climate, environmental and economic benefits of replacing fossil fuels with biogas; socio-economic, operational and environmental costs; and stakeholder interests in use of biomethane.

B3.1.2.1 Energy consumption

Road transport represents the largest energy consumer, accounting for 72% of total demand in 2011 (Figure B5). The EEA 32 countries consumed approximately 441 mega tonnes oil equivalent (Mtoe) providing energy for transport in 2010 (Figure B5). Energy consumption from transport has grown by over 30% since 1990 (Figure B6). Between 1990 and 2007, annual transport energy consumption in the EU-27 showed continual growth. Due to the economic recession between 2007 and 2009, however, total energy demand in the transport sector declined by 4.2% (European Environmental Agency, 2012a). The EU-15 Member states consume approx. 82.7% while the new EU-12 Member States consume 10.7% and the remaining 6.6% by other EEA countries (European Environmental Agency, 2012a).

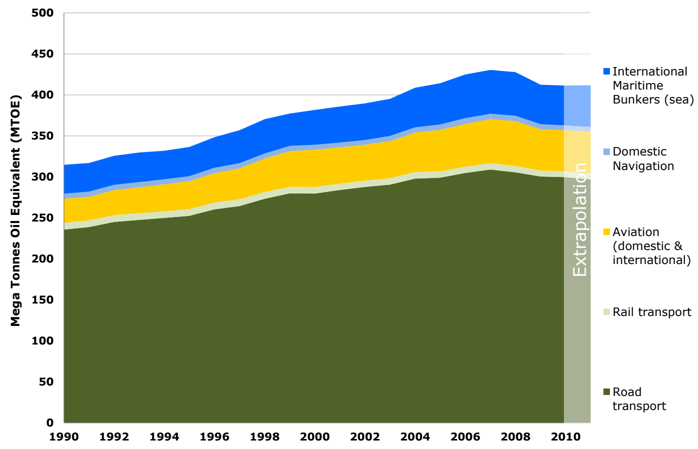


Figure B5. Total energy consumption in transport in Mtoe from 1990 onwards. Note: Transport modes included are bunkers (sea), air (domestic and international), inland navigation, rail and road (split by passenger and freight). The most recent year is an extrapolation based on monthly deliveries (Source: European Environmental Agency, 2012a)

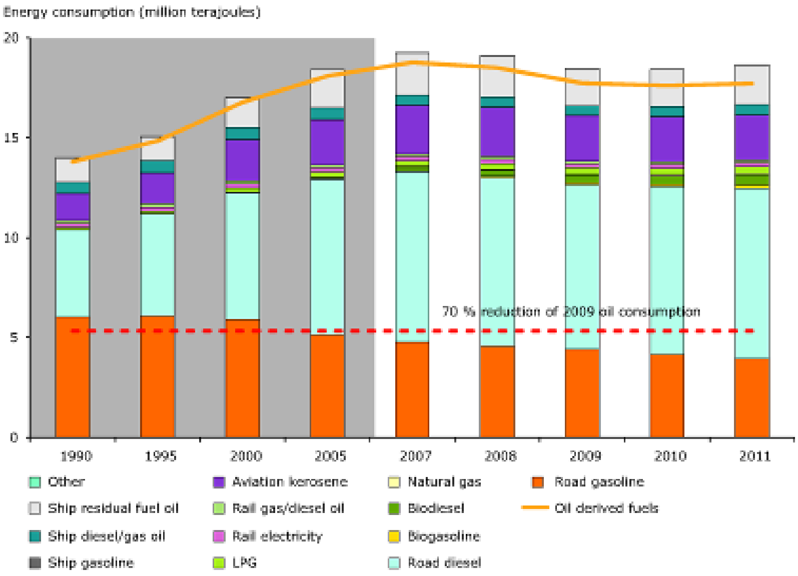


Figure B6. Transport energy consumption (EEA-32 excluding Iceland and Liechtenstein) (Source: European Environmental Agency, 2012a)

Energy efficiency (Figure B7) has improved during this period – for example, the energy efficiency of the average new passenger car in Europe improved by over 20 % in the past decade (European Environmental Agency, 2012b). The effects of these efficiency improvements have been offset, however, by an overall increase in transport demand. Long term projections foresee that economic recovery will sustain renewed growth in transport energy consumption to at least 2020 (albeit at a lesser rate than in the previous decade, as policies designed to reduce transport energy use begin to take effect). Though this period, transport demand is expected to grow faster than energy consumption: in other words the energy intensity of transport will decrease.

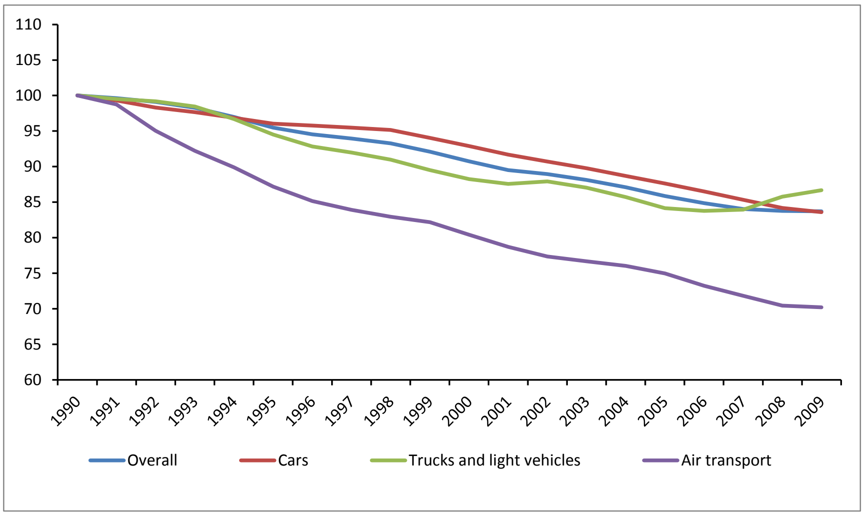


Figure B7. Energy efficiency for different transport modes in Europe (Source: European Environmental Agency, 2012b); ODYSSEE database. Energy efficiency in transport sector. The Odyssee database is available at http://www.odyssee-indicators.org/.

B3.1.2.2 Environmental factors

Figure B8 shows sector-wise GHG emissions in Europe. In addition to accounting for 30% of European energy consumption, the transport sector is responsible for 23% of CO_2 emissions (European Commission, 2011). As evident in Figure B8, CO_2 emissions from EU transport sector have increased continuously over the last two decades. In contrast, all other sectors have either more or less stabilised or significantly decreased (European Commission, 2011). Although the total CO_2 emissions of the EU-27 have stabilised over the period, it is imperative to reduce levels in order to mitigate climate change.

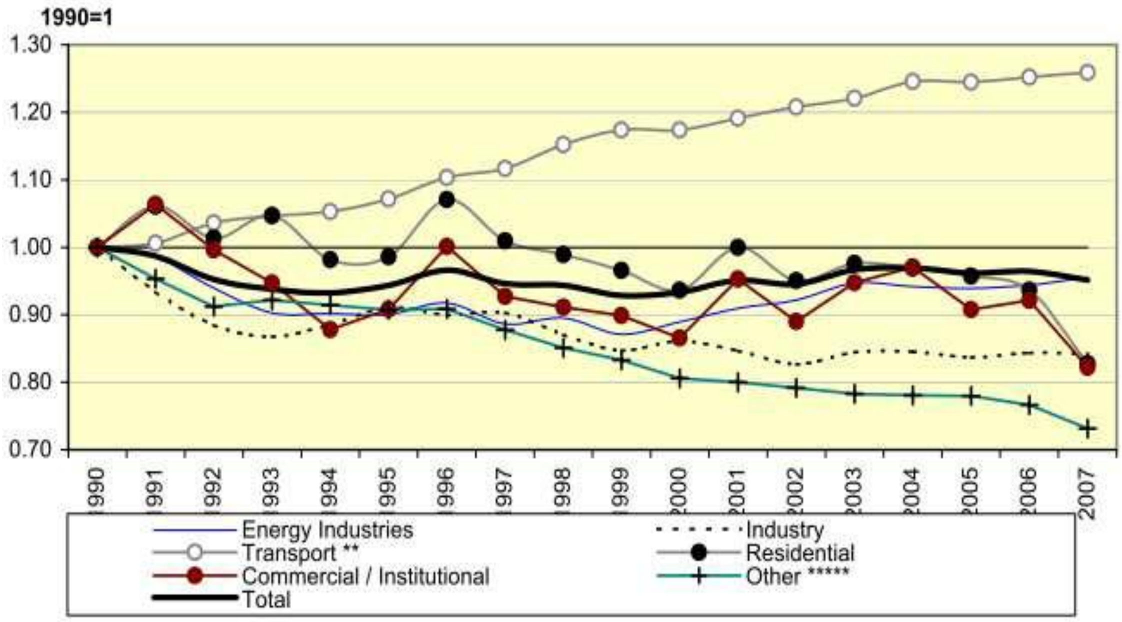


Figure B8. Sector wise CO_2 emissions in EU-27 (Source: European Commission, 2011)

In order to limit the average global temperature rise to 2°C by 2100, Intergovernmental Panel on Climate Change (IPCC) states that atmospheric CO_2 concentrations must be kept below 400 ppm CO_2 equivalent and the increase in atmospheric concentrations must be stopped by 2015 at the latest (Science Daily, 2011). Therefore, an ideal initiative to curb the GHG emissions would be to replace the use of fossil fuel in the transportation sector. Wide use of biomethane and/or other renewable fuels in transport sector would not only replace limited fossil fuel but also minimises the net carbon emission.

Specific CO_2 emissions of road transport are presented in Figures B9 and B10. The data show that specific CO_2 emissions have decreased since 1995, mainly due to an improvement in the fuel efficiency of passenger car transport (Figure B7). Recent EU Regulations setting emission performance standards for new passenger cars are expected to further reduce CO_2 emissions from light-duty (LD) vehicles in view of the 130 and 95 g km^{-1} emission targets set for 2015 and 2020 respectively (Figure B11). Specific energy efficiency of light- and heavy-duty (HD) trucks has improved, but road transport still consumes significantly more energy per tonne-km than rail or ship freight transport. CO_2 emissions from light commercial vehicles are also expected to decrease in view of the 175 and 147 g km^{-1} emission targets set for 2017 and 2020 respectively (European Environmental Agency, 2013).

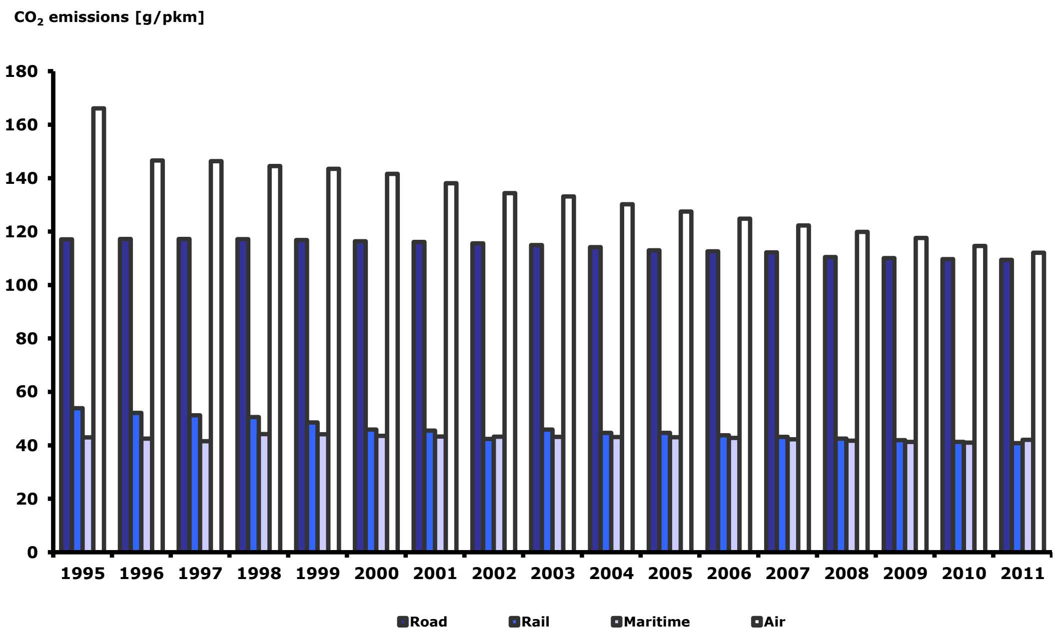


Figure B9. Development of specific CO_2 emissions, defined as emissions of CO_2 per transport unit (passenger-km), by passenger transport mode (road, rail, maritime, air) over the period 1995 to 2011. Data coverage: EEA-32 excluding Iceland and Liechtenstein (Source: European Environmental Agency, 2013)

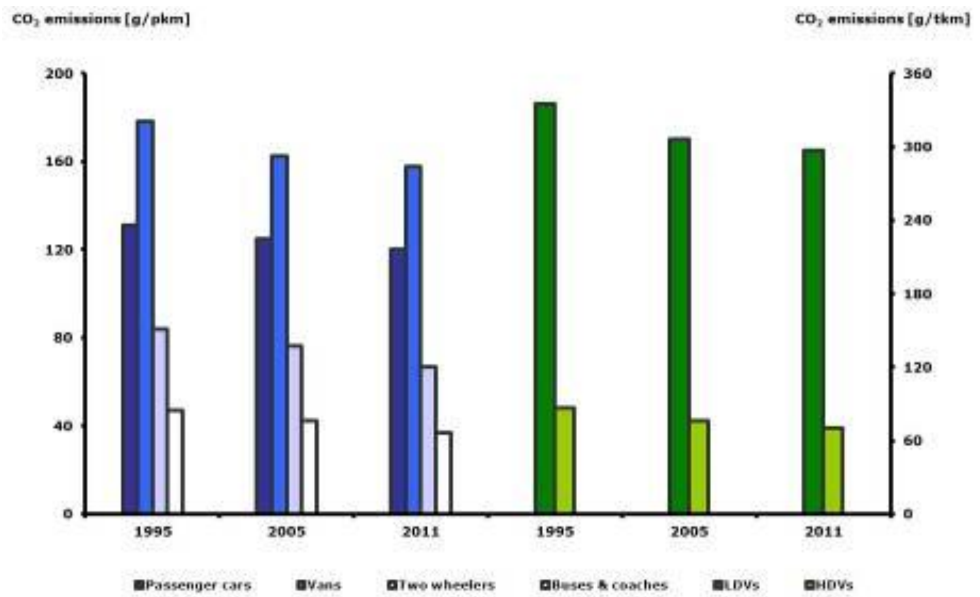


Figure B10. Development of specific CO_2 emissions for the road transport mode, by category (passenger cars, vans, two wheelers, buses and coaches, light-duty vehicles, heavy-duty vehicles) in 1995, 2005 and 2011. Data coverage: EEA-32 excluding Iceland and Liechtenstein. (Source: European Environmental Agency, 2013).

