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# D5.2: Evaluation of Existing Low Cost Gas Bottling Systems for Vehicles Use Adaption in Developing Economies

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Lead contractor: Foundation for Innovation and Technology Transfer (IIT)

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**D5.2: Evaluation of Existing Low Cost Gas Bottling Systems for Vehicles Use Adaption in Developing Economies**

# 1 Introduction

Biogas is an energy source which is produced from biodegradable/organic wastes, and hence contributes simultaneously to waste management and to building a sustainable environment. Wastes of variable qualities and quantities, such as animal dung, agricultural wastes and food and municipal solid waste, are available in rural and urban areas. This waste can be utilised for both centralised large-scale and decentralised small-scale biogas production. Decentralised production is a feasible low-cost option in developing nations as biogas can be produced at the same site as locally available wastes. The raw biogas can be upgraded using simple technologies and can be bottled, thus facilitating its use in applications such as domestic and commercial cooking, power generation via engines and as vehicle fuel. Low cost small-scale biogas upgrading and bottling technology is thus a step towards achieving financial stability for the common man. This report focuses on the feasibility of bottling upgraded biogas, and on systems that are economically viable and easy to install and handle, for decentralised biogas production in developing economies.

The aim of this report is to provide a broad and systematic evaluation of the present technologies available for bottling, and an assessment of the current status and potential issues for the use of bottled upgraded biogas as a fuel for vehicles in the developing economies.

# 2 Potential for small-scale biogas upgrading, bottling and distribution

## 2.1 Biogas production and potential in developing economies

Biogas produced from anaerobic digestion is a green and cost-effective replacement of wastes. Anaerobic digestion has the potential to meet energy requirements in rural areas, and also counter the effects of reckless burning of biomass resources. An additional benefit is that the quantity of digested slurry is approximately the same as that of the feedstock in a biogas plant. This slurry can be dried and sold as high quality compost. This means increased income for the farmers. Small-scale digestion plants primarily using animal wastes have seen widespread use throughout the world, with many plants in developing countries. These plants are generally used to provide gas for cooking and lighting for a single household. The present status of biogas plants installed in some of the developing countries is summarised in Table 1.

Several countries in Asia have embarked on large-scale programmes for domestic biogas production. These include China (about 40 million household digesters by 2010), India (about 4.5 million units by March 2010), Nepal (more than 225,000 plants by end of 2010) and Vietnam in fourth place with more than 150,000 systems (Renewables, 2010). Sri Lanka is lagging relatively behind with not more than 6,000 biogas units installed. In Bangladesh, up to 2009 the total number of installed biogas plants was 34,484 (Sri Lanka Domestic Biogas Programme, 2011). In comparison, there are only about 75 family-size biogas plants in Afghanistan (AEIC, 2010). In India, Pakistan and Bangladesh biogas produced from the anaerobic digestion of manure in small-scale digestion facilities is called gobar gas.

**Table 1.** Domestic size biogas plants installed in developing economies

| No. | Country | Biogas Plants Installed to 2010 |
|---|---|---|
| 1. | China | 40 million |
| 2. | India | 4.5 million |
| 3. | Nepal | 225,000 |
| 4. | Vietnam | 150,000 |
| 5. | Afghanistan | 75 |
| 6. | Sri Lanka | 6,000 |
| 7. | Bangladesh | 34,484 |
| 8. | Pakistan | 4000 |
| 9. | South Korea | 49 |
| 10. | Malaysia | 24 |

*Sources: Based on various sources as mentioned in text and references*

*Malaysia.* In Malaysia the major substrate for biogas production is Palm oil mills residue. There were only 24 biogas plants operating in Malaysia which represented 5.8 per cent of the total palm oil mills in the country till 2010. The technology for biogas production in the country is progressing slowly (Good Returns, 2010).

*South Korea.* The potential for biogas production derived from highly concentrated organic waste, mainly from food waste, livestock manure, and sewage sludge, is about 96000 tonnes of oil equivalent in South Korea. To date, there are about 49 biogas plants in South Korea that are generally recognized as economically and technically unsuccessful due to lack of knowhow, deficient technologies and policies (Young et al., 2012.)

*Pakistan.* According to a recent livestock census, Pakistan has almost 159 million animals which can produce approximately 652 million kg of waste per day from cattle and buffalo only. This has the potential to generate 16.3 million $Nm^3$ day-1 of biogas and 21 million tonnes of bio-fertiliser per year (Adnan, 2011, Amjid 2011). Apart from the Pakistan Government, a number of NGOs have installed 4000 bio-gas plants for domestic use in the rural areas of Pakistan against the technical potential of about five millions digesters based on availability of feed stock for demonstration purpose on cost sharing basis (Pakistan Today, March 2012).

*India.* An estimate indicates that India has the potential of generating $6.38 \times 10^{10}$ $Nm^3$ of biogas from 980 million tonnes of cattle dung produced annually (Vijay et al, 2006). If organic wastes such as sewage, MSW, industrial effluent, and distillery wastes are also taken as feedstock for biogas production, the total biogas potential would increase further. There are around 300 distilleries throughout India which collectively have a potential of producing 1200 million $Nm^3$ biogas, and 2000 tannery units capable of producing 787,500 $Nm^3$ of biogas (MNRE, 2001). The increasing number of poultry farms can also add to biogas productivity as with a current population of 649 million birds, another 2173 million $Nm^3$ of biogas can be generated (Mittal, 1996).

## Africa

Large volumes of suitable waste are available in Africa, but biogas production is still far less developed than in Asia. Of the 54 recognised African states, 23 have biogas plants, but these are primarily small to medium-sized domestic digesters (Parawira, 2009). The leader in small-scale biogas development is Tanzania, with over 1000 digester installations up to 2009 (Parawira, 2009); the country is currently in the middle of a development program aiming for installation of a further 12,000 digesters by the end of 2013. The Africa Biogas Partnership Program (ABPP) has focused on the establishment of biogas plants in six countries - Burkina Faso, Ethiopia, Kenya, Senegal, Tanzania and Uganda - with a goal of 70,000 biogas installations to the end of 2013 (Tanzania Domestic Biogas Program, 2012).

**Latin America**

In Latin America, biogas technology is emerging to provide small bio-digesters to rural residents, through efforts such as the Network for Biodigesters in Latin America and the Caribbean (RedBioLAC) which has member organisations in Bolivia, Costa Rica, Ecuador, Mexico, Nicaragua and Peru, with installations ranging from 20 systems to over 2000 installed (Garwood, 2010). Bolivia is the leader in domestic biogas plants with over 1000 small biogas digesters installed (Kranert et al., n.d.).

Large-scale biogas plants exist for effluents from palm oil mills and large agricultural operations in Colombia, Honduras and Argentina (Biotec, 2012). Despite the fact that Brazil has an extensive bioethanol program, it has only a few bio-digestion plants (Salomon and Silva Lora, 2009).

As can be seen from Table 1, biogas is becoming an increasingly important source of energy in developing countries. It is an important fuel source in rural areas because it is generated from *readily-available* biomass like animal dung and agricultural waste. At the rural level the potential is tapped by the installation of small-scale domestic biogas plants, in the capacity range of 1-20 $Nm^3$ $day^{-1}$. These plants are fed with locally-available waste and produce biogas for use as a cooking fuel or as a fuel in biogas engines to generate electricity. Because of the small quantities produced, upgrading and bottling of biogas from domestic-size biogas plants is neither energy-efficient nor economically feasible. There is, however, a huge potential for the installation of small to medium-size biogas plants in the developing countries: raw biogas produced from dairy farms, animal rearing farms, fruit and vegetable market wastes, restaurant and kitchen wastes etc can be upgraded and bottled for applications such as cooking, power and transport.

Hence, there is an urgent need to increase the applicability of this green fuel other than cooking and power by bottling of the upgraded biogas. For biogas producers, this multiplication of the possible number of consumers is attractive.

## 2.2 Need for and methods of biogas upgrading

Raw biogas produced from anaerobic digestion is often around 60% methane and 29% $CO_2$, with trace components of $H_2S$ and moisture. It is therefore not ideal for use as a vehicle fuel apart from local on-site use (e.g. farm tractors), and not suitable for grid injection. The traces of $H_2S$ produce $H_2SO_4$ which corrodes the inside of pipes, fittings etc. The solution is the use of a biogas upgrading or purification process whereby other constituents in the raw biogas stream are absorbed or scrubbed off, leaving over 90% methane per unit volume of gas.

Several techniques for biogas upgrading exist and are continuously being improved, while new techniques are under development. These improvements in new and traditional techniques can reduce investment and operational costs. For biogas upgrading, technologies such as water scrubbing, pressure swing absorption (PSA), chemical and physical absorption and cryogenic processing are commercially available and many others are in the pilot phase study level. The most widely used technologies for biogas upgrading are water scrubbing, PSA, organic physical and chemical scrubbing. Out of these technologies, water scrubbing and PSA are considered to be most appropriate at a small scale due to their low cost and easy maintenance (Kapdi et al., 2005). Biogas upgrading technologies are discussed in detail in VALORGAS deliverable D 5.1.