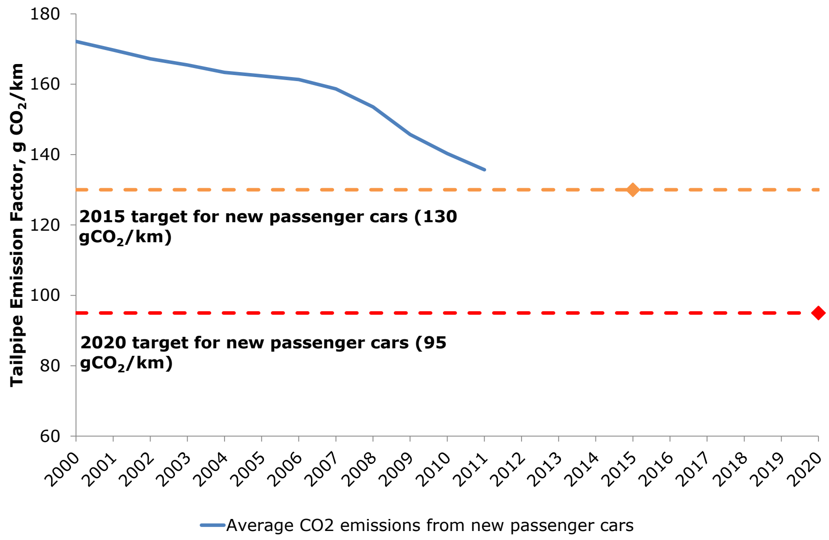


Figure B11. EU Regulation setting emission performance standards for new passenger cars (Source: European Environmental Agency, 2013).

B3.1.2.3 Energy security and fossil fuel supply

World energy demand and especially fossil fuel consumption is steadily increasing due to economic growth in certain countries, e.g. China and India. However, the supply of fossil fuels is predicted to decrease in the near future. Figure B12 illustrates the situation graphically, showing the fall of production from known fields and indicating the need to secure new production by new discovery or reserve growth, which in reality is beyond the physical limits of the planet.

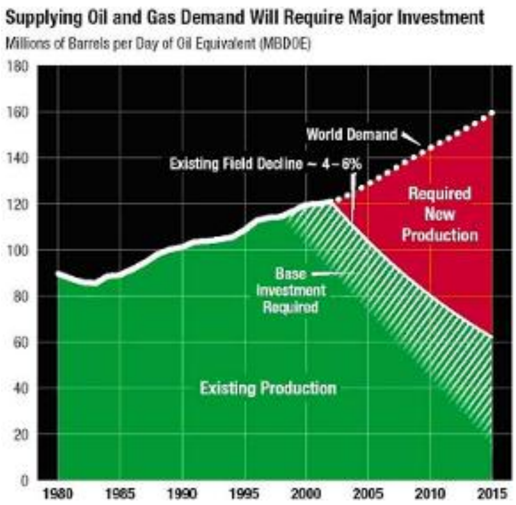


Figure B12. Effect of peak oil on future supply and demand (Source: ExxonMobil, 2004)

According to the peak oil scenario, oil would not only be exhausted but also become very expensive to explore and extract as sources are depleted. Further, the dependency on fossil fuel from politically unstable regions with increasing demand and depleting supply would lead to unstable and insecure energy supply. Therefore, switching to alternative fuel sources would not only check GHG emissions but also provide energy security and avoid price hikes.

B3.1.2.4 Increase in transportation congestion and poor air quality

The need for transportation for the ever growing population is increasing and so is the traffic congestion. Currently, the number of vehicles in EU transport sector is 222 million in 1995 to 307 million in 2009 and the growth rate is 1.5% (European Environmental Agency, 2010). During the same period, the number of vehicles per 1000 inhabitants has increased from 375 to 486 (European Environmental Agency, 2010). As a result, air pollution due to the emissions of SOx and NOx and particulate matter from the transport sector has been on the rise. The impact of air pollution and traffic congestion on human health and environment has been reported in the form of loss of human lives and endangering species, and destruction of ecosystems and habitats. A sustainable solution for this ever-growing problem would be to increase public transportation and shift to renewable energy sources. This way, the transport sector could become more efficient and also more people can travel without road congestion.

As noted above, biogas is considered a CO_2-neutral fuel and its combustion produces mainly CO_2 and water vapour: there is no dust, slag or ash in the combustion from biogas. The emissions of CO, SOx, NOx, heavy metals and particulate matter are lower from biomethane than from petrol and diesel combustion in buses (Dahlgren et al., 2012). Figure B13 shows a comparison of a number of fuels with local emission on the y-axis and global effect (CO_2) on the x-axis. Compared to other fuels, biogas has the lowest CO_2 emissions and pollutants in the market today together with the lowest global impact. In addition, calculations show that replacing fossil vehicle fuels by biogas would reduce the CO_2 emission per unit of energy by 90% (Concawe, 2006). The benefits can be doubled if biogas is produced from manure, due to the decreased emissions of both CH_4 and CO_2. The reduction, measured in CO_2 equivalents, can then be as large as 180% per unit of energy (Börjesson, 2007). Therefore, introduction of biomethane in public transport such as buses and taxis, or personal cars etc., is considered a promising alternative for effective ways to increase energy efficiency and decrease GHG emissions. Public transport is a great economic and environmental gain when more citizens choose not to travel by car on behalf of public transportation.

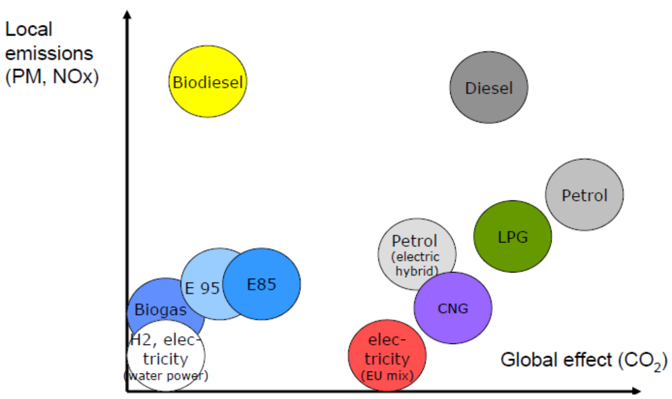


Figure B13. Environmental emissions of different fuels (Source: Strömberg, 2010)

B3.1.2.5 Reduction of methane emissions from organic materials

Methane is one of the more potent GHG with a global warming potential (GWP) 25 times greater than that of CO_2 in a 100 year period (IPCC, 2007). Environmental problems associated with conventional methods of handling and storing of organic wastes (viz., manure and municipal solids wastes) include spontaneous emissions of CH_4 under favourable anaerobic conditions. These CH_4 emissions can be avoided by digesting the manure in biogas plants which contain the produced CH_4. The collected biogas can then be used for combustion. However, it is important in this context that there are no CH_4 emissions from the biogas plants, pre- and post-storage tanks and/or during biogas upgrading. Methane can still be formed during post-methanation in the post-storage tank if temperatures and conditions are favourable (Kaparaju and Rintala, 2003). Similarly, methane slips of 1-2% are reported during the biogas upgrading depending upon the upgrading technology used (Beil and Beyrich, 2013). Collection of the methane produced by landfills can further reduce losses to the atmosphere.

B3.1.3 Societal Benefits

B3.1.3.1 Decentralised energy and transport fuel production for local needs

Many European countries are dependent to a large extent on the import of liquid fossil fuels and natural gas for their energy and transport needs. The increased global world demand and the peak oil scenario threaten to drive up fuel prices. Furthermore, fossil fuel is often imported from politically unstable regions and thus results in an unstable and unpredictable energy supply. In order to reduce fossil fuel dependence and to secure a future supply of energy and fuel, a local or regional biogas chain could be the answer. If the biomethane is produced and utilised locally or in the same region, then the region could be independent from oil imports and move towards sustainable and locally produced energy supply. Therefore, biogas could help to secure both energy security and security for transport fuel supply. The biogas market can be acting on a local level where the biogas is produced, distributed and consumed in the same regional area. Organic wastes such as manures, municipal solid waste, sewage sludges and energy crops could become feedstock for the biogas plants in such a system. The local farmers can receive bio-fertiliser within the community. Local energy companies, industries and vehicle fleets are provided with energy and vehicle fuel through a gas grid or short distance distribution trucks.

B3.1.3.2 Regional development and local employment opportunities

Figure B14 shows the involvement of local and regional stakeholders in the implementation of biomethane projects in local transport sector. As can be seen, the biomethane chain involves many stakeholders from feedstock cultivation/generation to biomethane production and utilisation (Dahlgren et al., 2012). Households, farmers, waste management companies, local and regional sewage treatment plants, companies that produce biogas are all needed. Additionally, companies that upgrade the biogas and distribute the biomethane and build filling stations or bus depots are needed in the biomethane chain. Every step in the biomethane chain needs technical and skilled personnel and knowledge addition. As a consequence new job opportunities are created in a wide range of job types, both locally and regionally. Therefore promotion of biomethane projects can benefit both local and regional investment, development and creation of new job opportunities.

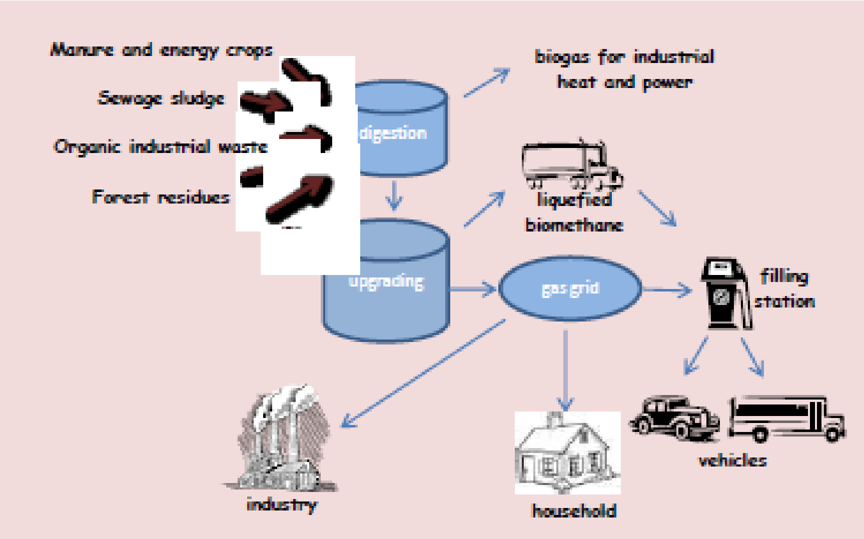


Figure B14. Biomethane chain from waste to energy sector to local transport (Source: Dahlgren et al., 2012)

B3.1.3.3 Sustainable waste management

Sustainable and efficient management of organic wastes involves the treatment of the wastes using environmentally sound technologies, recovery of energy in the waste for society and recycling of the nutrients to arable land as fertiliser (i.e. bio-fertiliser). All organic solid wastes including energy crops are important resources and can be exploited in a sustainable way. Utilising organic wastes in this way also reduces the amount of waste that must be disposed of and the costs associated with their disposal can be avoided. Integrated waste management with energy and nutrient recovery would facilitate sustainable urban development and creation of sustainable recycling systems for energy and nutrients between rural and urban areas (Dahlgren et al., 2012). Moreover, recycling of nutrients will reduce the production and consumption of synthetic fertilisers and the associated GHG emissions.

B3.1.3.4 Societal, environmental and economic benefits of biomethane in local and public transport

The greatest economic and environmental gain for the society is when biomethane is used in local and public transportation: for instance, when the produced biomethane is utilised for own vehicle use on the farm or company vehicles at the wastewater treatment plant, or when used in public transport like buses and taxis. Public transportation makes a better use of the urban space than a car-dominant society. According to Dahlgren et al. (2012), the urban space gained with public transport is shown in Figure B15. As seen, a 175 m wide road is needed to carry 50,000 people per hour per direction traveling by car, while the space needed to carry the same number of people travelling by a public bus is just 35 m (International Association of Public Transport, 2011). In addition, with fewer vehicles running, cities are less congested and also less noisy as biogas driven engines are quieter than diesel engines. Another societal benefit with the use of public transportation is higher urban air quality due to reduced gaseous and particulate emissions.

Figure B15. Public transport alleviates congestion (Source: Dahlgren et al., 2012; International Association of Public Transport, 2011)

B4 Biogas production in Europe

In this section, current biogas production in Europe is presented. Most of the estimates of future potential are based on the assumption of a general decrease in waste streams, in accordance with other environmental ambitions such as increasing overall resource efficiency.

B4.1 Present biogas production in Europe

The major sources of biogas in Europe in 2011 are presented in Figure B16. As can be seen, the total biogas production in Europe is 117.2 TWh in 2011 (EurObserv'ER, 2012). Among the different types of biogases, 56.7% of biogas is produced from the anaerobic digestion of organic waste in both agricultural and centralised biogas plants while the remaining gas is produced in landfills (31.3%) and sewage treatment plants (12%) (EurObserv'ER, 2012).

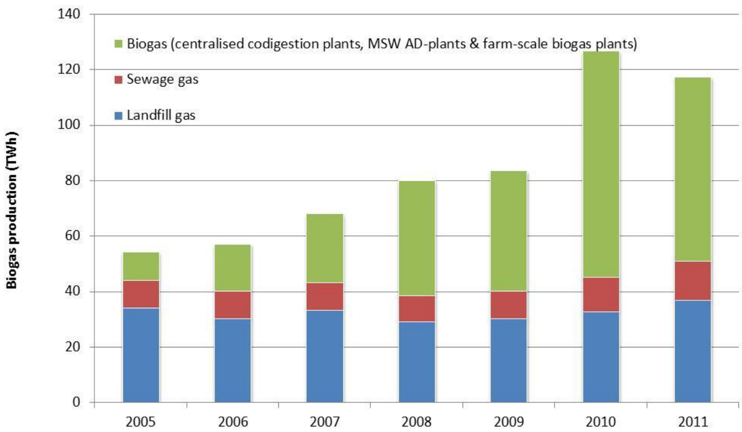


Figure B16. Major source of biogas production in Europe in 2005-2011 (Source: EurObserv'ER 2012; Biogas barometer, 2005–2008. Published by The European Forum for Renewable Energies/EurObserv'ER. Downloadable from /http://www.eufores.orgS).