Existing biogas upgrading systems are suitable and optimised for large-scale operations and hence demand high capital investment. In most cases, with increasing gas prices and current systems of grants/subsidies, upgrading systems above 50 $Nm^3$ $hour^{-1}$ can be economically viable: Appendix A contains an example of an energy analysis and economic assessment for a 200 $m^3$ $day^{-1}$ biogas plant with a 20 $m^3$ $hour^{-1}$ upgrading plant in India.

In developing countries at present farm-scale digesters, small-scale cattle sheds, kitchen waste plants and wastewater treatment plants are using their wastes to generate biogas as a fuel to produce heat or electricity to meet their own energy demands, or for selling and injecting into the power grid if production exceeds the demand. Many of these are motivated towards upgrading and bottling of the raw biogas and using it in a decentralised way.

## 2.3 Versatility of biogas use

Biogas can be divided into two grades: raw biogas ($CH_4$ 55-65 % and $CO_2$ 35-45 %) and upgraded ($CH_4$ > 90 % and < 10 % other gases). Both forms of biogas are utilised in different ways, as shown in Figure 1. Raw biogas is a low-grade fuel as it has a lower percentage of methane and hence it is the cheapest fuel for rural people. 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 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 by pipelines. Hence raw biogas being economical and easily available can fulfil the basic cooking and electricity needs of rural people.

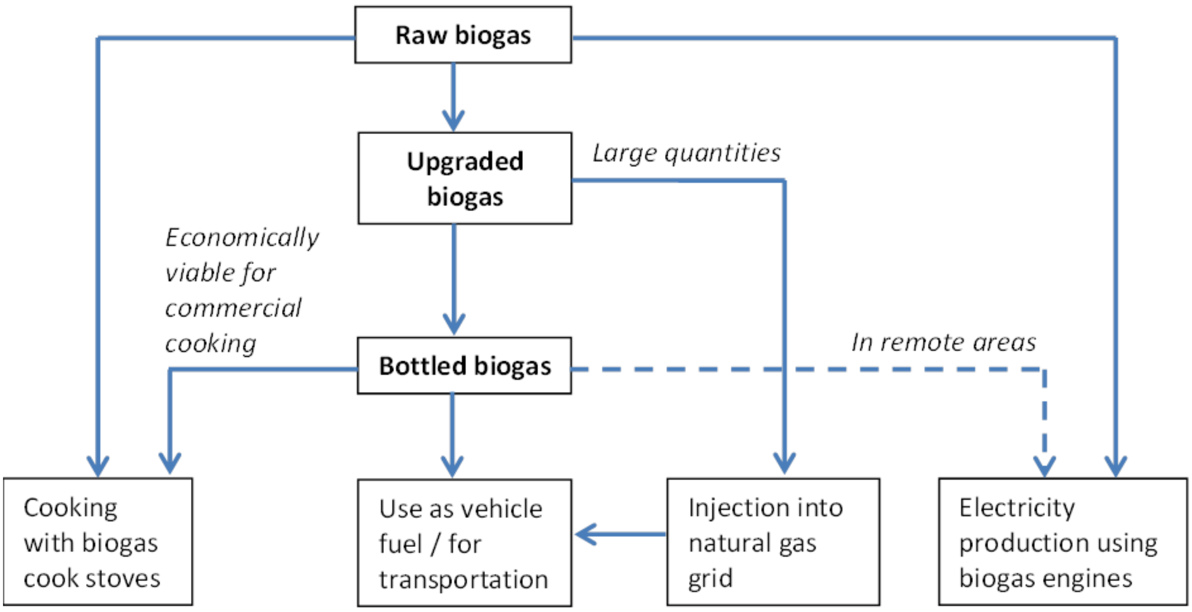



**Figure 1.** Different uses of biogas (*Source: Authors*)

Upgrading biogas widens the scope of its utilisation. When produced in centralised plants in large quantities, upgraded biogas can be injected directly into the natural gas grid and then dispensed into vehicles as a transport fuel. In developing countries, biogas is produced mainly in small to medium-size decentralised biogas plants, hence upgrading and then injection into the grid is not possible due to limitations in quantity and quality and cost constraints. For the purposes of feeding-in, however, the gas must meet the quality specifications of the relevant legal provisions and may only deviate within the range of these quality standards.

Natural gas pipeline networks are available in many areas of the world, and provide an unlimited storage and distribution option for upgraded biogas (Krich et al., 2005). The biggest challenge to use of these systems for upgraded biogas injection is that they are typically owned by government or private organisations. The upgraded biogas producer must negotiate an agreement or contract with the pipeline owner (e.g. the local gas utility). For such an agreement it is essential that the upgraded biogas meets natural gas pipeline quality standards (e.g. gas composition, properties etc). Hence after injection into the natural gas pipeline network the upgraded biogas can be used as a direct substitute for natural gas by any user application which is connected to the gas grid: for example vehicles, domestic gas appliances, commercial/industrial equipment, and compressed natural gas (CNG) refuelling stations (Krich et al., 2005). In practice, however, there may be significant resistance from the pipeline owners and utilities towards attempts to distribute upgraded biogas via the natural gas network. One reason for this is concern for the poor quality of the gas which may have potentially serious effects on gas utilisation equipment. Hence, there are strict requirements for gas quality monitoring of the upgraded biogas supply from the natural gas pipeline network, which in turn may lead to high costs for upgraded biogas producers. Therefore, distribution of upgraded biogas through dedicated pipelines or the natural gas grid is often impractical or prohibitively expensive and road transportation of compressed upgraded biogas may be a more reliable distribution option (Krich et al., 2005).

Another option for utilising upgraded biogas is to compress and bottle it to facilitate easy storage and transport of the high-grade fuel. From the upgrading site bottled biogas is transported using a cascade of cylinders and can suit user applications in the following ways:

- As a vehicle fuel bottled biogas can be dispensed into vehicles using simple dispensing/filling stations instead of highly sophisticated infrastructure required for large-scale biogas / natural gas from the gas grid. When dispensed using simple dispensing / filling systems, bottled biogas is quite economical when used as a vehicle fuel (Appendix A).

- As a cooking fuel, raw biogas is cost effective for cooking but bottled biogas (Figure 2) can be used instead of LPG cylinders: as shown in Appendix A, bottled biogas can be economical for commercial cooking rather than domestic cooking. Bottled biogas also becomes a feasible option for cooking in remote areas where pipeline distribution of cooking gas (LPG) and raw biogas is not possible.

**Figure 2.** Bottled biogas used as a cooking fuel
(*Source: http://biogasapplication.blogspot.in/2010/03/new-perspective-in-biogas-technology.html*)

- 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 as shown in Figure 3 and can facilitate electricity production. The economics of electricity production from bottled biogas is unsatisfactory and very costly but it can be harnessed as a high grade fuel in remote areas.

a) Trailer for transportation of cascade of cylinders
*(Source: http://trade.indiamart.com/details.mp?offer=1642656088)*

b) Cascade of cylinders for storage and transportation of compressed gas
*(Source: http://maxengg.tradeindia.com/cng-storage-cylinders-70720.html)*

**Figure 3. C**ylinders for storage and transportation of compressed upgraded biogas

The market applications for biogas are summarised in Table 2.

**Table 2.** Versatility of biogas use

| Raw Biogas | Upgraded Biogas |
|---|---|
| • Cooking | • Injection into natural gas grid *(if large quantities of upgraded gas* Vehicle Fuel *are available*)<br>• Bottled upgraded biogas |
| • Electricity | • Cooking fuel – Economical for commercial cooking<br>• In remote areas bottled gas can be transported<br>• For electricity production from biogas engine bottled gas can be transported |

## 2.4 Viable options for low cost small-scale upgraded biogas storage, bottling and distribution in developing economies

There is a problem of availability of a natural gas grid in most parts of the developing countries but the potential for growth of the *natural gas* market is increasing tremendously, especially since a large number of cities in developing countries such as India are embarking on natural gas vehicle programmes (Roychowdhury, 2010). In this context, bottling of upgraded biogas assumes importance and appropriate technologies and systems need to be developed. On the basis of production capacity, biogas generation can be classified in three levels: domestic, community (village), and industrial.

The range of application of biogas technology in the developing world is limited for uses such as cooking fuel and heating homes. In developing countries, the main use of biogas has been domestic with some community-level applications. The Renewables 2010 Global Status Report (Renewables, 2010) states that more than 30 million households get cooking, heating, and lighting from family-scale digesters, as their main occupation is agriculture and animal rearing.

As noted above, small-scale domestic-size biogas production plants and biogas upgrading and bottling technologies catering to the transport needs of individual families do not satisfy realistic economic criteria and are thus not a feasible option. Therefore, currently, there exists no corporate market for this small-scale approach to biogas generation, as it is not as lucrative as larger-scale approaches or other forms of fuel (Baron et al., 2008).

Possible options for the adoption of bottled biogas are:

- Medium size biogas plants could be installed in dairies, cattle sheds, poultry farms, piggery farms and animal rearing farms. In addition to this, fruit and vegetable market waste, water-borne biomass such as water hyacinth, algae and a variety of such agro-wastes can be used to generate biogas. On-site low cost small-scale bottling plants can meet the needs of transportation fuel of the biogas plant owners. Appendix C can be referred for an example of biogas production and bottling from a medium size biogas plant and its use as a vehicle fuel.
- Biogas can be produced from community-sized biogas plants intended to recycle biodegradable Municipal Solid Waste (MSW), sewage wastewater, farmyard manure, food waste etc. and centralised human habitations such as hostels, restaurants, military barracks, and hotels (see also VALORGAS deliverable D2.5).
- Large capacity biogas plants could be used for distilleries, STP, 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. The viability of biogas plants at different levels of production is shown in Table 3.

**Table 3.** Viability of 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 |
|---|---|---|
| Domestic small-size | 1-20 $Nm^3$ $day^{-1}$ for domestic purposes (family sized) | • Upgrading and bottling of small-scale biogas produced from domestic size biogas plants is neither energy-efficient nor economically viable. |
| Medium size | 85 - 500 $Nm^3$ $day^{-1}$ 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.<br>• Collection and transportation in pressurised tankers to centralised upgrading and bottling station.<br>• Distribution of bottled gas to far off places or filling stations for vehicle fuel applications. |
| Large-size | Above 600 $Nm^3$ $day^{-1}$ for commercial purpose | • On-site upgrading and bottling becomes economically viable.<br>• 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. |

## 2.5 Status of the biogas sector in developed and developing countries

The biogas sector has grown rapidly in the past few years in most parts of the world, particularly in Europe and in some Asian countries. In those countries biogas production is usually at a centralised level from landfills, wastewater treatment plants or large dairies (Jönsson and Persson, 2003) as shown in Figure 4. Since the production of biogas is usually large-scale (hundreds to thousands of $Nm^3$ $day^{-1}$), upgrading becomes economical. Due to this, natural gas grid injection of upgraded biogas is practised in most of these countries. Major developments have taken place in many European countries, particularly pertaining to the utilisation of upgraded biogas in transportation sector: for example buses and cars are run on upgraded biogas from the grid, and in Sweden a train is being powered by biogas (IEA Task 37, N.D), as shown in Figure 5. Because of the development of feed-in tariffs in many countries biogas is also used for electricity production at large scale and injected into the power grid (Sakulin, 2010) At present around 11 countries in Europe, including Sweden, Switzerland, Italy, and Germany, are producing upgraded biogas and around 9 including the UK have established upgraded biogas standards for grid injection (Wellinger, 2012). The major portion of the upgraded biogas is injected into the grid and the rest is flared. For dispensing biogas from the grid highly sophisticated infrastructure like pipelines, high pressure compressors and filling stations is available. For transportation of upgraded biogas large-scale tankers are available for storing and transporting it to filling stations (Jönsson and Persson, 2003) as shown in Figure 6a and b and Figure 7.


**Figure 4.** Large-scale biogas production (Jönsson and Persson, 2003).


**Figure 5.** Biogas-powered bus and train in Sweden *(Source: IEA Bioenergy Task 37, http://www.iea-biogas.net/_download/linkoping_final.pdf)*


a) Upgraded biogas storage tanker    b): Upgraded biogas dispensing station

**Figure 6.** Upgraded biogas storage and distribution in (*Source: Jönssonand Persson, 2003*).

**Figure 7.** Biogas Motorcycle (*Source: http://www.inforse.org/europe/dieret/altfuels/biogas.htm*)

This situation is in complete contrast to the developing countries, where there is a huge potential for biogas but the scale of production is small as compared to the developed nations. Biogas production is mostly decentralised and mainly in domestic (small)/ institutional or community biogas plants. At present, in most developing countries research is being carried out on the potential for bottled biogas. Five demonstration biogas bottling plants are operating in India and 21 commercial plants will be installed in the near future (MNRE, 2011). Policies pertaining to biogas bottling have been formulated and will be published by the Bureau of Indian Standards in the next six months. To date no policies or standards have been formulated in most of the developed countries, and this may be one reason why bottling of biogas and it use in transport is not being more widely adopted.

In developing counties, the highest percentage of the total biogas production comes from the many small-scale digesters with capacities up to 1-20 $Nm^3$ $hour^{-1}$. For these plants it is not feasible to upgrade the gas to natural gas quality and inject this in the natural gas grid or use it as commercial fuel at a gas station. Other conditions may apply when the gas is not used commercially but only locally within a small community or farm. Commercial proliferation of medium to large-size biogas plants is the need of the hour to make upgrading and bottling of biogas economically viable. The cost for quantity and quality control together with high performance, security and gas transport/injection makes it too expensive for small-scale applications.

## 3 Status of biogas upgrading and bottling for vehicle use

### 3.1 Europe

Biogas upgrading and bottling for use as a vehicle fuel is being practiced in most parts of Europe with Sweden having the largest number of upgrading plants. Currently, there are 23 small-scale (<50 $Nm^3/h$ raw gas capacity) biogas upgrading plants in Europe. Of these, about 11 are involved in upgrading biogas to vehicle quality (97 % methane) (Petersson et al., 2009). Details of these plants are summarised in Table 4.

**Table 4.** Small-scale biogas upgrading and bottling for vehicular use in Europe

| Place | Substrate | Utilisation | $CH_4$ content (%) | Technology | Capacity ($Nm^3$ $hour^{-1}$ Raw Gas) | In Operation Since |
|---|---|---|---|---|---|---|
| Kalmari farm, Laukaa, Finland | Energy crops, manure | Vehicle fuel | 96 | Water Scrubbing (WS) | 6 | NA |
| Margarethen am Moos, Austria | Energy crops and manure | Vehicle fuel | >95 | Membrane | 70 | 2007 |
| Ulricehamn, Sweden | Sewage sludge | Vehicle fuel | 97 | PSA | 20 | 2003 |
| Lilla Edet, Sweden | - | - | 97 | PSA | 25 | 2005 |
| Rümlang, Switzerland | Biowaste | Vehicle fuel | 96 | PSA | 30 | 1995 |
| Biorega Otelfingen, Switzerland | Biowaste | Vehicle gas | 96 | PSA | 50 | 1998 |
| Zalaegerszeg, Hungary | Sewage sludge | Gas grid, Vehicle fuel | 97 | WS | 50 | NA |
| Eslov, Sweden | Biowaste, sewage sludge | Vehicle fuel | 97 | WS | 80 | 1999 |
| Katerineholm, Sweden | Sewage sludge | Vehicle fuel | 97 | WS | 80 | 2009 |
| Motala, Sweden | Sewage sludge | Vehicle fuel | 97 | WS | 80 | 2009 |

Based on: IEA Task 37 (2011)

## 3.2 Asia and developing countries

In most developing countries, biogas production is common but upgrading is less popular. In countries like India and China biogas upgrading and bottling technology has been implemented to demonstrate the use of biogas as a vehicle fuel. Use of biogas for vehicular applications is increasing in a number of European countries, and some developing economies are moving in this direction.

### Asia

*China.* In China, gas-driven vehicles are based on the application and development of natural gas but not much attention is being paid to biogas vehicles. Across the whole country, there are few upgrading plants designed for biogas utilisation as a vehicle fuel. The exceptions of biogas bottling and it use as a vehicle fuel are in Liao Ning and Guangxi provinces where there are some demonstration projects (Wang et al., 2006)**.**

*India.* In India four pilot-scale biogas upgrading and bottling projects have been installed since 2006 where the bottled biogas is used as a vehicle fuel for captive use (MNRE, 2010b). Details of these are given in Table 5. Under the demonstration stage, the Ministry is providing central financial assistance (CFA) for implementation of projects on entrepreneurial mode. So far 21 biogas bottling projects with an aggregate capacity of 37, 016 cu m/day have been sanctioned in ten states in India which are Chhattisgarh, Gujarat, Haryana, Karnataka, Maharashtra, Punjab, Madhya Pradesh, Andhra Pradesh, Uttar Pradesh and Rajasthan (Bamboriya, 2012.)