Figure B17 presents biogas production in top 12 European countries in 2011. Currently, there are approx. 12000 biogas plants in Europe (EurObserv'ER, 2012). Germany is the leading European country in terms of number of biogas plants installed, absolute biogas production volumes as well as in future biogas production potential. The number of biogas plants in

Germany has increased from 2,600 in 2005 to 8792 in 2011 with nearly 1310 biogas plants installed in 2011 alone (EurObserv'ER, 2012). During the same period, the installed power generation capacity has grown from 650 MW to 2904 MW and represents 60.9% of total biogas production in Europe (EurObserv'ER, 2012). The projected growth of this industry for 2020 shows 25,000 digesters supplying Germany with 76 million MWh, or 17% of electricity production, powering 22 million homes, creating €26 billion in revenue, and employing 85,000 people (Stamatakos, 2012). These projections do not include biogas available from food or municipal waste, so the potential impact of the entire biogas industry is even larger than the projections above.

Biogas is mainly utilised for production of heat and/or energy in cogeneration plants, with the next largest use being upgrading for grid injection or as vehicle fuel. It is estimated that biogas-related electricity production in 2020 will be 64 TWh while the gross production of heating and cooling from biogas in 2020 is estimated at 61.2 TWh (Baxter, 2011). The share of biogas in transport is approximately 6 TWh and the total estimate for final energy consumption sourced from biogas in 2020 is more than 132 TWh. Adjusting for conversion efficiency (assumed electric efficiency of 35% and thermal efficiency of 40%), this corresponds to approximately 336 TWh of primary biogas production. Germany is mainly producing biogas as a fuel for electricity production in CHP plants (Gunaratne et al., 2010) and upgraded biogas is being injected into the natural gas grid (EurObserv'ER, 2012; IEA Bioenergy, 2013). In contrast, the Swedish government is showing a strong interest in producing biogas from the farm-scale biogas industry (76% of the total biogas production). Most of the sewage gas produced in Sweden is upgraded to biomethane and used in public transport (IEA Bioenergy, 2013).

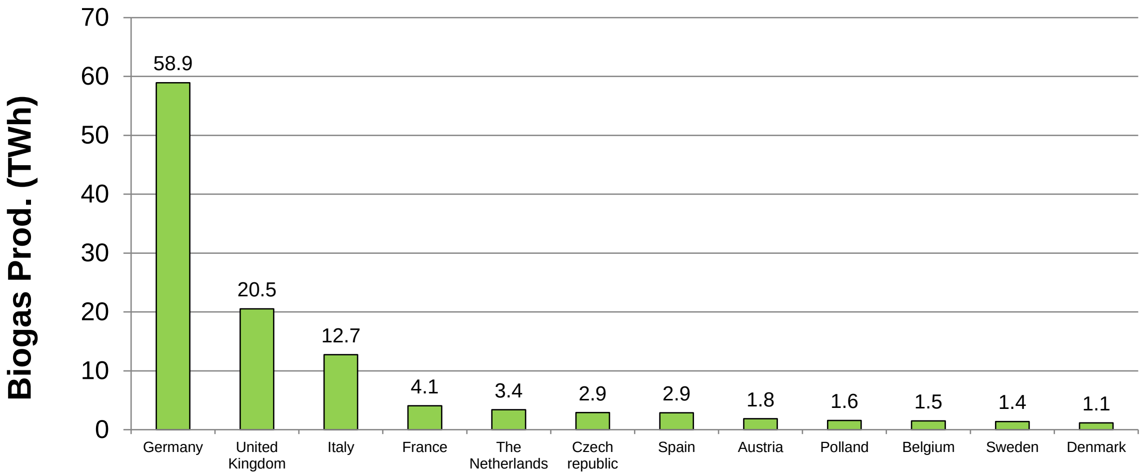


Figure B17. Biogas production in top 12 European countries in 2011 (Source: EurObserv'ER 2012)

Among the newly joined EU Member States, biogas production in Poland is high and can be harnessed with better organisation (Gunaratne et al., 2010). Out of 1759 industrial wastewater treatment plants (WWTPs) and 1471 municipal sewage treatment plants (MSTPs), only 46 MSTPs are involved in biogas production. The livestock industry in the country (cattle, swine and pig farms) also accounts for a significant share of the biogas potential (Gunaratne et al., 2010).

B4.2 Future biogas production potential in Europe

Biogas industry has grown substantially within Europe during recent years. The growth of the biogas industry in some European countries has been driven largely by feed-in tariffs (e.g. Germany), Renewables Obligation Certificates (UK) and tax exemptions (Sweden), that have created a market for electricity production from landfill gas and farm-based biogas plants (Ahman, 2010). Power generation in Germany accounted for the main share of the energy produced from biogas, which is also related to government incentives for power generation from renewable energy sources. Although biogas production from landfill and sewage sludge still dominates within the EU (see section B4.1), the potential biogas production from feedstocks such as wet manure, undigested sewage sludge and food processing residues is estimated to be 224 TWh by 2030 (European Environmental Agency, 2006), compared to 70 TWh produced in 2007 (Ahman, 2010). This estimate also includes a general decrease in waste streams in accordance with other environmental ambitions such as increasing overall resource efficiency. The environmentally compatible biogas potential from dedicated grass grown on agricultural lands within the EU is estimated to be 602 TWh by 2030 (European Environmental Agency, 2006). The potential from agricultural lands includes cereals, oil crops, grass (cuttings), maize double cropping systems and perennial grasses especially suited for fermentation to biogas (Ahman, 2010). Growing crops for biogas on agricultural lands is expected to increase after 2015 due to double cropping systems. The expansion of double cropping systems will not compete with either food production or with the production of woody biomass from e.g. short rotation forestry. The potential energy from for woody biomass is larger, however, and is estimated to be up to 4760 TWh (Ericsson and Nilsson, 2006). The total environmentally compatible potential for bioenergy production by 2030 is estimated to be 3444 TWh, of which 1120 TWh is from waste streams, 644 TWh from forestry and the rest from agricultural lands (European Environmental Agency, 2006).

B5 Market potential of natural gas as vehicle fuel

B5.1 Extent and potential of natural gas in World and Europe

In the last decade the natural gas vehicle (NGV) market has turned into a growth business (Figure B18). The annual growth in NGV was 26% between 2001 and 2007, with the number of vehicles increasing from 1.7 million to 7 million (IANGV, 2011). In 2011, there were 15 million NGVs of all classes in the world (IANGV, 2011). It is expected that the NGVs growth by 2020 would be 65 million vehicles at 18% annual growth rate and 9% market share (IANGV, 2011). In Europe, NGV's increased from 0.5 (2003) to 1.6 million (2011) in Europe (NGVA Europe, 2013). Light-duty vehicles (LDV), mostly after-market converted vehicles, are the most dominant and the market in Europe is usually driven by the price difference between natural gas and gasoline. In contrast, diesel in most European countries is often subsidised and thus, application of biomethane for heavy duty vehicles (HDVs) is less significant when the fuel cost is considered (Svensson, 2013). Further, most European governments do not use fuel subsidies to boost their national markets, but instead have rather high taxation levels on fossil fuels, with exceptions for diesel in some market sectors (Benjaminsson and Rojas, 2012). Consequently, HDVs are more prevalent in Europe. Thus, captive bus fleets or trucks could play a major role in many European countries for biomethane use. Even a small proportion of biogas buses would provide a biomethane market as their consumption is equal to 20-30 LDVs (Svensson, 2013). However, the main reason for the ever-increasing NGV market in Europe is the need to improve the use efficiency of refuelling infrastructure and to decrease air pollution from local transport in urban areas. Among the European countries and worldwide, Italy is the leading country in the use of NGVs since their emergence in the 1940s with nearly 779 100 LDVs and 3500 HDVs in 2011 (NGVA Europe, 2013).

Figure B18. Worldwide market growth trend and projected market share of NGVs in Europe for 2020 and 2030. (Source: NGVA Europe, 2013).

B5.2 NGV Market Growth in Europe (1995-2010)

Figures B19 and B20 present the detailed development of NGV from 2003 for all European countries. These statistics are provided by NGVA Europe. Data from 1995 until 2002 are based on estimates by the International Association of NGVs (IANGV).

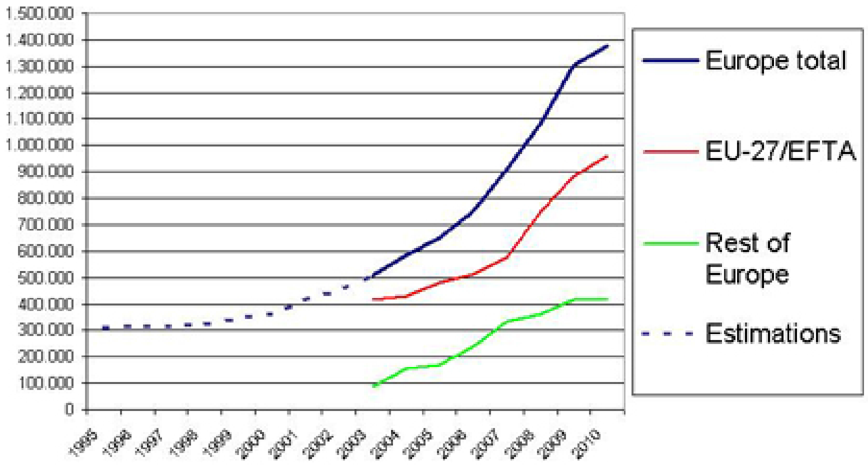


Figure B19. Comparative NGV development (1995-2010) in Europe (Europe total) and EU27 (Source: NGVA Europe 2013)

Before 1995, the European NGV market was basically limited to Italy. Since then the number of NGVs in Europe has been growing steadily (NGVA Europe, 2013). During the last five years the market growth for NGVs in Europe picked up significantly and NGVA Europe expects it to be much higher in the near future due to current EU Policy on alternative/renewable fuels and reduction in GHG emissions. But the trend in the European NGV market development will be influenced by unpredictable factors and national incentives.

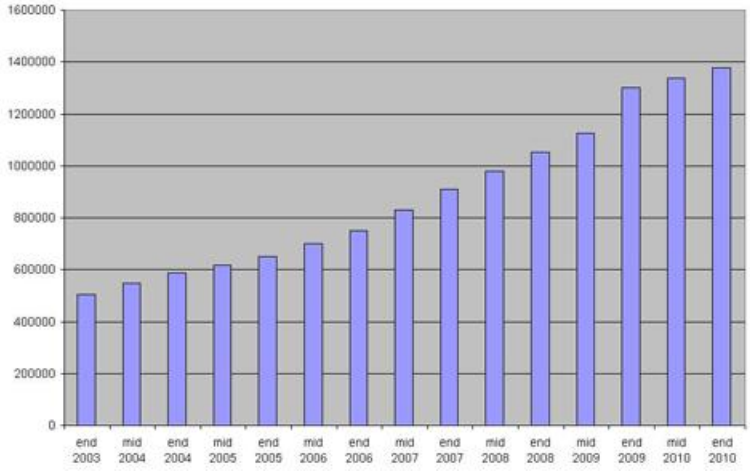


Figure B20. Europe NGV development 2003-2010 (Source: NGVA Europe, 2013)

B5.3 Market potential of biomethane as vehicle fuel

Biomethane still plays a marginal role in the current NGV market. Table B1 presents the NGVs and fuel consumption in EU-25, other European countries and European Free Trade Association (EFTA). Figure B21 shows the NGVs sales in Europe in 2013. It is evident from Table B1 that the current share of biomethane as vehicle fuel in European NGVs is 121 GWh year^{-1}, with only 9 countries reporting the use of biomethane in NGVs (NGV Europe, 2013). For instance, Switzerland and Italy are the leading European countries in NGVs on the road with 85% and 77% vehicles, respectively. But the share of NGVs running on biomethane is 23% in Switzerland and 0% in Italy (NGVA Europe, 2013). On the other hand, the share of NGVs in Sweden is a meagre 4% but the biomethane share as fuel for NGVs is a staggering 60%. Countries with a relatively small share of NGVs in the market but high biomethane penetration are Germany (8.8% NGVs & 20% Biomethane), Finland (0.11% and 25%) and the Netherlands (0.61% & 50%) (NGVA Europe, 2013). Iceland is the only European country with 7 % NGVs in market but 100 % share of biomethane.

When compared to global NGVs market, a more mature market for introduction of biomethane in the existing NGV market is mostly concentrated in Europe (Figure B21). Globally, the amount of biomethane consumption as vehicle fuel is 738 TWh year^{-1} in 2013 (NGVA Europe, 2013). The corresponding value for Europe is 190 TWh year^{-1} (NGVA Europe, 2013). The share of biomethane in the NGV market in Europe has increased from 93.1 GWh year^{-1} in 2012 to 121 GWh year^{-1} in 2013. Among the European countries (NGVA statistics for 2013), Sweden is the frontrunner with annual biomethane use of 67.4 GWh year^{-1} followed by Germany (44.2 GWh year^{-1}) and Switzerland (3.6 GWh year^{-1}).

There is a tremendous potential for use of biomethane in local transport, especially in countries where local or regional governments are responsible for both waste management and operation or procurement of public transport. In the EU-27 alone there is a potential market of 2 million city buses that could be powered by biogas, requiring an estimated 500 TWh of energy by 2020 (Svensson, 2012). This is based on the estimate that each bus travels 60,000 km $year^{-1}$ with an average biomethane consumption of 408 kWh per 100 km or approx. 245 MWh bus^{-1} $year^{-1}$ (Svensson, 2012). The relative cost of producing natural gas quality biomethane for vehicle use in local transport is quite high, especially in countries where natural gas, petrol and/or diesel fuel is subsidised or lightly taxed. In fact, natural gas is the most adverse competitor of biomethane, especially with the fall in prices in recent years. Nevertheless, given the proper incentives by government, based on external costs such as public health, environmental hazards and subsidy costs, the market potential will expand for biomethane.