**Table 5.** Biogas bottling in India at demonstration level

| No. | Place | Substrate | Utilisation | Raw Biogas Composition | Purified Biogas Composition | Technology | Plant Capacity ($Nm^3$ $hour^{-1}$ raw gas) | In Operation Since |
|---|---|---|---|---|---|---|---|---|
| 1 | Rajasthan Go Seva Sangh Plant, Jaipur | Cow dung | Vehicle fuel and electricity production for medicine making and lighting | 55-60% $CH_4$, 35-40% $CO_2$ | 95% $CH_4$, 3-4% $CO_2$, $H_2S$ below detectable level, 1-2% other gases. | Water scrubbing | 20 | 2006 |
| 2 | MGVAS Bhilwara Plant | Cow dung | Transport fuel in CNG vehicle electricity generation, battery charging for inverter operation | 55% $CH_4$, 32% $CO_2$ | 95% $CH_4$, 3-4% $CO_2$, $H_2S$ below detectable level, 1-2% other gases. | Water Scrubbing | 20 | 2008 |
| 3 | Nasik, Maharashtra | Cow dung, agricultural waste etc | Power generation, cooking and industrial application | 55% $CH_4$, 32% $CO_2$ | 98% $CH_4$, 1-2% $CO_2$, $H_2S$ below detectable level, 1-2% other gases. | Water Scrubbing and Pressure Swing Adsorption | Water Scrubbing Capacity: 20 Pressure Swing Adsorption (PSA) Capacity: 50 | 2011 |
| 4 | Abohar, Mukatsar, Punjab | Cow dung, agricultural waste etc | Heating/cooking demand of the hotel industry nearby | 55% $CH_4$, 32% $CO_2$ | 95% $CH_4$ 3-4% $CO_2$, $H_2S$ below detectable level, 1-2% other gases. | Water Scrubbing | 25 | 2010 |

*Pakistan.* In Pakistan, nearly 70 % of the rural population of Pakistan can potentially benefit from biogas energy as these plants are low in cost and can be run with a small budget. The research carried out by the University of Agriculture, Faisalabad indicates that demand for small biogas power generation units is increasing steadily as a decentralised source of energy can ensure uninterrupted power supply to villages(Renewable energy Magazine, 2011). Many agencies such as the Pakistan Dairy Development Company (PDDC), Pakistan Council for Renewable Energy Technologies (PCRET) and Rural Support Programs Network (RSPN) are working to disseminate this renewable energy technology, but a national biogas policy is needed to make this technology accessible and boost uptake rates. The study also suggests that installation of biogas bottling plants represents an added opportunity. To date in Pakistan, there are no demonstration projects on biogas use in vehicles (Farming and Agriculture, 2011).

*Bangladesh.* In Bangladesh, the University of Bangladesh has conducted research on the prospects of biogas cylindering/bottling and financial analyses of biogas bottling business. To date there are no demonstration plants for biogas bottling in Bangladesh but the economic assessment study conducted by the university states that upgraded biogas bottling and its use as CNG in Bangladesh will give a high profit to the entrepreneur (Ahmed, 2010).

*Thailand.* In Thailand, extensive research is being carried out in the field of biogas bottling and its use as a vehicle fuel. To date, however, no demonstration plants have been set up to show the application of upgraded biogas bottling. A study was conducted on the use of bottled biogas in a Liquefied Petroleum Gas (LPG) cylinder to run a motorcycle. It was found that using upgraded biogas can save energy cost € 0.08/km more than that of gasoline. The study showed that if the motorcycle is run about 50 km/day and the cost for motorcycle modification with biogas engine kit is € 540, the payback period will be 2.5 years (Singbua and Suntivarakorn, 2011). The Office of Energy Policy and Planning Department has also signed an agreement to improve the quality of research on upgraded biogas to be bottled and used as a vehicle fuel. The IEA bioenergy newsletter of March 2012 states that majority of state-owned oil and gas firm PTT Plc is due to invest €7.5 million on the development of vehicles powered by biogas in Thailand. Agricultural waste will be converted into methane and used as an alternative to fossil fuels in vehicles. The upgraded biogas will be used for vehicles in rural areas that are located too far from NGV refuelling stations. Two methane gas production units are installed on pig farms in Chiang Mai, Thailand (IEA Task 37, 2012; NGV Global, 2012).

*Malaysia.* Palm Oil is one of the major industries in Malaysia. At present wastes from the palm oil industry in Malaysia releases 1.5 billion $m^3$ of methane into the atmosphere annually. Research has suggested that if biogas produced from palm oil wastes is upgraded and distributed by using appropriate technologies, then this natural gas equivalent upgraded methane is enough to run about 15% of vehicles on the Malaysian roads (Biogas Energy Solutions, 2012). Research is being carried out on application of biogas in place of natural gas in vehicles but to date there are no demonstration plants for upgraded biogas use in vehicles (NBI, 2010).

*Indonesia.* In Indonesia, a search of websites found no references to bottling of biogas or biomethane, but biogas storage and biogas bottling are considered to be an important research area for development. In 2005, the Indonesian Centre for Agricultural Engineering Research and Development (ICAERD) installed a digester with a biogas production of 6 $Nm^3$ $day^{-1}$ intended for small-scale farming (Widodo et al., 2005). In 2006 further research and development was conducted on biogas upgrading and bottling at laboratory scale. Biogas bottling was conducted in a 70-litre tank but the pressure was limited to 0.087 bar only (Widodo et al, 2006) (Figure 8).


**Figure 8**: Biogas reactor and bottling research in Indonesia (*Source: Widodo et al, 2006)*

*Sri Lanka.* The importance of biogas is well understood in Sri Lanka and extensive research is being carried out on the implementation of biogas technology as an alternative to transport fuel. The University of Moratuwa has conducted pilot-scale demonstration studies on the use of biogas as a transport fuel in an auto rickshaw by bottling it in LPG cylinders (Alwis, 2012) as shown in Figure 9. Apart from this, several important developments in terms of policies, regulations and standards have been realised by the Government of Sri Lanka by studying the policies/standards and technologies in different developed and developing countries for example India and Europe for effective implementation in Sri Lanka (Alwis, 2012).

a) Pilot scale biogas plant

b) Biogas bottling in LPG cylinder

c) Biogas feeding to three wheeler

d) First ignition

**Figure 9.** Pilot scale demonstration of biogas as a transport fuel at University of Moratuwa *(Source: Alwis, 2012)*

e) First run

**Figure 9 continued.** Pilot scale demonstration of biogas as a transport fuel at University of Moratuwa *(Source: Alwis, 2012)*

*Japan.* Japan has two biogas upgrading plants in town of Tarumi in Kobe City operating since 2004 and 2007 which upgrades biogas for vehicle fuel utilisation (IEA Task 37, 2011). Another plant is located in the city of Hitachi, Ibaraki Prefecture which was scheduled for delivery in November 2010, with installation early 2011 in Japan for the production of upgraded biogas for vehicular fuel application (Flotech News, 2010). Japanese toilet manufacturer Toto has created its own 'green driving machines' as shown in Figure 10. It is a toilet combined with a three-wheel motorcycle. The Toilet Bike Neo runs on biogas (Buffetoblog, 2011). It uses biogas not made from human waste, but from livestock waste and household wastewater provided by Shika-oi Town in Hokkaido and Kobe city. The upgraded and compressed biogas run motorcycle recently completed a journey of more than 1,000 km (600 miles) across Japan (Tempo, 2011).


a) ToTo Biogas Motorcycle in Japan
(*Source:http://www.wired.co.uk/news/archive/2011-10/03/toto-poo-powered-motorcycle/viewgallery#!image-number=1*)

b) Biogas motorcycle in Japan
(*Source: http://buffetoblog.wordpress.com/2011/11/09/a-motorcycle-fueled-by-poop/*)

**Figure 10.** Biogas motorcycles in Japan

*Taiwan.* Biogas technology in Taiwan is not new and research and experiments have been carried out on the use of raw biogas in vehicles since the 1990s. In Taiwan, The National Institute of Taiwan has conducted research on biogas utilisation and policies for establishing green livestock farming in Taiwan. Taiwan Livestock Research Institute (TLRI) developed biogas utilisation techniques in the 1990s, and also demonstrated the utilisation of compressed biogas in a car (Figure 11) (Su, 2011). Kun Shan University of Taiwan has also conducted research to investigate the implementation of biogas fuel in motorcycles, which are Taiwan's most popular vehicle. Experiments were carried out on raw biogas as a motorcycle fuel. Researchers commented that the thermal efficiency of biogas is low and engine power is sacrificed (Arévalo et al., 2011). A survey on the internet revealed that at present no research is being carried out on the upgrading and bottling of biogas and then its use in vehicles in Taiwan.

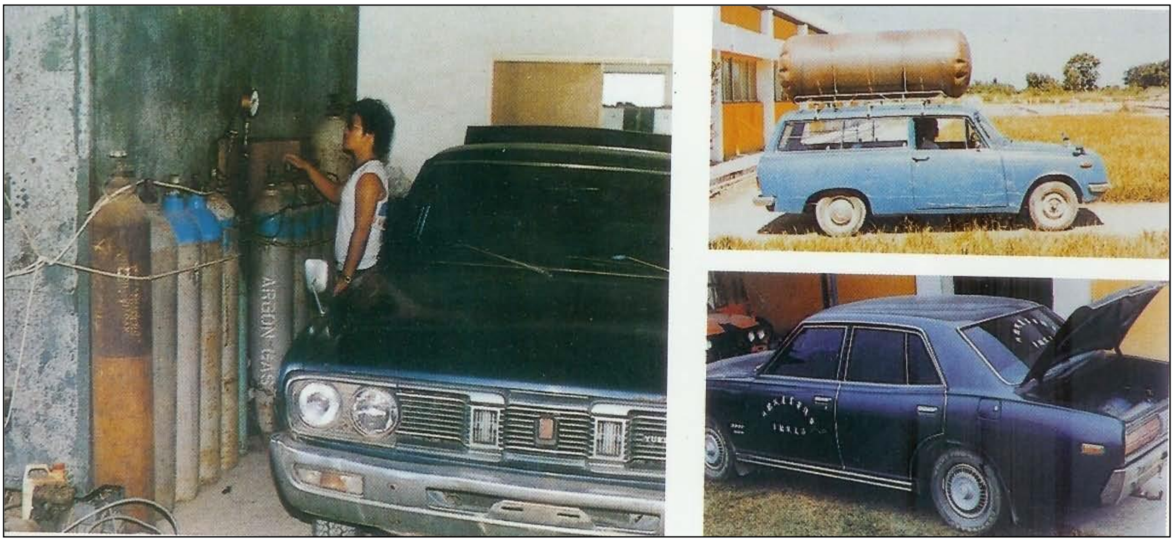


**Figure 11**: Biogas bottling and utilisation in vehicles in Taiwan (*Source: Su J.J., 2011*)

*South Korea.* In South Korea municipalities are interested in biogas for transport rather than other end-uses like heating and electricity. A research conducted in Korea on the feasibility of using upgraded biogas as a vehicle fuel produced from food waste water revealed that the price of the upgraded biogas can be 60-80% more profitable than electricity generation with the current feed-in-tariff system. Because of this reason there is an emerging interest in the development of biogas as a road transport fuel. Three upgraded biogas development projects as an alternative to transport fuel have been recently launched in Seoul, Ulsan and Gangwon Province, with technological cooperation from Swedish companies (Jang, 2009).

## Latin America

At present the most common use of biogas technology in Latin America is in wastewater treatment. In Santiago, Chile, upgrading of biogas from the largest wastewater anaerobic digestion plant in South America – 'La Farfana' - was commenced in 2009, to take advantage of a production of 24 million $m^3$ biogas per year (WASH Technology, 2009) as shown in Figure 12. The biogas was previously used only to heat the digesters, with excess gas being flared (Metrogas, 2009). Since 2009, however, excess gas is now supplied to the natural gas grid, through a partnership between the water and gas utilities Aguas Andinas and Metrogas (Aguas Andinas, 2012). The gas from the plant is transported by a 13.5 km pipeline to

Metrogas' Gas de Ciudad (Town Gas) facility, which supplies gas to 30,000 homes. The biogas replaces town gas, a mixture of methane and syngas previously produced from methane and higher-weight hydrocarbons by cracking (CDM, 2006). The NGV journal in its recent article of July 2012 stated that Metrogas Chile will start producing natural gas from biogas to power vehicles from 2014. They intend to run a second stage of development in La Farfana biogas plant to obtain biomethane through an upgrading process that can convert it to natural gas (consisting of 96% methane). This project claims that about 3,500 NGVs will benefit from the project (NGV Journal).

**Figure 12**: Biogas production and upgrading plant in LaFarfana, Chile (*Source: NGV Journal*)

**Africa**

In Africa the interest in biogas technology has been stimulated by the promotion efforts of various international organisations and foreign aid agencies through their publications, meetings and visits (Mshandete and Parawira, 2010). Development of large-scale AD is still at a very early stage; only 3 countries in Africa have more than one digester with capacity of greater than 100 $m^3$ (Parawira and Mshandete, 2009), and only one example of a plant which included bottling of biogas was found. A large-scale digester for abattoir waste has been built in Ibadan, Nigeria's second-largest city. The digester uses anaerobic fixed-film technology to process wastes from the large abattoir, which processes nearly two-thirds of animals in Oyo State and is reportedly generating 1,800 $m^3$ of biogas per day (Brown, 2006). The gas is upgraded and compressed to provide bottled biogas as a replacement for bottled LPG for up to 5,400 families per month (Schenker, 2008). Most available information on the plant was written before the plant was commissioned in June 2008, except for the Schenker article, written in December of that year. According to that article, the project was planned to be replicated at other sites; one plant was in the process of being developed in Ilorin, Nigeria for cassava waste (Schenker, 2008). No further information on the current status of the plant or its biogas compression and upgrading system could be found, however, so the current status of this and related plants is unknown.

An article in Mail & Guardian in December, 2010 showcased another development in biogas use as a transport fuel in South Africa. Novo Energy, an energy and technology company is building a dispensing station for demonstration purposes on a landfill site near OR Tambo International airport, Johannesburg, South Africa (Mail & Guardian, 2010) as shown in Figure 14. The article stated that Novo will also offer motor car owners a free conversion so that their cars can run on biogas. This article was also published in Biogas News in December the same year (Biogas News, 2010). It estimated fuel savings of between 15% and 25%. Using gas to power vehicles is not new but this attempt although on a small scale would be the first one for South Africa. It targeted full-scale operation by Feb 2011, but no current information on the present status of the plant or its system could be found.


**Figure 13.** A dispensing station for demonstration purposes on a landfill site near OR Tambo International airport

## 4 Use of natural gas in vehicles and possibility of replacement by biogas

Natural gas has 75-98 % methane with small percentages of ethane, butane, propane while biogas has about 60 % methane and 40 % carbon dioxide. Biogas improved by upgrading typically has a methane content of more than 90 %, equivalent to natural gas. After upgrading and compression it can be used as vehicle fuel just like CNG, with lower emissions than natural gas and diesel. Upgraded biogas is also fully compatible with existing CNG vehicle systems and natural gas vehicles (NGV) are capable of running on both upgraded biogas and natural gas.

### 4.1 Upgraded biogas use in existing natural gas vehicles

Compressed natural gas (CNG) as a transport fuel has had a significant degree of success in some of the developing economies like Pakistan, Iran, Argentina, Brazil, and India; and in some European countries such as Germany, Italy and Austria. Germany is leading the way in the development of 'renewable gas' as a transport fuel, in the form of upgraded biogas. There are over 860 CNG service stations providing a blend of CNG and upgraded biogas (bio-CNG) to over 90,000 natural gas vehicles; two of these stations only sell upgraded biogas (Power G., 2011). Such development is yet to begin in most of the developing economies as few or no upgraded biogas facilities are currently in operation. Worldwide, there were 14.8 million natural gas vehicles by 2011, led by Iran with 2.86 million, Pakistan (2.85 million), Argentina (2.07 million), Brazil (1.70 million), and India (1.10 million). The Asia-Pacific region leads the world with 6.8 million NGVs, followed by Latin America with 4.2 million vehicles (Worldwide NGV Statistics, 2012). In the Latin American region almost 90% of NGVs have bi-fuel engines, allowing these vehicles to run on either CNG or petrol (Compressed Natural Gas, 2011). CNG cars available in Europe are bi-fuel vehicles burning one fuel at a time. Any existing petrol vehicle can be converted to a bi-fuel (petrol/CNG) vehicle. Table 6 shows the number of natural gas vehicles operating worldwide to December 2011 with the percentage of biogas vehicles, according to the statistics of the Natural Gas and Biogas Vehicle Association (NGVA).

**Table 6.** NGV population and biogas vehicle share to December 2011

| Country | NGV Population | % All NGVS in World | Biomethane share in NGV market (%) |
|---|---|---|---|
| Developing countries | | | |
| Iran | 2,859,389 | 19.70 | 0.0 |
| Pakistan | 2,850,667 | 19.64 | 0.0 |
| Argentina | 2,044,131 | 14.68 | 0.0 |
| Brazil | 1,702,790 | 11.73 | 0.0 |
| India | 110,379 | 7.58 | 0.0 |
| Italy | 779,000 | 5.37 | 0.0 |
| China | 600,000 | 4.13 | 0.0 |
| Colombia | 348,747 | 2.4 | 0.0 |
| Thailand | 267,698 | 1.84 | 0.0 |
| Ukraine | 200,019 | 1.38 | 0.0 |
| Developed countries | | | |
| USA | 112,000 | 0.77 | 0.0 |
| Iceland | 255 | 0.00 | 100 |
| Norway | 762 | 0.01 | 10.0 |
| Sweden | 40,029 | 0.28 | 59.1 |
| Switzerland | 10,228 | 0.07 | 21 |
| Germany | 96,215 | 0.66 | 6 |
| France | 13,500 | 0.09 | 3 |
| Finland | 985 | 0.01 | 3 |

NGVA statistics indicate that in 2007, 12,000 vehicles were being fuelled with upgraded biogas worldwide, increasing to 70,000 biogas-fuelled vehicles by 2010. As shown in Table 6, the majority of natural gas vehicles are in the developing countries but in all of these countries. NGVs are being run on natural gas due to the availability of the natural gas grid in most areas. In these countries biogas production, upgrading and bottling is at an early stage and a small scale, hence grid injection or bottling of upgraded biogas is non-existent.