Table B1. Natural Gas Vehicles and fuel consumption in EU Member States, other European countries and European Free Trade Association (EFTA) (Source: NGVA Europe, 2013)

Country	Natural Gas Vehicles								Date		Monthly gas consumption (M Nm3)			Biomethane	Date	
	Total NGVs	LD+MD +HD Vehicles	LD Vehicles	MD+HD Buses	MD+HD Trucks	Other	% of total LD+MD+HD vehicles in the country	% of total NGVs in the area	Month	Year	Reported consumption	Theoretical consumption	Ratio	Share	Month	Year
EU countries																
Austria	7 717	7 715	7 500	167	48	2	0,15 %	0,70 %	June	2013	13,50	2,00	677 %	0 %	June	2012
Belgium	499	486	472	3	11	13	0,01 %	0,05 %	June	2013	0,00	0,13	0 %	0 %	0	0
Bulgaria	61 270	61 270	61 000	240	30	0	1,83 %	5,58 %	June	2013	15,00	11,79	127 %	0 %	June	2012
Croatia	155	155	66	71	18	0	0,01 %	0,02 %	May	2013	0,08	0,28	30 %	0 %	December	2011
Czech Republic	5 500	5 410	4 954	401	55	90	0,11 %	0,50 %	June	2013	1,30	2,27	57 %	0 %	June	2013
Denmark	15	15	15	0	0	0	0,00 %	0,00 %	June	2013	0,00	0,00	0 %	0 %	0	0
Estonia	194	194	170	18	6	0	0,03 %	0,02 %	December	2013	0,65	0,10	634 %	0 %	June	2013
Finland	1 239	1 215	1 150	50	15	24	0,03 %	0,11 %	June	2013	0,32	0,40	78 %	25 %	June	2013
France	13 538	13 538	10 000	2 493	1 045	0	0,04 %	1,23 %	June	2013	6,00	12,41	48 %	3 %	December	2011
Germany	96 349	96 293	94 707	1 496	90	56	0,20 %	8,77 %	June	2013	23,00	21,81	105 %	20 %	June	2013
Greece	708	708	6	600	102	0	0,01 %	0,06 %	June	2013	1,33	2,11	63 %	0 %	0	0
Hungary	4 062	4 060	4 000	50	10	2	0,12 %	0,37 %	June	2013	0,22	0,90	24 %	2 %	June	2013
Ireland	3	3	3	0	0	0	0,00 %	0,00 %	June	2013	0,00	0,00	0 %	0 %	0	0
Italy	846 523	846 523	843 023	2 300	1 200	0	2,07 %	77,03 %	June	2013	75,00	162,24	46 %	0 %	June	2013
Latvia	18	18	18	0	0	0	0,00 %	0,00 %	December	2011	0,00	0,00	79 %	0 %	June	2011
Lithuania	200	200	75	125	0	0	0,01 %	0,02 %	December	2012	0,20	0,39	51 %	0 %	December	2012
Luxembourg	261	261	221	39	1	0	0,07 %	0,02 %	June	2013	0,06	0,16	35 %	0 %	July	2007
Netherlands	6 680	6 677	5 650	686	341	3	0,07 %	0,61 %	June	2013	0,00	4,10	0 %	50 %	0	0
Poland	3 392	3 350	3 000	320	30	42	0,02 %	0,31 %	June	2013	1,17	1,59	73 %	0 %	June	2013
Portugal	586	486	46	354	86	100	0,01 %	0,05 %	December	2011	1,16	1,34	87 %	0 %	December	2010
Slovakia	1 284	1 284	900	334	50	0	0,06 %	0,12 %	June	2013	1,00	1,31	76 %	0 %	June	2013
Slovenia	48	48	23	20	5	0	0,00 %	0,00 %	June	2013	0,08	0,08	95 %	0 %	June	2012
Spain	3 781	3 644	859	1 547	1 238	137	0,01 %	0,34 %	June	2013	7,84	8,52	92 %	0 %	June	2013
Sweden	44 321	44 319	41 820	1 851	648	2	0,92 %	4,03 %	June	2013	11,70	15,02	78 %	60 %	June	2013
United Kingdom	559	519	20	3	496	40	0,00 %	0,05 %	December	2011	3,00	1,50	199 %	0 %	August	2010
Total	**1 098 902**	**1 098 391**	**1 079 698**	**13 168**	**5 525**	**511**	**0,40 %**	**100,00 %**				**250,47**				
EFTA countries																
Iceland	918	918	900	2	16	0	0,42 %	7,06 %	November	2012	0,17	0,22	79 %	100 %	November	2012
Lichtenstein	143	143	64	61	18	0	0,50 %	1,10 %	December	2011	0,10	0,25	40 %	0 %	April	2007
Norway	877	876	353	514	9	1	0,03 %	6,75 %	June	2012	1,60	1,63	98 %	10 %	June	2012
Switzerland	11 058	10 998	8 126	2 572	300	60	0,24 %	85,09 %	June	2013	1,61	10,08	16 %	23 %	December	2011
Total	**12 996**	**12 935**	**9 443**	**3 149**	**343**	**61**	**0,16 %**	**100,00 %**			**3,48**	**12,18**	**29 %**			
Other European countries																
Armenia	244 000	244 000	192 000	17 300	34 700	0	55,45 %	33,12 %	December	2011	26,53	190,56	14 %	0 %	September	2011
Belarus	4 600	4 600	4 600	0	0	0	0,14 %	0,62 %	September	2011	1,03	0,83	124 %	0 %	September	2011
Bosnia & Herzegovina	21	21	20	1	0	0	0,00 %	0,00 %	October	2010	0,00	0,01	0 %	0 %	0	0
Georgia	3 000	3 000	3 000	0	0	0	0,56 %	0,41 %	May	2008	0,00	0,54	0 %	0 %	0	0
Macedonia	54	54	7	47	0	0	0,02 %	0,01 %	January	2011	0,02	0,14	14 %	0 %	April	2007
Moldova	2 200	2 200	2 200	0	0	0	0,42 %	0,30 %	September	2011	0,38	0,40	96 %	0 %	June	2011
Russia	90 050	90 000	65 000	10 000	15 000	50	0,25 %	12,22 %	June	2013	30,40	86,70	35 %	0 %	December	2011
Serbia	838	838	788	50	0	0	0,05 %	0,11 %	Ocotber	2012	0,31	0,29	106 %	0 %	October	2012
Turkey	3 850	3 850	1 850	2 000	0	0	0,04 %	0,52 %	December	2011	4,20	6,33	66 %	0 %	December	2011
Ukraine	388 000	387 981	19 400	232 788	135 793	19	5,13 %	52,67 %	May	2012	83,00	1109,24	7 %	0 %	November	2009
Total	**736 613**	**736 544**	**288 865**	**262 186**	**185 493**	**69**	**1,21 %**	**100,00 %**				**1 395,04**				
All European NGV countries	**1 848 511**	**1 847 870**	**1 378 006**	**278 503**	**191 361**	**641**	**0,54 %**	**100,00 %**				**1 657,69**				

* LD (Light Duty), MD (Medium Duty), HD (Heavy Duty)

Notes:

The column 'theoretical monthly consumption' is calculating total monthly consumption if cars consume 180, buses 3000, trucks 3000, and other vehicles 90 Nm3 per month

There is a huge difference between different truck types. A 44 ton truck in long distance road transport, or HD urban trucks and buses in intensive use may consume up to 8000 Nm3 per month.

The final column compares this number with the reported consumption (if available), otherwise shown as 0 %. Figures far below 100 % might indicate that the true fleet of vehicles is lower than reported, or that vehicles reported as trucks or buses are in fact light/medium duty vehicles. Theoretical values of less than 50% or more than 200% of reported values are an indication of outliers.

Globally, there are more than 17.7 million NGV recorded across 83 countries in 2013, rising from 15 million NGVs at the end of 2011. The annual growth rate was 26% between 2002 and 2007 with 33.7% since 2009 (NGVA Europe, 2013). For 2020, it is projected that there will be 65 million NGVs on the road with a market share of 9% and at a growth rate of 18% (NGVA Europe, 2013). Currently, there are more than 1.8 million NGVs in Europe (EU/EFTA) and are expected to reach 15-16 million vehicles by 2020 (Svensson, 2013). Among the NGVs, there are approx. 650 000 biomethane fuelled vehicles in Europe (NGVA Europe, 2013). This represents a very small share of the total EU vehicle market: 0.38% vehicles, 1.7% buses, 0.09% trucks. The introduction of small-scale LNG or LBM could stimulate the use of natural gas or biomethane in trucking. From Table B2 it can be seen that 74.5% of NGVs are LDVs (NGVA Europe, 2013).

Table B2 shows that in the EU/EFTA region, there are about 4191 CNG refuelling points of which around 3460 are for available public and 731 private use (NGVA Europe, 2013). Furthermore, 285 CNG refuelling stations are in planning stage. As of June 2013, almost 2615 of these public refuelling stations are based in Austria (175), Germany (844), Italy (912) Sweden (138), Switzerland (133), and Bulgaria (105). Italy and Germany have the biggest market share in terms of NG vehicles and CNG refuelling stations (Table B2).
Market development in Germany is expected depending on taxation. For instance, there is a lower tax for methane as a fuel in Germany up to 2017. If this level of taxation continues beyond 2017, it is possible that there will be 2500 stations in Germany by 2020 (Svensson, 2013). Similarly, the Netherlands is very positive in developing CNG infrastructure, having developed 85 CNG stations for public use in only 3 years (NGVA Europe, 2013).

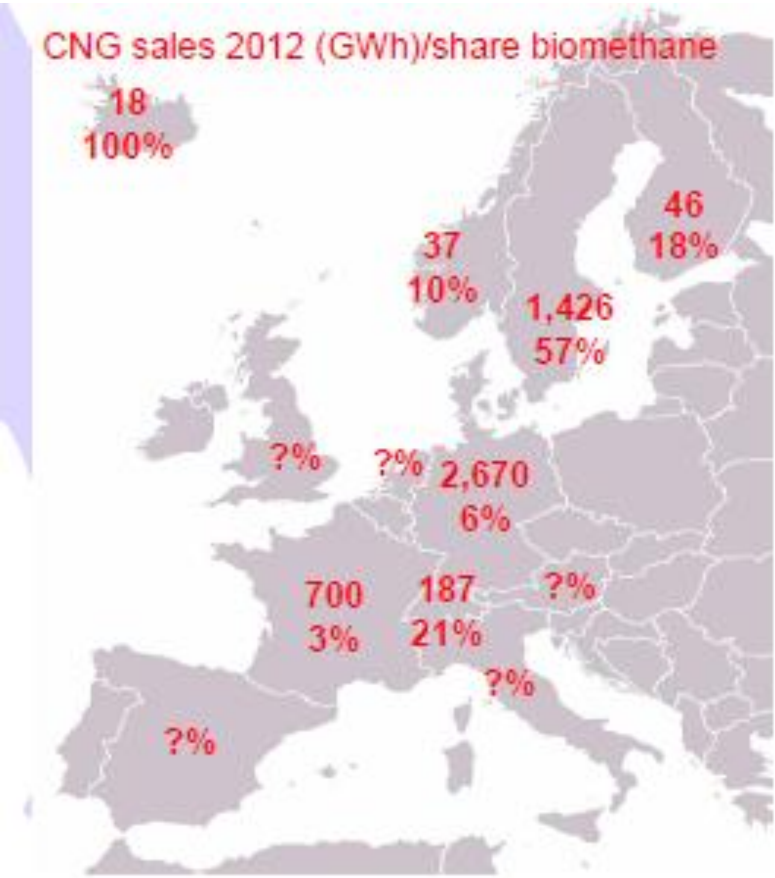


Figure B21. Biomethane sales in EU road transport (Source: NGVA Europe, 2013)

Table B2. Natural Gas Vehicles and CNG fuel stations in EU Member States, other European countries and European Free Trade Association (EFTA) (Source: NGVA Europe, 2013)

Country	Total NGV population (other than ships, trains and aircraft)								Date		CNG stations					L-CNG stations	LNG stations	All stations	VRA **	Date	
	Total NGVs	LD+MD +HD Vehicles	LD Vehicles	MD+HD Buses	MD+HD Trucks	Other	% of total LD+MD+HD vehicles in the country	% of total NGVs in the area	Month	Year	Total	Public	Private	Planned	% of total CNG stations in the area	Total	Total	Total		Month	Year
EU countries																					
Austria	7 717	7 715	7 500	167	48	2	0,15 %	0,70 %	June	2013	180	175	5	0	6,1%	0	0	180	0	June	2013
Belgium	499	486	472	3	11	13	0,01 %	0,05 %	June	2013	16	12	4	19	0,5%	0	0	16	17	June	2013
Bulgaria	61 270	61 270	61 000	240	30	0	1,83 %	5,58 %	June	2013	106	105	1	7	3,6%	0	0	106	0	June	2013
Croatia	155	155	66	71	18	0	0,01 %	0,01 %	May	2013	2	2	0	1	0,1%	0	0	2	0	May	2013
Czech Republic	5 500	5 410	4 954	401	55	90	0,11 %	0,50 %	June	2013	74	47	27	8	2,5%	0	0	74	102	June	2013
Denmark	15	15	15	0	0	0	0,00 %	0,00 %	June	2013	2	2	0	3	0,1%	0	0	2	0	June	2013
Estonia	194	194	170	18	6	0	0,03 %	0,02 %	December	2013	4	4	0	1	0,1%	0	2	6	1	June	2013
Finland	1 239	1 215	1 150	50	15	24	0,03 %	0,11 %	June	2013	19	18	1	4	0,6%	0	0	19	10	June	2013
France	13 538	13 538	10 000	2 493	1 045	0	0,04 %	1,23 %	June	2013	144	35	109	3	4,9%	0	0	144	200	June	2012
Germany	96 349	96 293	94 707	1 496	90	56	0,20 %	8,77 %	June	2013	915	844	71	85	30,8%	0	0	915	0	June	2013
Greece	708	708	6	600	102	0	0,01 %	0,06 %	June	2013	4	0	4	12	0,1%	0	0	4	0	June	2013
Hungary	4 062	4 060	4 000	50	10	2	0,12 %	0,37 %	June	2013	18	3	15	8	0,6%	0	0	18	50	June	2013
Ireland	3	3	3	0	0	0	0,00 %	0,00 %	June	2013	0	0	0	9	0,0%	0	0	0	3	June	2013
Italy	846 523	846 523	843 023	2 300	1 200	0	2,07 %	77,03 %	June	2013	959	912	47	0	32,3%	7	0	966	100	June	2013
Latvia	18	18	18	0	0	0	0,00 %	0,00 %	December	2011	1	1	0	0	0,0%	0	0	1	1	December	2011
Lithuania	200	200	75	125	0	0	0,01 %	0,02 %	December	2012	4	4	0	3	0,1%	0	0	4	5	December	2012
Luxembourg	261	261	221	39	1	0	0,07 %	0,02 %	June	2013	7	6	1	2	0,2%	0	0	7	0	June	2012
Netherlands	6 680	6 677	5 650	686	341	3	0,07 %	0,61 %	June	2013	186	119	67	30	6,3%	1	7	194	558	June	2013
Poland	3 392	3 350	3 000	320	30	42	0,02 %	0,31 %	June	2013	33	24	9	1	1,1%	1	1	35	100	June	2013
Portugal	586	486	46	354	86	100	0,01 %	0,05 %	December	2011	5	1	4	1	0,2%	0	0	5	0	December	2011
Slovakia	1 284	1 284	900	334	50	0	0,06 %	0,12 %	June	2013	14	10	4	0	0,5%	0	0	14	15	June	2013
Slovenia	48	48	23	20	5	0	0,00 %	0,00 %	June	2013	6	1	5	1	0,2%	0	0	6	4	June	2013
Spain	3 781	3 644	859	1 547	1 238	137	0,01 %	0,34 %	June	2013	66	18	48	12	2,2%	12	12	90	0	June	2013
Sweden	44 321	44 319	41 820	1 851	648	2	0,92 %	4,03 %	June	2013	195	138	57	0	6,6%	4	8	207	21	June	2013
United Kingdom	559	519	20	3	496	40	0,00 %	0,05 %	December	2011	9	1	8	4	0,3%	9	13	31	10	December	2011
Total	**1 098 902**	**1 098 391**	**1 079 698**	**13 168**	**5 525**	**511**	**0,40 %**	**100,00 %**			**2 969**	**2 482**	**487**	**214**	**100,0%**	**34**	**43**	**3 046**	**1 197**		
EFTA countries																					
Iceland	918	918	900	2	16	0	0,42 %	0,08 %	November	2012	2	2	0	2	0,1%	0	0	2	0	December	2010
Lichtenstein	143	143	64	61	18	0	0,50 %	0,01 %	December	2011	3	3	0	0	0,1%	0	0	3	0	December	2011
Norway	877	876	353	514	9	1	0,03 %	0,08 %	June	2012	24	21	3	5	0,8%	3	0	27	0	June	2012
Switzerland	11 058	10 998	8 126	2 572	300	60	0,24 %	1,01 %	June	2013	138	133	5	3	4,6%	1	1	140	0	June	2013
Total	**12 996**	**12 935**	**9 443**	**3 149**	**343**	**61**	**0,16 %**	**100,00 %**			**167**	**159**	**8**	**10**	**100,0%**	**4**	**0**	**171**	**0**		
Other European countries																					
Armenia	244 000	244 000	192 000	17 300	34 700	0	55,45 %	22,20 %	December	2011	345	345	0	0	11,6%	0	0	345	0	September	2011
Belarus	4 600	4 600	4 600	0	0	0	0,14 %	0,42 %	September	2011	42	42	0	0	1,4%	0	0	42	0	September	2011
Bosnia & Herzegovina	21	21	20	1	0	0	0,00 %	0,00 %	October	2010	2	2	0	0	0,1%	0	0	2	2	June	2011
Georgia	3 000	3 000	3 000	0	0	0	0,56 %	0,27 %	May	2008	50	50	0	0	1,7%	0	0	50	0	August	2011
Macedonia	54	54	7	47	0	0	0,02 %	0,00 %	January	2011	1	0	1	3	0,0%	0	0	1	0	January	2011
Moldova	2 200	2 200	2 200	0	0	0	0,42 %	0,20 %	September	2011	24	24	0	0	0,8%	0	0	24	0	September	2011
Russia	90 050	90 000	65 000	10 000	15 000	50	0,25 %	8,19 %	June	2013	252	211	41	15	8,5%	1	0	253	4	May	2012
Serbia	838	838	788	50	0	0	0,05 %	0,08 %	Ocotber	2012	9	7	2	3	0,3%	0	0	9	1	October	2012
Turkey	3 850	3 850	1 850	2 000	0	0	0,04 %	0,35 %	December	2011	6	6	0	0	0,2%	0	0	6	0	December	2011
Ukraine	388 000	387 981	19 400	232 788	135 793	19	5,13 %	35,31 %	May	2012	324	132	192	40	10,9%	0	0	324	8	May	2012
Total	**736 613**	**736 544**	**288 865**	**262 186**	**185 493**	**69**	**1,21 %**	**100,00 %**			**1 055**	**819**	**236**	**61**	**100,0%**	**1**	**1**	**1 057**	**15**		
All European NGV countries	**1 848 511**	**1 847 870**	**1 378 006**	**278 503**	**191 361**	**641**	**0,54 %**	**100,00 %**			**4 191**	**3 460**	**731**	**285**	**100,0%**	**39**	**44**	**4 274**	**1 212**		

* LD (Light Duty), MD (Medium Duty), HD (Heavy Duty)

**VRA (small Vehicle Refuelling Appliance)

In addition to CNG filling stations, there are also 39 public L-CNG stations (liquefied to compressed natural gas) and 44 LNG (liquefied natural gas) in Europe (NGVA Europe, 2013). L-CNG stations supply Liquefied Natural Gas (LNG) from cryogenic storage using a cryogenic pump, which compresses the LNG. L-CNG technology is mainly concentrated in the UK and Spain, but it is thought to be emerging fast as an alternative to diesel in MDs and HDs for long distances. In addition to the number of vehicles shown in Table B2 for Spain, 20 trucks are reported to operate on LNG (prototypes, pilots or aftermarket conversions) (Svensson, 2013). New applications in distribution and logistics services are expected for trucks, vans and taxis, but not in private cars in the near future for the Spanish market.

B5.3.1 Can biomethane demand match supply in Europe?

The potential biomethane supply can be compared with current energy use in the EU transport sector of approximately 3360 TWh (of which 1400 TWh is freight), which is projected to grow to 4200 TWh (2240 TWh freight) by 2030 (EU-Trends, 2003). Of the current 3360 TWh of transport fuels, only 5.6 TWh is natural gas and 42 TWh is light petroleum gases (LPG) used mostly in HD vehicles. According to EU-Trends (2003), 84 TWh of the total transport fuel demand is used for 'public road transport' (mainly local buses). This scenario assumes an enforced efficiency of passenger cars in the EU down to 120 g CO_2 km^{-1} and a normal efficiency development of freight transport.

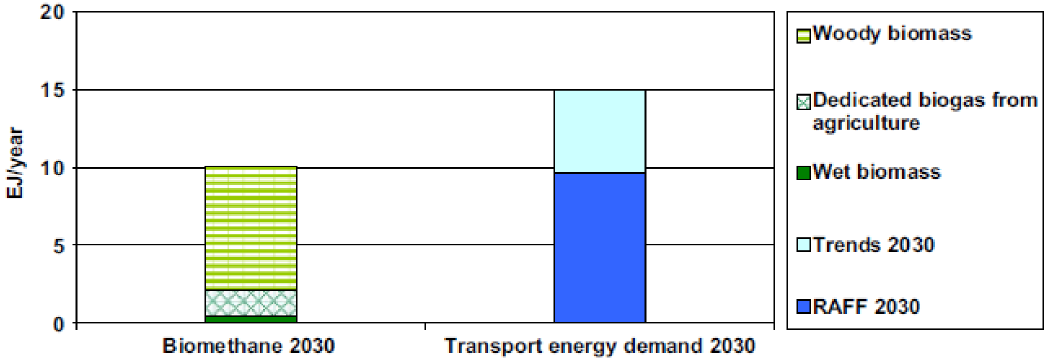


Figure B22. Potential biomethane production and future transport energy demand 2030 for EU25. Notes: RAFF denotes RApid eFFiciency scenario and illustrates the technical efficiency potential upto 2030 and is further explained in Ahman and Nilsson (2008). Sources: Ahman and Nilsson (2008), EU-Trends (2003), European Environmental Agency (2006, 2007). Note 1EJ = 280 TWh.

Figure B22 shows the potential biomethane supply in the EU-25 for 2030. The general assumption made in Figure B22 is that all suitable biomass resources will be used for biomethane. Not all biomass will be available for the transport sector, however, as other sectors also need to phase out fossil fuels and will thus be competing for the limited biomass resources. The technical potential for biomethane is thus large: as an example, a 20% share of biomethane in the EU-25 transport sector in 2030 would need to use 40% of the potential wet biomass supply and 33% of the potential woody biomass supply within the EU (Ahman, 2010). With increased energy efficiency in the transport sector, these values could be reduced to 30% of the wet biomass and 20% of the woody biomass (Ahman, 2010). According to Enerdata, 169 TWh RES-T were consumed in 2010 and 381 TWh RES-T are expected to be needed in 2020. It is envisaged that the expansion of biodiesel and bioethanol usage would be decrease due to EC proposals. This possible gap of ~180 TWh RES-T by 2020 has to be met by biomethane.

B5.3.2 Biomethane market development for local transport – the Swedish Example

The market for biomethane and natural gas in Sweden has been steadily increasing over the last decade. In 2009, 1.4 TWh of biogas was produced at 230 Swedish digestion plants (SGA, 2011). The main feedstocks for biogas production include sewage sludge, source-sorted food wastes and wastes from the food industry. In 2009, a total of 488 GWh of biogas has been upgraded to produce biomethane for local transport (Svensson, 2013). This corresponds to 36% of the total registered biogas production in the country. The remaining biogas was used for heating (49%), for electricity production (5%) and flared off (10%) (SGA, 2011).

Sewage treatment plants produce most biogas in Sweden. Of the total 1363 GWh of biogas produced in Sweden in 2009, sewage treatment plants produced 605 GWh (44%), followed by 335 GWh from landfill (25%), 299 GWh from co-digestion plants (22%) and 106 GWh from industrial plants (8%) (SGA, 2011). Small-scale on-farm biogas production contributed only 1% (18 GWh) to the total biogas production (SGA, 2011). Production from co-digestion and farm-scale plants in 2009 increased, however, while it remained unchanged at sewage treatment plants.

The biomethane increase in 2009 was 38% above 2008 production (SGA, 2011). This increase in demand took place when the demand for natural gas remained unchanged (Figure B23). In the year 2009, a sharp increase in the demand over supply of biomethane has been noticed in Stockholm (Svensson, 2013). This led to shipment of compressed biogas by trucks from outside the city. Roughly 40% of the biomethane sold in Stockholm was supplied by natural gas back-ups in the filling stations. Of the upgraded biogas, 151 GWh was injected into the existing natural gas network in south-west Sweden, at stations located at Laholm, Falkenberg, Helsingborg, Malmö, Bjuv, Göteborg and Lund (SGA, 2011).

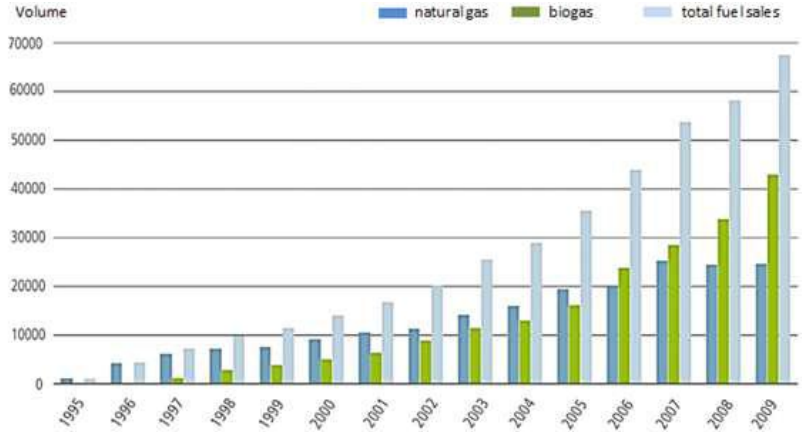


Figure B23. Sold volumes of compressed biogas (CBG) and compressed natural gas (CNG) in Sweden (Source: SGA, 2011)

Biomethane market demand according to vehicle types in Sweden is shown in Figure B24. Buses account for the largest demand. Stockholm Public Transport (AB SL) manages the public bus transport system in Stockholm County and is the largest consumer of biomethane in the Stockholm region. Today, AB SL has more than 2000 buses in service. The first biogas bus came into operation in 2004 and the fleet grew to 230 biogas buses by 2011 (SGA, 2011). Stockholm City Council, the owner, plans further transformation of buses from diesel to biomethane to meet their environmental goals: 50% of the bus traffic within AB SL is to run on renewable biofuels by 2011, 75% by 2016 and 100 % by the year 2025 (SGA, 2011).

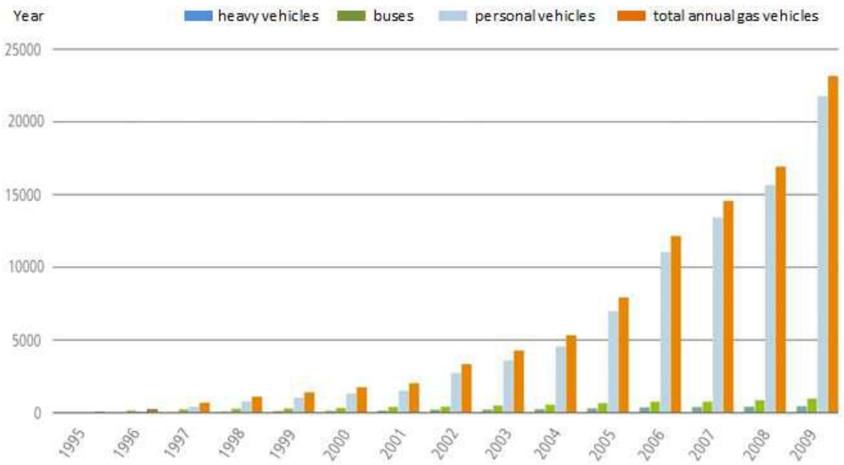


Figure B24. Number of gas vehicles in Sweden (Source: SGA, 2011)

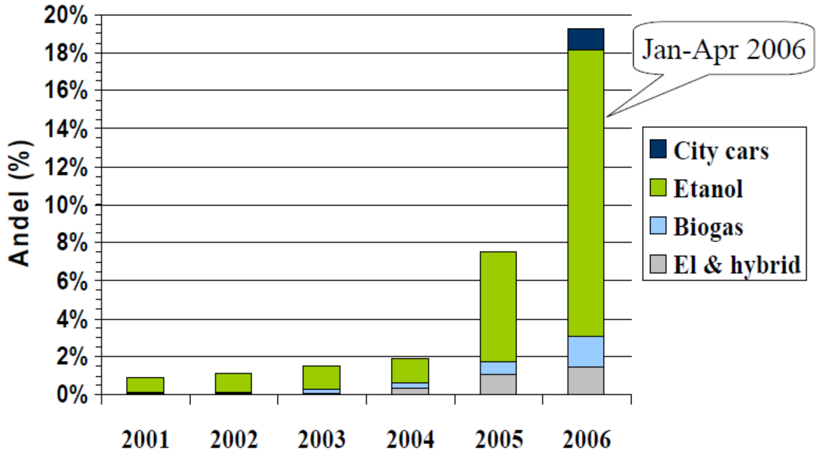


Figure B25. Sales of vehicles running on clean and renewable energy fuels in Stockholm (2001-2006). Source: Strömberg (2010).