In Europe, Sweden reports that more than half of the gas used in its 40,029 natural gas vehicles is biogas. Germany and Austria have established targets of 20% biogas in natural gas vehicle fuel. In the United States, biogas vehicle activities have been on a smaller scale (NGVA Europe, 2012). In most of these developed countries biogas production is being done at a large scale. These countries also have biogas standards for grid injection; hence a percentage of NGVs is being run on upgraded biogas which is injected in the grid. Bottling of upgraded biogas and its use in natural gas vehicles is not common practice in these countries.

## 4.2 CNG conversion kits

Upgraded biogas can be directly used in natural gas vehicles without any modifications in the engine architecture. If an existing petrol or diesel vehicle has to run on biogas, easily-available CNG conversion kits can be installed as shown in Figure 14.

**Figure 14.** Car with CNG conversion kit (*Source: http://naturalgasconversion.net/)*

A CNG conversion kit is a set of components and tools that are installed in a vehicle so that it can operate using both petrol and CNG. These usually include parts such as regulator, high pressure tubing and fittings, pressure gauge, filling nozzle, hoses, hose clamps, closed loop fitting system, emulator, timing advance processor, fuel change over switch as well as the necessary wiring, straps and screws as shown in Figure 15. The fuel change over switch allows the driver to switch from petrol to CNG with the flick of a button. CNG conversion kits usually do not include the CNG tank or cylinder or the cylinder valve, which are purchased separately.

The price of a CNG conversion kit is usually in the range of Rs 40,000/- to 65,000/- (~670 - 900 €). The price varies according to the type and size of kit for different types of vehicles.

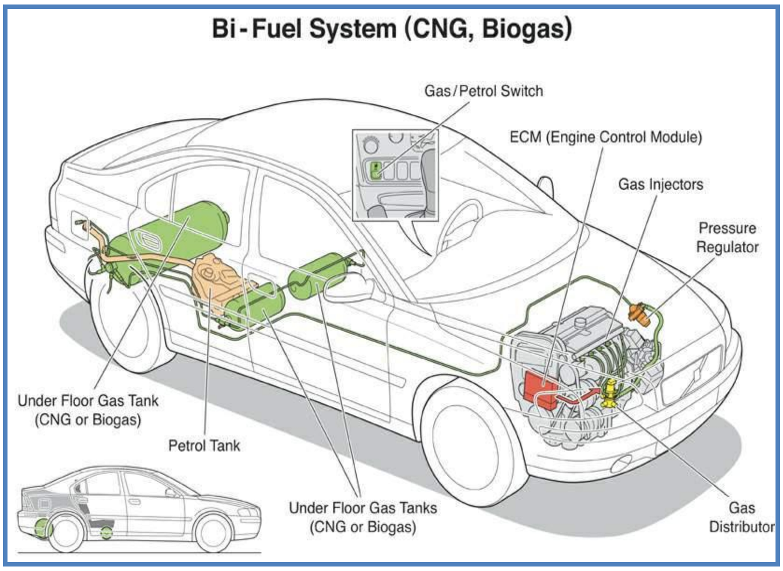



**Figure 15.** CNG conversion kit
(*Source: Murphy J. D; 2005, http://www.cre.ie/docs/09_jerry_murphy_ad_biogas.pdf)*

Creating a market for upgraded biogas takes time and there are many obstacles. As natural gas and upgraded biogas are interchangeable in vehicles, and bottled gas may also be used in natural gas vehicles, the two fuels may be used in parallel. In this way a market can be built up for gas-powered vehicles fuelled mainly by natural gas, and upgraded biogas can then be phased in as it becomes available in sufficient volumes. In some countries this has already been done, while others are just introducing upgraded biogas into the CNG market. Natural gas as vehicle fuel reduces the $CO_2$ emissions by about 25% compared to petrol because of the lower carbon content per energy value. Running vehicles on upgraded biogas may reduce overall $CO_2$ emissions even further, if the biogas comes from waste products.

# 5 Technologies for small-scale biogas bottling systems

It is a rare that there is sufficient on-site vehicle fuel demand for all of the upgraded biogas that an upgrading plant could produce, and most or all of the upgraded biogas must be transported to a pumping /dispensing station where upgraded biogas is required. Upgraded biogas has low energy density at atmospheric pressure; therefore, the most economical and efficient way to transport upgraded biogas over the road is in compressed form.

A biogas bottling system typically consists of the following equipment, as shown in Figure 16:

a) High pressure gas compression
b) Storage for upgraded biogas
c) Dispensing nozzle system

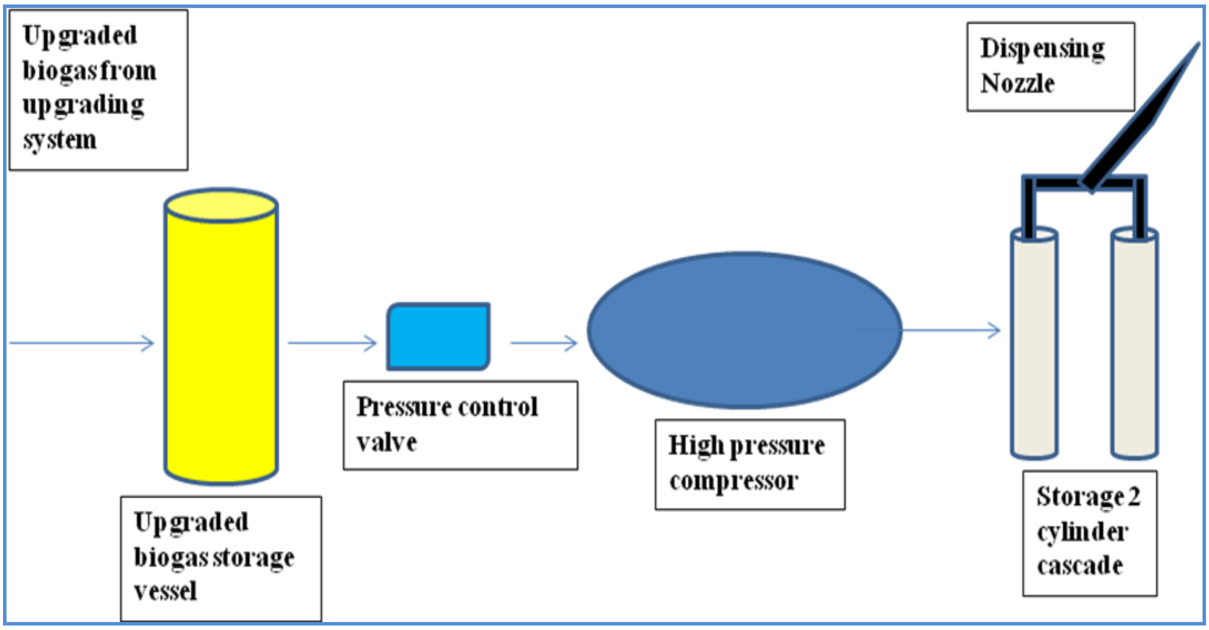



**Figure 16.** Upgraded biogas bottling system (*Source: Authors*)

## 5.1 Technical regulations and standards governing biogas bottling

In the previous sections it is clear that the composition and properties of upgraded biogas are equivalent to natural gas. Hence the regulations and standards applicable to natural gas bottling/dispensing and usage are also applicable on upgraded biogas bottling and usage. The International Organisation for Standards (ISO) has an active technical committee working on standards for natural gas fuelling stations for vehicles (Svensson, 2011). Existing international standards include for compressed natural gas are summarised in Table 7 below:

**Table 7.** Standards governing biogas bottling as applicable to natural gas

| Standard | Title | Meaning | Source |
|---|---|---|---|
| ISO 15403 | This is a standard for *natural gas quality* | The aim of this standard is to provide manufacturers, vehicle operators, fuelling station operators with information on the fuel quality for natural gas vehicles (NGVs) required to operate compressed-natural-gas vehicle equipment successfully. | http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=44211 |
| NZ 5454: 1989 | New Zealand published the first cylinder standard specifically for NGV service in 1989 | is the standard for light weight steel automotive compressed natural gas cylinders for use in New Zealand | Trudgeon, 2005 |
| ISO 11439: 2000 | International standard for Gas cylinders - | **Gas cylinders - High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles. - 1st edition.** | http://www.pngis.net/standards/details.asp?StandardID=ISO+11439%3A2000 |
| IS 15490: 2004. | An Indian standard for cylinders | For on-board storage of compressed natural gas as a fuel for automotive vehicles | http://www.standardsbis.in/Gemini/search/BasicSearch.action |
| ISO 14469-2:2007 | International standard for compressed natural gas (CNG) vehicle nozzles and receptacles | It applies only to nozzles and receptacles which have a service pressure of 200 bar. ISO 14469-2:2007 is applicable to compressed natural gas in accordance with ISO 15403 | http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=37253 |
| New Zealand Standard (NZS) Nozzles AS/NZS 2229/2004 | This standard was prepared by joint Australian/ New Zealand committee- This is Fuel dispensing equipment for explosive atmospheres | NZS nozzle has the o-ring feature at the front with slow filling time. | http://infostore.saiglobal.com/store/details.aspx?ProductID=364752 |
| ANSI/AGA NGV-1-1994 | Compressed Natural Gas Vehicle (NGV) Fuelling Connection Devices | This standard applies to newly produced compressed Natural Gas Vehicle (NGV) fuelling connection devices, hereinafter referred to as devices, constructed entirely of new, unused parts and materials. NGV fuelling. | Source: Jenks C.W., Research Results Digest, April 1998. |

## 5.2 High pressure gas compression

Extensive research and development has been carried out on methods for producing, upgrading and bottling of biogas. The energy density of upgraded biogas is comparatively low at ambient pressure and as a result it must be compressed at high pressures (e.g. 200-250 bar) to allow the storage of sufficient fuel in vehicles before refilling. A wide range of compression mechanisms is available but, based on applicable pressure range and simplicity of implementation (Baron et al., 2008), the most suitable ones for the current purpose are the reciprocating and diaphragm types as summarised in Figure 17.