The main driver for this market development has been the decisions taken by the regional public transportation authorities and long term agreements between public transportation authorities and biomethane producers. The drastic market development for private cars and taxis has also been a contributing factor to the sudden market development for biomethane. One of the best examples in Sweden is the case in 'Taxi Stockholm' which has a fleet of 1500 cars where 500 of them run on biomethane (SGA, 2011). The company itself has imposed certain environmental goals i.e. to maintain their environmental stewardship in par with the local and national targets. Decreasing the company's emissions of fossil fuel derived CO_2 with 70% from 2005 to 2012. The percentage of environmentally classified cars was 80% by 2010 and 95% by 2011 (SGA, 2011). Several other taxi companies in Stockholm have also got biogas cars in their fleet and have plans to increase the number in the future. The promising feature of taxis is that their road life time is short (3-4 years), so any decisions made on new taxis come into effect rapidly. The private biomethane vehicle market is also growing on a par with the public market, due to increased awareness and individual environmental concerns. The sale of cars driven by other renewable fuels, especially bioethanol, is also increasing (Figure B25). New technology concomitantly with market development is paving the way to liquefied biogas (LBG) in Sweden. Storage in liquefied form during distribution provides as much as 3 times more energy per unit volume than CBG.

B6 Role of small-scale biomethane producers in Europe

Table B3 shows the small-scale biomethane gas producers in Europe who upgrade biogas with a maximum upgrading capacity of 100 Nm^3 $hour^{-1}$ or less (about 5 GWh $year^{-1}$). Pilot projects are also included. During the last few years, the number of small-scale biogas upgrading units of both <50 Nm^3 $hour^{-1}$ and 50-100 Nm^3 $hour^{-1}$ capacity has been increasing in Europe. Currently, there are approx. 38 units of 50-100 Nm^3 $hour^{-1}$ capacity and 15 units of <50 Nm^3 $hour^{-1}$ (IEA Bioenergy, 2013). In VALORGAS deliverable D5.3 (2012), it was reported that the number of small-scale biogas upgrading units in Europe with a capacity of <50 Nm^3 $hour^{-1}$ was 11. This increase reflects the fact that small-scale upgrade is an area under development. However, the role of small-scale biomethane producers (< 50 Nm^3 $hour^{-1}$ raw gas) in local transport is small (16.6 GWh $year^{-1}$) in the current biomethane consumption of 190 TWh year^{-1} by approximately 1.8 million NGVs or 650000 biomethane vehicles in Europe (IEA Bioenergy, 2013). Table B3 also indicates that Sweden is at the forefront of small-scale biomethane production and use of the produced biomethane for vehicle fuel.

Table B3. List of biogas upgrading units in Europe with <100 Nm^3 hour^{-1} capacity (Source: IEA Bioenergy, 2013)

No.	Biomethane plant	Upgrading Technology	Plant capacity	Technology provider	Biomethane use
1	Plönninge, Sweden	Waterscrubbing/PA	17	Bio Rega, Sweden	Vehicle fuel
2	Nynäs gård, Sweden	Waterscrubbing/PA	22	Bio Rega, Sweden	Vehicle fuel
3	Katrieholm, Sweden	Water scrubbing/PA	80	Greenlane	Vehicle fuel
4	Motala, Sweden	Water scrubbing/PA	80	Greenlane	Vehicle fuel
5	Ulricehamn, Sweden	PSA	20	GPM vast	Vehicle fuel
6	Sundsvall, Sweden	Cryogenic	70	GtS, Sweden	
7	Eslöv, Sweden	Water scrubbing/PA	80	Malmberg Water, Sweden	Vehicle fuel
8	Alvik	Biosling/Water scrubbing/PA	50	Artic Nova	--
9	Halsua, Finland	Water scrubbing/PA	--	Metener Ltd	--
10	Laukaa, Finland	Water scrubbing/PA	40	Metener Ltd	Vehicle fuel
11	Chambery, France	Water scrubbing/PA	30	--	Vehicle fuel
12	Lille Marquette, France	Water scrubbing/PA	100	Greenlane	--
13	Sydeme de Forbach, France	Membrane	100	--	--
14	Collendoorn, The Netherlands	Membrane	50	--	Gas grid
15	Beverwijk, The Netherlands	--	80	BioGast	Gas grid
16	Mildrecht, The Netherlands	Chemical absorption	50	BioGast	Gas grid
17	Fredrikstad, Norway	Membrane	Pilot	MemfoACT	Vehicle fuel
18	Hovringa (Trondheim), Norway	Membrane	Pilot	MemfoACT	Vehicle fuel
19	Lillehammaer, Norway	Membrane	Pilot	MemfoACT	Vehicle fuel
20	Bachenbuöach, Switzerland	PSA	50	--	Vehicle fuel

No.	Biomethane plant	Upgrading Technology	Plant capacity	Technology provider	Biomethane use
21	Bischofszell, Switzerland	Genosorb Absorption	100	--	Gas grid
22	Inwil, Switzerland	--	--	--	Gas grid
23	Jona, Switzerland	Genosorb Absorption	55	--	Gas grid
24	Lucerne, Switzerland	PSA	75	Xebec	Gas grid
25	Obermeilen, Switzerland	Chemical absorption	100	--	Gas grid
26	Otelfingen, Switzerland	PSA	50	--	Vehicle fuel
27	Romanshorn, Switzerland	Genosorb Absorption	100	--	Gas grid
28	Rumlang, Switzerland	PSA	30	--	Vehicle fuel
29	Samstagern, Switzerland	PSA	50	--	Gas grid
30	Utzensdorf, Switzerland	PSA	100	Xebec	Gas grid
31	Widnau, Switzerland	PSA	100	Xebec	Gas grid
32	Vacarisses (Barcelona), Spain	Chemical absorption	100	--	Vehicle fuel
33	Jameln, Germany	Chemical absorption	100	--	Gas grid/ Vehicle fuel
34	Utzensdorf, Germany	PSA	100	--	Gas grid
35	Zalaegerszeg, Hungary	Water scrubbing/PA	85	DMT	Vehicle fuel
36	Eugendorf/Salzburg, Austria	PSA	40	Xebec	Gas grid/ Vehicle fuel
37	Margarethen, Austria	Membrane	70	TUW/Axiom	Vehicle fuel
38	Pucking, Austria	PSA	10	--	Gas grid
39	Vienna University of Technology, Austria	Membrane	6	TUW	Gas grid

B7 Expectations

The conclusion of the Expert Group on Future Transport Fuels (European Expert Group on Future Transport Fuels. 2011) is that biomethane in Europe should be fed into the natural gas grid than compressing and bottling for further use e.g. as vehicle fuel. Injection of biomethane into the gas grid is currently done only in 9 European countries: Austria, France, Germany, Netherlands, Norway, Sweden, Switzerland, UK and recently also in Italy. Injection of biomethane in the gas grid i.e. 'greening' of the gas grid via biomethane in Europe is expected to be explored in the future, as it would be more economical and efficient compared to dedicated compressed biomethane. This would mean that methane-powered vehicles would be refuelled by the gas grid, to avoid parallel investments in a biomethane bottling and distribution network. Sweden, however, is a special case as there is an elementary natural gas distribution network in the south (Figure B26) and thus the production and use of biogas in existing NGVs is much more important (65% of the total methane used in approx. 36000 NGVs is biogas). Methane is expected to make an important contribution to achieve the GHG emissions reductions targets, improve local air quality and reduce noise, if the appropriate infrastructure is put into place. Large fleets of urban buses, taxis and delivery vans are particularly suitable for the introduction of alternative fuels.

With respect to role of biomethane in local transport, the National Renewable Energy Actions Plan (NREAP) reports for the EU Member States that more or less the overall 10 % Renewable Energy Source (RES) target in transport would be reached by means of E10 (10 % ethanol blends) and B7 (7% biodiesel blend), along with the measures and reforms that would be taken towards this target (European Commission, 2012). As blending biofuels with fossil fuels not exceeding the above mentioned limits, specified by the Fuel Quality Directive (10% ethanol in E10, and 7% biodiesel in B7), has the advantage that neither new engines nor new infrastructure are necessary. Increasing ethanol and biodiesel content in the blends may require some adaptations to certain exhaust treatment designs. However, manufacturers foresee a lag in the achievement of this target and with possibly a few alternatives at present (i.e. electricity, biomethane from the natural gas grid). Thus, these alternatives will have to enter the market and it is considered that the European NGV market will grow significantly in Europe in the short, medium and long term (2020, 2030 and 2050 respectively), expecting to reach total market shares of 5%, 9% and 16% - 20% respectively, in both passenger and freight transport for all transport modes (European Commission, 2012).

Figure B26. Natural gas network in Sweden (Source: Svensson, 2013).

B8 Case studies of biomethane use in local transport in Europe

The following case studies provide as examples of the potential for application of small-scale biogas upgrading for local transport utilisation in Europe. Technical aspects of these case studies are already presented in VALORGAS Deliverable D5.3. Biogas upgrading and use of biomethane for grid injection or vehicle fuel is common and applicable in Europe. Currently, there are two common approaches on supply of biomethane in Europe:

1. Supply to natural gas grid
2. Supply to filling stations next to biogas plants ('local application') or transport to filling stations by tank lorries

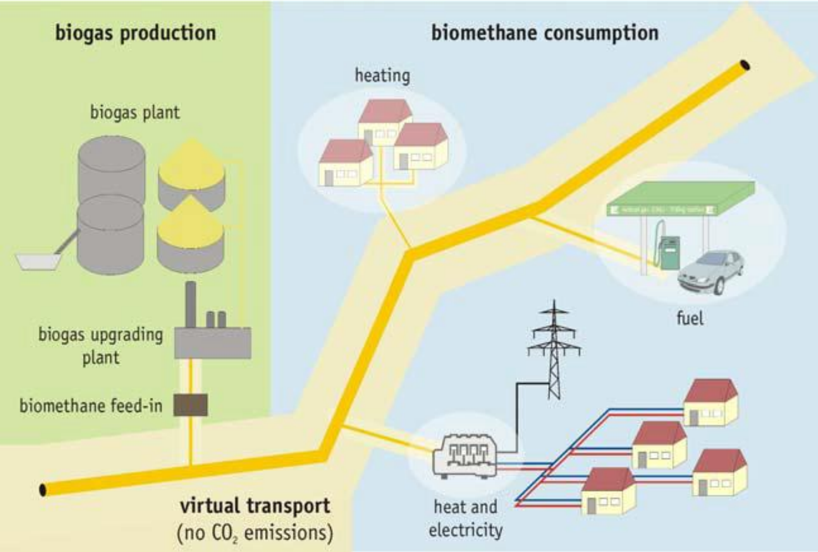


Figure B27. Typical biomethane production and consumption in Europe (Source: Baumgartner et al., 2010)

However, biogas bottling (at least for use as a vehicle fuel) is not so common in Europe compared to other countries e.g. India as most of the biogas producers and/or upgrading units are located within the national natural gas grid. Therefore, it is more economical and advantageous to use the existing natural gas infrastructure to transport the upgraded biogas for its utilisation (Figure B27). On the other hand, compression and bottling of biomethane is more common in small-scale biogas plants as these plants are located in remote areas and are far from the national natural gas grid.

Case study 1: Kalmari farm, Finland
(Source: IEA Bioenergy net, 2012; www.iea-biogas.net)

The small-scale biogas upgrading unit of Metener Ltd at Kalmari farm in Finland uses high pressure water scrubbing upgrading technology. The size of the upgrading system is well suited for farms as well as for small communities. The raw gas intake can be selected between 30 to 100 Nm^3 $hour^{-1}$. In other words, the gas production is between 1000-4000 MWh $year^{-1}$. The upgraded product gas is H-level biomethane with Wobbe index of 45.6-54.7 MJ Nm^{-3} and energy content of 36-50 MJ kg^{-1} (30-40 MJ Nm^{-3}). During normal operation, the product gas has a CH_4 content of 92-99% depending on the raw gas quality.

The upgraded product gas is dehumidified and stored in a high pressure storage system (250-270 bar). In 2011, a new card-operated vehicle filling station with high pressure gas tanks (300 Nm^3, 270 bar) was installed. The gas demand at Kalmari's farm filling station has doubled each year. Currently, around 100 vehicles including two delivery lorries and one taxi use the upgraded biomethane as vehicle fuel.

Case Study 2: Zalaegerszeg, Hungary, Okoprotec
(Source: http://www.okoprotec.hu/termekek)

The first biogas upgrading plant in Hungary was built at the wastewater treatment plant in Zalagearszeg by DMT environmental technology, Netherlands. This upgrading unit is a small-scale plant able to treat 50-100 Nm^3 $hour^{-1}$ of raw biogas coming from two anaerobic sludge digesters, and is used to optimise the energy utilisation of the WWTP. Biogas is upgraded to any desired methane quality. The biomethane can be injected in the gas grid, used for CHP, or further compressed to be used as vehicle fuel. A small storage operating at 220 bar and a dispenser to facilitate direct fuelling of the company's car fleet are also available. Because of the small-scale nature of the installation, some components of the plant were simplified compared to large-scale systems. For instance, both the desulphurisation and the final drying of the gas are based on non-regenerative absorption technology. As the gas is mainly used locally, monitoring and control is simplified and the exact gas quality for fuel use is set at 96% or higher instead of controlling at 97±1%.

Case study 3: BioSling, Sweden
(Source: Artic Nova, 2010; http://www.articnova.se/biosling_e.html)

Artic Nova developed and manufactured a small-scale upgrade facility on behalf of BioSling AB, Sweden. BioSling is a unique design that allows small-scale biogas producers with cattle or energy crops to upgrade raw biogas for use as high-quality vehicle fuel or for gas grid injection in a cost-efficient way comparable to or even better than upgrading systems used with larger biogas operations. The BioSling system upgrading capacity provides up to 600 Nm^3 day^{-1} of vehicle-quality gas (97% methane) or the equivalent of about 650 litres day^{-1} of petrol. The BioSling upgrading process consists of rotating spirals or coils of hoses forming the main components responsible for CO_2 scrubbing (see VALORGAS D5.1 for details).

Case study 4: Bruck an der Leitha, Austria
(Source: DENA, 2010; Virtual Biogas Project, www.virtuellesbiogas.at)

The biogas plant in Bruck an der Leitha, Vienna has an upgrading plant designed to produce biomethane at the rate of 100 Nm^3 $hour^{-1}$, corresponding to approximately 180 Nm^3 $hour^{-1}$ of raw biogas. The produced biomethane meets the applicable Austrian laws for grid injection and vehicle fuel standards ('Österreichische Vereinigung für das Gas- und Wasserfach ÖVGW G31 (Erdgas in Österreich - Gasbeschaffenheit) and G33 (Regenerative Gase - Biogas). Therefore, the produced biomethane is a fully-fledged natural gas substitute and it is permissible to inject this gas into the public natural gas grid. The upgraded biogas is fed into the EVN grid and is transferred to the gas station operator OMV and to Vienna Energy to be used as biofuel. Parallel to this grid injection two CHP-gas engines (830 kW_{el} each) are operated at the biogas plant in Bruck an der Leitha producing electric power and district heat.

The produced biomethane is transported to the gas distribution station via a 2.8 km pipeline. Depending upon the gas quality (complying with the Austrian standards), the biomethane is injected into grid or used for electricity generation in the gas engines of the biogas plant. The supplied biomethane is transported via the local natural gas grid at up to 3 bar to the nearby city of Bruck an der Leitha (population about 7600). The total produced biomethane is consumed in the city during the winter months; additional fossil natural gas is needed to supply the city to 100%. During the summer months the local consumption of Bruck an der Leitha is significantly lower than the produced biomethane; therefore, the surplus biomethane is compressed to 60 bar and fed to the regional gas grid (grid level 2). As a result constant operation of the biogas upgrading plant over the whole year is possible, ensuring optimum plant utilisation and cost structure.

Case study 5: Plucking, Austria
(Source: Baumgartner et al., 2010)

The Pluking biogas plant in Austria upgrades biogas to natural gas quality and it is injected into the existing natural gas grid. An existing biogas plant that used biogas for generation of electricity serves as a gas production plant. The upgrading plant capacity is 10 Nm^3 $hour^{-1}$ of raw gas. The technology applied is pressure swing adsorption (PSA). The plant produces about 6 Nm^3 $hour^{-1}$ of biomethane. This is an annual energy production of 400,000 kWh, equivalent to the average annual requirement of 40 household apartments. The upgraded biogas fulfils the quality requirements of the ÖVGW directive G31. The biomethane can also be used as vehicle fuel or for cogeneration (for example stationary fuel cells), and is not dependent on the availability of gas injection.

Case study 6: Schwaighofen biogas plant, Austria
(Source: Baumgartner et al., 2010)

The biogas upgrading plant in Schwaighofen, Austria has a plant capacity of 18 Nm^3 $hour^{-1}$ of raw gas and the upgraded biogas is fed into the natural gas distribution network, and offered for sale at separate gas stations as 'Bio-natural-gas'. CNG cars can be refilled using the upgraded biogas from the gas station.

Case study 7: Eugendorf/Salzburg plant, Austria
(Source: Baumgartner et al., 2010)

Two biogas upgrading units at Eugendorf (Salzburg) and Margarethen am Moos (Lower Austria) produce biomethane for direct use of the upgraded biogas at a biogas filling station installed at the biogas plants. The upgrading plant in Eugendorf is 22 Nm^3 $hour^{-1}$ of raw gas capacity and the produced biomethane is used for feed-in into the gas grid and also as vehicle fuel. The technology applied is PSA.

Case study 8: St. Margarethen am Moos plant, Austria
(Source: Baumgartner et al., 2010)

The biogas plant at Margarethan am Moss uses one-step membrane technology and has a plant capacity of 70 Nm^3 $hour^{-1}$ of raw biogas. The upgraded biogas, which has the quality of natural gas, is sold at a gas station. Since 2008, CNG vehicles can refuel at the biogas station with upgraded biogas under the brand name of 'methaPUR'. The production output is about 25 kg $hour^{-1}$.

Case study 9: Plönninge biogas plant, Sweden
(Source: Svensson and Orwén, 2011; Bioprocess Control Sweden AB, 2011)

The Plönninge biogas plant at Plönninge Agricultural High School was built to promote small-scale biogas production in agricultural enterprises. The plant also serves as a demonstration plant for future farm-based biogas plants in the region and around the world.

The produced biogas is consumed in three different ways using the following systems: i) in a gas burner for producing heat; ii) in a Stirling engine for producing electricity and heat; and iii) in an upgrading unit for producing biomethane as a vehicle fuel. Originally only the gas burner was installed at the plant but in order to promote the production of higher value products, the Stirling engine and the biogas upgrading unit were installed in 2008; the Stirling engine began operation in 2011. The biogas upgrading plant has a raw biogas capacity of 17 Nm^3 $hour^{-1}$. Biogas is upgraded to biomethane by a water scrubbing process. The biomethane is used as fuel for the local vehicles.

B9 Recommendations for promotion of biomethane use in local transport in Europe

Based on the work carried out in this part of the deliverable, including desk and case studies, discussions with other industry experts, and literature and policy reviews, the following comments and recommendations can be made concerning promotion of the use of biomethane in local transport in Europe:

Standardising the financial support at European level to promote biomethane in local transport and meet the RES-T target

- There is still huge difference between European countries in relation to the type and level of financial incentives that are being offered for biogas used for electricity generation directly at site, and for upgrading to biomethane for vehicle fuel.
- All European countries could have similar and equal financial support for biomethane and CHP, and biomethane projects should receive more support by 2015.
- Some European countries e.g. Croatia, Hungary, Italy and Spain have reported that they do not have any incentives for biomethane in 2012. In Germany, electricity from biomethane (supplied via gas grid) is rewarded with a bonus on top of the existing feed-in tariff that is paid for biogas CHP at site. In order to justify the effort for upgrading, a heat utilisation of 100% from the biomethane CHP is required. In this connection, however, biomethane CHPs compete for appropriate heat sinks not only with other renewable heat sources but especially with natural gas CHPs which are supported by an individual mechanism. On the other hand, Austrian incentives are currently dependent on new RES-E tariffs. These do not appear to favour biomethane projects compared to CHP. Hence, a slight increase in support is needed for biomethane.

Strong and clear incentives and tax exemptions to promote biomethane use in local transport

- Different countries have different policies on use of biomethane. Reports from some European countries e.g. Germany, Netherlands, Italy indicated that there may be more support for biomethane as a vehicle fuel with development in infrastructure. Other countries indicated that it is likely that less support would be given to biomethane as a vehicle fuel (e.g. use of green gas certificates in the UK).

- Powerful incentives such as exemption from congestion charges, reduced tax on the use of company cars for private purposes, promotion of sales of gas cars in the private sector and requirement for gas cars or other clean technologies in procurement of transport services such as service cars, buses, waste collection and taxis should be encouraged.
- Monetary incentives should form an integral part of an overall policy to promote clean cars. Incentives will not have any significant impact until clean cars have performance and reliability comparable to a conventional car. In Sweden, economic incentives to choose clean cars were very powerful instruments to increase biogas car sales. Incentives that reduce operating costs (e.g. lower price of fuel) seem to be stronger than incentives affecting purchase price, even if in Bern and Vasteras such dedicated aid has had a certain impact. Incentives that introduce a privilege for clean cars are stronger than incentives that attempt to “even out” differences between clean cars and their conventional counterparts

Efficiency conditions that apply for CHP electricity generation should not be applied to biomethane incentives

- Biomethane production is the solution for de-coupling electricity production from heat utilisation. In order to make use of this advantage and to justify the technical effort for upgrading and use as local transport fuel, the CHP electricity efficiency should be decoupled from heat utilisation. In Germany and the Netherlands, utilisation of waste heat is required to access the incentives and this may make it difficult to initiate new projects. In the UK, there is no efficiency requirement for biogas used as CHP but it can be expected in 2015. In Spain, there is a royal Decree (661/2007) that required all CHP plants to have a minimum efficiency of 50% and higher efficiency to be eligible for higher CHP incentives. As of January 2012, however, all incentives were temporarily cancelled with no fixed date for new guidelines

Removal of barriers in promotion and use of biomethane

- In order to promote the use of biomethane directly as a vehicle fuel, either in compressed form (CBM) or liquid form (LBM), we need to remove the barriers to biomethane as a vehicle fuel e.g. tax on biomethane when blended with natural gas as a vehicle fuel, lack of incentives for biomethane upgrading thus making the necessary clean-up uneconomical, and finally lack of sufficient infrastructure and cross-border trading.

Flexible biomethane business concepts for biomethane market development

- The business concept for biomethane market development should be flexible and based on the local rather than national or European business model. For instance, in Linkoping and Vasteras cities of Sweden, there is one municipal company that produces and distributes the biomethane to the end user and takes responsibility for the whole chain. On the other hand, in Stockholm, a more commercial concept is applied where a private distributor has purchased biomethane from different municipal producers and has supplied a network of public filling stations. Similarly in Lille, the transport operator is the major purchaser of biomethane as the local authority responsible for public transport (LMCU) has made this purchase to be mandatory in the public contract.

- In the UK, it is unlikely that any biomethane will be used directly as a vehicle fuel, as injection to grid and taking out as natural gas with Green Gas Certificates is the preferred model. This has technical advantages in that CNG production is intermittent whereas biogas/biomethane is continuous.

Strong local policies with public-private partnership to expand the local biomethane market

- For a self-sustained market for biomethane, local stakeholders (local authorities and companies) should play a pivotal role in stimulating local use of biomethane as a fuel.
- Both the public and private sectors need to be involved in implementing actions to expand the use of biogas as a fuel for local transport.
- Local municipalities need to offer special incentives such as free parking in the city for clean vehicles, and actively communicate the advantages of clean vehicles to citizens.

Development of dedicated distribution network for biomethane market expansion

- To achieve high market penetration, a balance between the three components biomethane production, infrastructure-distribution and market demand has to be made.
- Development of biomethane infrastructure, especially the distribution and filling station network, will encourage and build confidence in customers in the local area. Public incentives (finding the location and ground financing), mass communication on common technical/safety rules for the building and the operation of filling stations, and urban planning rules to support gas filling stations network are needed.
- In cities or towns where there is no natural gas grid, distribution of compressed biomethane can be done using small local biomethane grids supplemented by transporting the biomethane using trucks and swap-bodies common in the gas industry.
- If biomethane vehicle quality requirements are maintained, then biomethane suppliers from several different small to medium sized biogas plants using various feedstocks or upgrading units with different upgrading technologies should be encouraged to use the common local network.

Strategy to introduce biomethane in different vehicles

- There should be a clear market strategy for the introduction of biomethane-driven cars in the market. Bioemthane driven passenger cars could be the first target, later followed by the introduction of biomethane buses, trucks, vans, taxis and company cars. Thus, the demand for biomethane for local transport would be gradual in order to accommodate the simultaneous development of the biomethane infrastructure and biogas driven vehicles.

Effective communication to encourage biomethane use

- Effective communication on environmental and economic benefits of biomethane as a vehicle fuel to individuals as well as public and private companies is needed. There is a lack of knowledge about environmental performance, practicalities (such as the location of the filling station) and cost issues around biomethane

It should also be noted that an essential step for implementing the above recommendations is to promote and increase biomethane production to match future demand.

B10 Summary and conclusions

The transportation sector is the highest energy consumer and a major source for GHG emissions in the Europe. It is also one of the most difficult sectors to deal with reducing its own emissions and switching to an alternative fuel. Transformation of personal vehicles and large fleets, such as public transportation, to run on biomethane can reduce fossil fuel use and GHG emissions associated with transport sector. Biomethane is considered as carbon neutral renewable energy and can be used in current natural gas driven internal combustion engines without any major changes. Use of biomethane in local transport especially in public transportation would bring several benefits such as local biofuel production, regional infrastructure development, employment opportunities, sustainable waste management and reduce GHG emissions in fossil fuel driven public transportation. Although the share of biomethane in the current NGV market in Europe is small, it is envisaged that market for biomethane vehicles will expand in the near future. Some European countries such as Germany and Sweden had implemented some strategies to promote biomethane at national and regional levels e.g. investment grants for biomethane production, lower tax for methane as a vehicle fuel, feed-in tariffs for biomethane injection in gas grid, subsidies for infrastructure development for biomethane transport and fuelling stations etc. Currently, biomethane is injected into the national natural gas grid and upgrading is commonly practiced by large-scale biogas units which are within the vicinity of the gas grid. The use of biomethane as vehicle fuel is the third main route. CNG is already competitive with gasoline and diesel due to high oil prices, and development of this market can be a lever for growth in compressed biomethane. However, the share of CNG in the European vehicle fuel market is very small and growth will have to be accommodated by investment in filling stations. On top of this, the market penetration of compressed biomethane or liquid biomethane will depend on support schemes, at least as long as natural gas prices are more competitive. Similarly, the role of small-scale biomethane producers in local transport is small and mainly confined to remote locations and off the natural gas grid. Strong cooperation among many actors in biogas production to biomethane distribution and use is required. Barriers such as weak infrastructure and balancing supply and demand, regulation and high investments need to be overcome during early market development. Therefore, small-scale production and use of biomethane in transport sector should be a focus in order to solve the economic and environmental problems associated with the fossil fuel dependent transport sector.

References for Part B

Ahman, M. 2010. Biomethane in the transport sector — An appraisal of the for gotten option. Energy Policy.