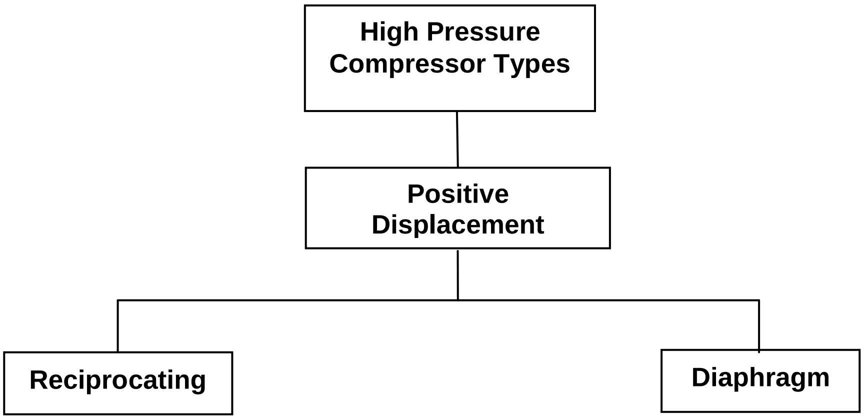
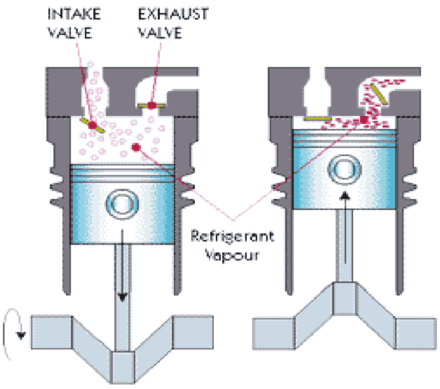



**Figure 17.** Types of High Pressure Natural Gas Compressors (*Source: Authors*)

a) Reciprocating compressors, shown in Figure 18 a and b, are essentially a piston where gas is brought into a cavity and the cavity is physically reduced in volume. It can also be used in either stationary or portable designs (Baron et al., 2008). Multi-stage reciprocating compressors are commercially available with discharge pressures ranging up to 300 bar (for natural gas applications).




a) *Source: http://www.fscc-online.com/ %22Passing%20Gas%22-article/passing_gas.html*


b) *Source: http://www.didwania.com/cng_technology.html*

**Figure 18.** Reciprocating compressors

b) Diaphragm compressors (also known as a membrane compressors) are a variant of the conventional reciprocating compressor as shown in Figure 19. The compression of gas occurs by the movement of a flexible membrane, instead of an intake element. The back and forth movement of the membrane is driven by a rod and a crankshaft mechanism. Only the membrane and the compressor box come in contact with the gas being compressed. Diaphragm compressors are used for hydrogen and compressed natural gas (CNG) as well as in a number of other applications (Perry and Green, 2007; Wikipedia 2012).

a) Diaphragm compressor *Source: http://www.didwania.com/cng_technology.html*

b) Diaphragm compressor (*Source: http://www.allproducts.com/manufacture97/diaphragm/product4_print.html)*

**Figure 19.** Diaphragm compressors

These types of high pressure gas compressors are further categorised by each compressor's special feature, such as:

- Number of compression stages
- Cooling method (air, water, oil)
- Drive method (motor, engine)
- Lubrication (oil, Oil-Free where Oil Free means no lubricating oil contacts the compressed air)
- Packaged or custom-built

Natural gas compressors are multi-stage compressors which are readily available in the market. Not many manufacturers are available in the market for small-scale application of compressing biogas. Therefore, for small capacity high pressure applications, diaphragm type compressors are preferred and few reputed companies are manufacturing high pressure compressors for small-scale capacities, for example Bauer Compressors Pvt Ltd, Indian Compressors Ltd, Coltri (Nuvair compressed gas solutions), DMC Ltd, Shanghai etc. A list of suppliers and manufacturers of small-scale high pressure natural gas compressors is given in Appendix B.

*IIT Delhi:* The high pressure compressor shown in Figure 20 was installed at IIT Delhi in 2005. It is a Gardner Denver three stage compressor with a low suction capacity of 5.1 $Nm^3$ $hour^{-1}$, capable of compressing gas up to 200 bar, and was imported from the UK.

**Figure 20.** Small-scale high pressure gas compressor at IIT Delhi (Old) (*Source: Kapdi S.S, 2006)*

A new compressor has been procured for small-scale compression and bottling of upgraded biogas in IIT Delhi as shown in Figure 21. It was procured from Indian Compressors Limited (http://www.didwania.com) in 2012. Its specifications are:

- Capacity - 5 $Nm^3$ $hour^{-1}$
- Suction - Ambient
- Stages - 4
- Action - Single
- Lubrication - Oil
- Cooling Method - Air
- Motor with starter - 4 hp flame proof


**Figure 21.** Newly procured high pressure small-scale compressor at IIT Delhi (*Source: Authors)*

### 5.3 Storage options for upgraded biogas

The requirements for a biogas/natural gas cylinder are:

a) High specific strength, modulus, toughness
b) High operating pressure > 200bar
c) Fuel density (n=PV/RT) > distance to re-fuel
d) Low weight which allows lower fuel consumption
e) Impact resistance
g) Long life (static and cyclic fatigue resistance)
h) Economic cost
i) Easy availability of the cylinder

Considering the above features the following options for the storage of upgraded biogas are available. The storage options for upgraded biogas with their advantages and disadvantages are discussed below.

#### 5.3.1 Liquefied Petroleum Gas Cylinders

Liquefied Petroleum Gas (LPG) is much easier to store in a tank than natural gas as it readily liquefies on cooling or compression. The gas is stored in liquid form under pressure in a steel container or a cylinder as shown in Figure 22, Normally available domestic LPG cylinders have a virgin pressure of 14 bar, and empty LPG cylinders are easily available in the market at a nominal price of Rs. 1250/- (~20 €) per cylinder. Upgraded biogas has properties similar to CNG, however, and cannot be liquefied easily. Hence upgraded biogas is normally stored at high pressure (200 bars), so the cylinders must be designed to withstand much more than LPG cylinders. The amount of upgraded biogas that can be stored in domestic LPG cylinders (33 litres volume) is only 0.35 kg at 14.2 bar. A typical domestic LPG cylinder is thus neither energy-efficient nor cost-effective for biogas bottling.

**Figure 22.** Domestic LPG cylinder (*Source: http://tntmagazine.in/news/meghalaya/lpg-cylinders-seized-in-shillong/)*

*LPG compression and storage trial - Thailand:* A study was conducted on the development of a biogas compression system and motorcycle modification for using biogas. A modified motorcycle was tested using biogas and petrol in order to know the engine performance, fuel consumption and gas emission. The compression system was designed to compress the biogas into 4 and 15 kg containers at 15 bar, as shown in Figure 23.

a) Compressor for bottling

b) LPG cylinder c) Motor-cycle run on LPG d) Biogas purification system

**Figure 23.** Demonstration of Biogas motorcycle using upgraded biogas in LPG cylinder in Thailand (*Source: Sinabua P. et al., 2011*)

The compression machine filled the 4 and 15 kg containers with 0.2 and 0.53 kg of biogas, respectively. The motorcycle was modified by installation of a biogas mixer and distribution systems in order to utilise biogas as a fuel. It was found that using biogas could reduce the fuel costs by 0.1 € $km^{-1}$ in comparison with petrol. If the motorcycle travels about 50 km $day^{-1}$ and the cost of motorcycle modification is €538, the payback period will be 2.5 years (Singbua P. et al., 2011)

The research was carried out to provide a demonstration of the potential of biogas-fuelled motorcycles. 'This scenario is attractive, because of the widespread use of small scooters and similar vehicles in Thailand and other developing countries, and because their relatively low fuel consumption per km gives them a reasonable range on one cylinder of compressed gas. But in practice it becomes uneconomical to use LPG cylinders for vehicle fuel in most applications because of the small quantity of biogas that can be stored in the cylinder.