Ahman, M. and Nilsson, L.J. 2008. Path dependency and the future of advanced vehicles and biofuels. Utilities Policy 16 (2), 80–89.

Artic Nova. 2010. A new plant system for biogas upgrading on a small scale, farm size level. Available at: www.articnova.se/biosling_e.html (Accessed on 12 Feb 2011).

Beil, M. and Beyrich, W. 2013. Biogas upgrading to biomethane. In: The biogas handbook: Science, production and application. Wellinger A., Murphy, J. and Baxter, D. (eds.). IEA Bioenergy. Woodhead Publishing ltd, UK. pp. 342-377.

Benjaminsson, J. and Rojas, N. 2012. Instruments for increased use of biogas in the transport sector - A comparative analysis of measures for introduction of biogas as fuel. Baltic Biogas Bus project. Available at: www.balticbiogasbus.eu (Accessed on 10 May 2013).

Baumgartner, B., Kupusovic, M. and Blattner, H.T. 2010. National Report on current status of biogas/biomethane production – AUSTRIA. GasHighWay project (IEE/08/545/SI2.528537) Available at: http://upload.legambiente.org/ecosportello.org/documenti/07austria_national_report.pdf (Accessed on August 2013)

Baxter, D. 2011. JRC European Commission, September 2011.

Biogas barometer. 2005–2008. Published by The European Forum for Renewable Energies/EurObserv'ER. Downloadable from /http://www.eufores.orgS.

Bioprocess Control Sweden AB. 2011. Operational guidelines for Plönninge biogas plant. Available at: http://www.regionhalland.se/PageFiles/9634/Operational_guidelines_Pl%C3%B6nninge_biogasplant.pdf (Accessed on Sept 2012)

Börjesson, P. 2007. Bioenergi från jordbruket – en växande resurs. Lunds Tekniska Högskola. SOU 2007:36.

Concawe. 2006. Conservation of Clean Air and Water in Europe. Well-to-wheels analyses of future automotive fuels and powertrains in the European context. WELL-to-TANK report, version 2b. European Commission, Joint Research Centre. Available at: http://www.europabio.org/sites/default/files/report/well-to-wheels_analysis_of_future_automotive_fuels_and_powertrains_in_the_european_context.pdf (Accessed on May 2013).

DENA. 2010. Biogas partner – A joint initiative. Biogas grid injection in Germany and Europe – Markets, Technology and Players. German Energy Agency. Available at: http://www.stromeffizienz.de/page/fileadmin/biogas/Downloads/Broschueren/biogaspartner_-_a_joint_initiative_2010.pdf (Accessed on April 2012)

Dahlgren, S., Gunaratne, T. and Fredriksson, T. 2012. Policies and strategies for introducing biogasbuses in public transport. Baltic Biogas Bus project (www.balticbiogasbus.eu)

Ericsson, K. and Nilsson, L.J. 2006. Assessment of the potential biomass supply in Europe using a resource-focused approach. Biomass and Bioenergy 30 (1), 1– 15.

Eriksson, P and Olsson, M. 2003. The potential of biogas as vehicle fuel in Europe – A technological innovation systems analysis of the emerging bio-methane technology. Department of Energy and Environment, Division of Environmental System Analysis, Chalmers University of Technology, Göteborg, Sweden, Report No. 2007:6, ISSN: 1404-8167.[Online] Available at: http://publications.lib.chalmers.se/records/fulltext/43365.pdf (Accessed on Aug 2012).

EurObserv'er. 2012. Biogas barometer. December 2012. Available at: http://www.eurobserv-er.org/pdf/baro212biogas.pdf (Accessed on 27 April 2013).

Europe's Energy Portal. 2011. EU Energy trends to 2030. P.24. Available at: http://www.energy.eu/publications/Energy-trends_to_2030.php (Accessed on 29 May 2013).

European Commission. 2011. EU Energy in Figures 2010, CO2 Emissions by Sector. Available at: http://ec.europa.eu/energy/publications/doc/statistics/ext_co2_emissions_by_sector.pdf (Accessed on12 May 2013).

European Commission. 2012. Assesment of the implementation of a European alternative fuel strategy and possible supportive proposals. Project MOVE C1/497-1-2011. FINAL

Report of the European Commission in the framework of contract TREN/R1/350-2008 LOT3-COWI. Available at: http://ec.europa.eu/transport/themes/urban/studies/doc/2012-08-cts-implementation-study.pdf (Accessed on 16 April 2013).

European Environmental Agency. 2006. How much bioenergy can Europe produce without harming the environment?, EEA Report no. 7/2006, Copenhagen, Denmark

European Environmental Agency. 2007. Estimating the environmentally compatible bioenergy potential from agriculture, Technical Report no.12/2007, Copenhagen, Denmark.

European Environment Agency. 2010. Vehicle ownership and truck intensity in the EEA http://www.eea.europa.eu/data-and-maps/figures/vehicle-ownership-and-truck-intensity

European Environment Agency. 2011a. Total primary energy consumption by energy source in 2008, EU-27. Available at: http://www.eea.europa.eu/data-and-maps/figures/primary-energy-consumption-by-fuel-1 (Accessed 28 May 2013).

European Environment Agency. 2011b. Primary energy consumption in the EU-27, 1990-2008. Available at: http://www.eea.europa.eu/data-and-maps/figures/primary-energy-consumption-by-fuel-1 (Accessed 28 May 2013).

European Environmental Agency. 2012a. Transport final energy consumption by mode (TERM 001). Available at: http://www.eea.europa.eu/data-and-maps/indicators/transport-final-energy-consumption-by-mode/assessment-2 (Accessed 28 May 2013).

European Environmental Agency. 2012b. Energy efficiency and energy consumption in the transport sector (ENER 023). Available at: http://www.eea.europa.eu/data-and-maps/indicators/energy-efficiency-and-energy-consumption-4/assessment (Accessed 28 May 2013).

European Environmental Agency. 2013. Energy efficiency and specific CO2 emissions (TERM 027) - Assessment published Jan 2013). Available at: http://www.eea.europa.eu/data-and-maps/indicators/energy-efficiency-and-specific-co2-emissions/energy-efficiency-and-specific-co2-5 (Accessed 28 May 2013).

European Expert Group on Future Transport Fuels. 2011. Future transport fuels. Available at: http://ec.europa.eu/transport/themes/urban/cts/doc/2011-01-25-future-transport-fuels-report.pdf (Accessed 28 May 2013).

EU-Trends. 2003. European Energy and Transport Trends to 2030. European Commission, DG for Energy and Transport, 2003.

European Union Committee. 2008. 27th Report of Session 2007-08. The EU's target for Renewable Energy: 20% by 2020. Volume 1. (Authority of the House of Lords) London

ExonMobil. 2004. A report on Energy Trends, Greenhouse Gas Emissions and Alternative Energy. Available at: http://esd.lbl.gov/SECUREarth/presentations/Energy_Brochure.pdf (Accessed on 15 May 2013).

Gunaratne, T., Torres, E., Sun, T.T. and Yu, W. 2010. Biogas infrastructure in the Baltic Sea Region. Department of Industrial Ecology, Royal Institute of Technology, Stockholm. Available at: http://www.balticbiogasbus.eu/web/Upload/Distribution_of_biogas/Act_5_1/Annex/Biogas%20infrastructure%20in%20BSR.pdf (Accessed on 10 May 2013)

IANGV. 2011. International Association of Natural Gas Vehicles. Current Natural Gas Vehicle Statistics. Available at: www.iangv.org

IEA. 2007. World Energy Outlook, International Energy Agency. OECD, Cedex/Paris (2007).

IEA Bioenergy. 2013. Biogas upgrading plant list. Available at: http://www.iea-biogas.net/_content/plant-list/plant-list.html (Accessed 30 Aug 2013).

IEA Biogas net. 2012. Pioneering biogas farming in Central finland. farm sCale biogas Plant ProduCes vehicle fuel, heat, electricity and biofertilzer. Available at: http://www.iea-biogas.net/_download/success-story-kalmari2012.pdf (Accessed 28 May 2013).

International Association of Public Transport. 2011. Public transport alleviates congestion. [Online] Available at: http://www.uitp.org/advocacy/pdf/alleviates_congestion.pdf (Accessed on 05 May 2013)

IPCC. 2007. IPCC Fourth Assessment Report: Climate Change 2007, Climate Change 2007: Working Group I: The Physical Science Basis. Available at: http://ftp.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html (Accessed 15 May 2013).

Kaparaju, P.L.N. and Rintala, J.A. 2003. Effects of temperature on post-methanation of digested dairy cow manure in a farmscale biogas concept. Environ. Technol., 24, 1315-1321.

Kugel, G. 1983. Aufbereitung von Klaergas (Biogas) in Erdgasqualitaet beim Niersverband. Korrespondenz Anwasser, 6/83, 395-399.

Kugel, G., Lohmann, J. and Becker, G. 1991. Klaergasaufbereitung in Erdgas-L-Qualitaet – Erfahrungen auf dem Gruppenklaerwerk I, Moenchengladbach-Neuwerk seit 1982. Korresspondenz Abwasser, 8/91, 1079-1084.

NGVA Europe. 2013. Natural Gas Vehicles in Europe. NGV Market Growth in Europe (1995-2010) Available at: http://www.ngvaeurope.eu/ngv-market-growth-in-europe-1995-2010 (Accessed on 02 May 2013).

NGVA Europe Statistics. 2012. European Natural Gas Vehicle Statistics. Available at: http://www.ngvaeurope.eu/european-ngv-statistics (Accessed on 17 May 2013).

Schulz, W. 2004. Untersuchung zur Aufbereitung von Biogas zur Erweiterung der Nutzungsmöglichkeiten. Available at: http://www.energiekonsens.de/cms/upload/Downloads/Projekte/Biogasstudie-2004.pdf (Accessed on 03 May 2013).

Science Daily. 2011. Climate Change: Halving Carbon Dioxide Emissions By 2050 Could Stabilize Global Warming. Available at: http://www.sciencedaily.com/releases/2009/05/090502092019.htm (Accessed 12 October 2012).

SGA. 2011. Biogas in Sweden. Swedish Gas Association. Available at: http://www. Biogasportalen.se (Accessed 08 April 2013).

Strömberg, J. 2010. Towards sustainable traveling Stockholm’s public transport. Stockholm Public Transport Authority, Stockholm. Available at: http://www.nymtc.org/download_file.cfm?filename=Jonas_Stromberg_NY_jan_07.pdf. (Accessed 18 April 2013).

Svensson, M. 2012. Biogas's development journey in Sweden and lessons to be learnt. Presentation at “Biogas Asia Pacific Forum 2012”, Bangkok 19th of July 2012

Svensson, M. 2013. Biomethane for transport applications. In: The biogas handbook: Science, production and application. Wellinger A., Murphy, J. and Baxter, D. (eds.). IEA Bioenergy. Woodhead Publishing ltd, UK. pp. 428-443.

Svensson. O. and Orwén. R. 2011. Åtgärd 1 biogas blir fordonsgas vid Plönninge biogasanläggning. Samverkan för en bättre miljö - Utvärdering av Halmstads kommuns Klimatinvesteringsprogram (KLIMP) 2007- 2011.

Stamatakos, E. 2012. Exploring biogas, an untapped source of clean renewable energy. Available at: http://www.eponline.com/articles/2012/01/12/exploring-biogas-an-untapped-source-of-clean-renewable-energy.aspx?admgarea=Features (Accessed on 16 May 2013).

Urban, W. 2013. Biomethane injection into natural gas networks. In: The biogas handbook: Science, production and application. Wellinger A., Murphy, J. and Baxter, D. (eds.). IEA Bioenergy. Woodhead Publishing ltd, UK. pp. 378-403.

VALORGAS. 2011. D5.1 - Evaluation of potential technologies and operational scales reflecting market needs for low-cost gas upgrading systems. http://www.valorgas.soton.ac.uk/deliverables.htm (Accessed August 2013).

VALORGAS. 2012. D5.3 Case and feasibility studies of small-scale upgrading in Europe and India. http://www.valorgas.soton.ac.uk/deliverables.htm (Accessed August 2013).

Part C: Joint conclusion Part A and B

Greenhouse gases emission reduction and environmentally friendly waste disposal are important global issues for climate change mitigation. The transport sector is one of the major sources of GHG emissions. Biomethane (upgraded biogas) can be used in place of fossil fuels in the transport sector and thus can reduce GHG emissions. Biomethane is an environmentally friendly fuel, and efforts are being made to harness biomethane from the biodegradable wastes. Technologies are being developed to convert biogas to biomethane and utilise it for vehicular applications. This has been established in Sweden in some cities where biomethane is injected in the natural gas grid and vehicles are running on it. In past few years in India, small-scale biogas upgrading and bottling technology has been developed and demonstrated in some places. Some demonstration vehicles e.g. a three wheeler in a cattle farm and a car in Indian Institute of Technology Delhi have been operating on upgraded biogas. The Bureau of Indian Standards (2013) has recently produced biomethane standards to be used for vehicular and other applications.

Decentralised biogas upgrading and bottling systems can be set up in rural areas where large quantities of organic resources are available for biogas production. In a cluster of villages a biogas upgrading unit can be set up and it is possible to run local vehicles on biomethane by compressing it to 200 bar in the readily available CNG cylinders. CNG infrastructure is presently available in major cities inIndia; hence decentralised biogas upgrading and bottling units can easily penetrate into the rural areas in India. The rising cost of petroleum products and the fact that more than 80% of these are imported in India, indicates the potential for utilising locally available organic wastes for biogas production and upgrading for the transport sector. This seems to be a viable option for reducing fossil fuel imports and contributing towards mitigation of climate change. In addition, utilisation of organic waste for biogas production provides quality manure which is used for organic agricultural production.

In Europe, there is a large natural gas market which can be utilised by biomethane. At present, upgraded biomethane from large-scale biogas plants is generally injected into the natural gas grid: this is practiced in many parts of Europe including Germany, Sweden, Switzerland etc. There are around 150 biogas upgrading and bottling plants which are producing biomethane and utilising it as a vehicle fuel. Hence, there is a large scope for further development of small-scale biogas upgrading for local transport use. As the use of bottled gas is less widespread in Europe, small-scale upgrading and distribution systems of the type developed by Metener are the most promising solution in this case.

It can therefore be concluded that there is an urgent need to provide financial support, tax incentives and other benefits to this technology by the government and there should be cooperation to raise awareness among various stakeholders of small-scale biogas upgrading and bottling systems to make these commercially viable in India and European Union.