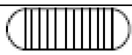
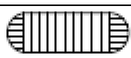
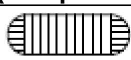
### 5.3.2 Compressed natural gas cylinders

CNG cylinders are strong and lightweight and undergo stringent cyclic testing to assess fatigue strength, usage life and to ensure safety and reliability under extreme climate conditions. A wide range of CNG cylinders are designed and manufactured to comply with national and international standards (Reinforcement.com, 2007). High-quality stainless steel CNG cylinders and cascade of cylinders are available for different capacities and various kinds of vehicles, like three-wheelers, cars, buses and delivery vehicles as shown in Figure 24a and b.

The storage tanks for compressed natural gas (CNG cylinders) must be strong, lightweight, and resistant to impact and temperature. Cylinders can be divided into the following three groups, depending on the materials used in their manufacture:

- metallic;
- metal-composite (metal liner strengthened by polymer composite material); and
- composite (polymer liner strengthened by polymer composite material).

**Table 8.** Types of CNG cylinders (*Source: Trudgeon, 2005)*

| Feature | Type 1 | Type 2 | Type 3 | Type 4 (composite) |
|---|---|---|---|---|
| |  |  |  |  |
| **Market Share** | 93 % | 4% | < 2% | < 2% |
| **Structure** | Metal | Metal Liner reinforced with resin impregnated continuous filament (hoop wrap) | Metal Liner reinforced with resin impregnated continuous filament (fully wrap) | Resin impregnated continuous filament with a non metallic liner |
| **Most commonly used** | CrMo steel | CrMo steel with glass fibre | Aluminium with HP glass and Carbon | HDPE liner with Carbon |

There are four types of cylinders based on their material of construction, as shown in Table 8. The Type 1 cylinders are the most commonly used since they are cheap and affordable but are made of steel, therefore are heavy. There are 3 other types of cylinders made of complex fibres and materials which are lighter in weight but are much more expensive as compared to Type-I cylinders (CNG Cylinders, 2012). Type 4 can be five times more expensive. With the same volume content, CNG-1 would be the heaviest in terms of weight, followed by CNG-2 and CNG-3 while CNG-4 would be the lightest. However, the market price of CNG-1 is generally the lowest followed by CNG-2 and CNG-3, while CNG-4 is generally the most expensive (ISO 11439 FAQ, 2012). Cars are usually fitted with full steel cylinders (Type I) with 200 bar operating pressure.

IS 15490: 2004 is an Indian standard for cylinders for on-board storage of compressed natural gas as a fuel for automotive vehicles. NZ 5454: 1989 is the standard for light weight steel automotive compressed natural gas cylinders for use in New Zealand (Trudgeon M., 2005).CNG cylinders for two standards as per ISO: 11439: 2000 CNG-1 / (NZS - 5454) and IS 15490: 2004 are readily available in the market in the price range of Rs 10,000- 20,000 (~ € 150 - 300).

a) Cascade of CNG cylinders (*Source: http://www.ramacylinders.in/cascade.html)*

b) CNG cylinder type I *(Source*: *http://www.made-in-china.com/showroom/vivianycx/product-detailDbsEFiuHEKWp/China-CNG-Cylinder-Type-1.html)*

**Figure 24. CNG cylinders**

*Some companies manufacturing CNG cylinders are:*

1. M/S Faber Industries, S.p.A , Italy
2. M/S Argentile, S.A, Argentina,
3. M/S Werthington Cylinder, G and H, Australia.

In India companies some of the following companies offer CNG cylinders in different sizes according to the customer's requirement.

1. Everest Kanto Cylinder Ltd., India,
2. Maruti Koatsu Cylinders Ltd,
3. M/S Jay Fe Cylinders Pvt. Ltd.
4. M/S Bharat Pumps and pressure India.

### *High Pressure Composite Cylinder - CNG Type 4*

High pressure composite cylinders are less in weight due to the light weight of the manufacturing material. The weight of a cylinder is reduced by replacing the metal with a lower weight polymer composite material as well as replacing the metal liner with a polymer liner. In this case the cylinder maintains its durability because of the high strength, lightweight epoxy impregnated carbon fibres used. This feature reduces the fuel consumption and hence the environmental footprint. It also increases distance between refuelling and provides resistance against corrosion (Reinforced Plastics, 2012). These cylinders have improved safety and increased life as compared to the type 1 (commonly used cylinder but heavier in weight). These composite cylinders are the most expensive cylinders. They come in the price range of INR 45,000-90,000 (€ 650-1300) per piece depending upon the capacity. They are usually black in colour as shown in Figure 25.

Details of High Pressure Composite Cylinder:

1) Carbon Fibre/Epoxy resin hoop and helical wrapped cylinder on aluminium liner
2) Light weight: 70% lighter than steel cylinder
3) Compact: High pressure and capacity
4) Durable: Anti-corrosion and excellent fatigue resistant
5) Safe: Designed to leak the stored source before accidental burst

*Design pressure* 15$^{o}$ C: 300 bar
*Working pressure* 15$^{o}$ C: 200 bar
*Max. filling pressure* 15$^{o}$ C: 260 bar


**Figure 25.** High pressure composite cylinders
(*Source: http://www.tradeindia.com/fp661116/High-Pressure-Composite-Cylinder-CNG-FCV.html)*

*Experimental studies.* Measurements were carried out at IIT Delhi to determine the time required for filling upgraded biogas at 200 bar in 60 and 35 l water capacity. In a 60-litre CNG cylinder the amount of gas that can be stored at 200 bar is approximately 9 kg and filling takes 1 hour 59 minutes; a 35-litre cylinder can store approximately 4 kg in 1 hour 30 minutes, as shown in Figure 26.

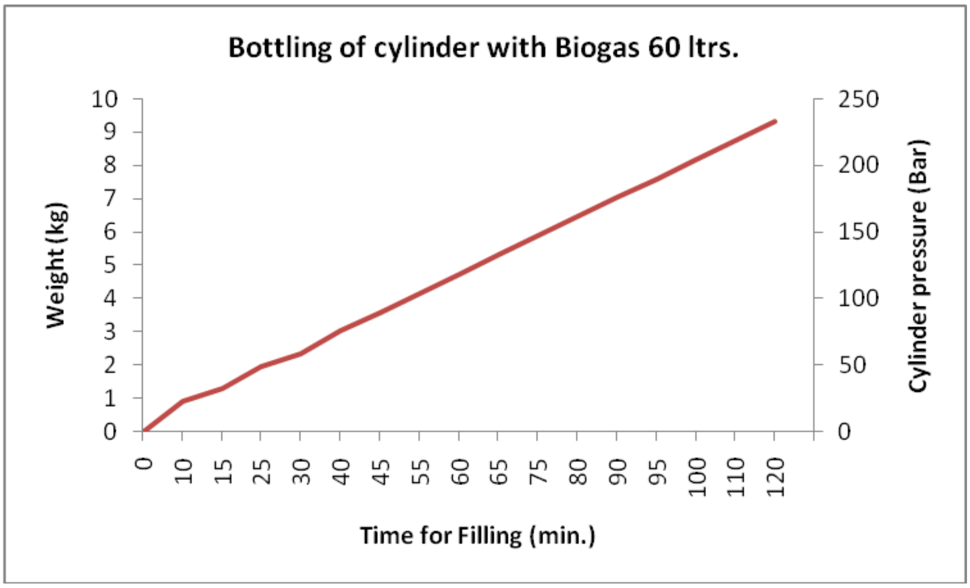



**Figure 26.** Graph showing the amount of upgraded biogas filled in 60-litre CNG cylinder (*Source: Authors)*

### 5.3.3 Hydrogen cylinders

Another option for the storage of upgraded biogas at 200 bar is hydrogen cylinders, as they comply with the cylinder standards. Hydrogen cylinders are also using ISO 11439 standards for hydrogen powered vehicles as the gas must be compressed to high pressure before storing. Most hydrogen cylinders are rated for storage at 345 bar, but some new hydrogen cylinders are rated for 690 bar. Both CNG and hydrogen gas can be stored at high pressures in the four types of high pressure cylinder mentioned above (Zalosh R., 2008). Hydrogen tanks are manufactured according to the draft standard ISO/DIS 15869.2 (11). It was originally drafted as an equivalent to ISO 11489 for CNG tanks with special requirements for hydrogen material compatibility and for hydrogen permeation testing (Zalosh R., 2008) (http://www.iso11439.com/faq.php). Because of these reasons upgraded biogas can be stored in hydrogen cylinders. The cost of hydrogen cylinders is approximately between Rs 20,000 - 30,000 (~ € 300 – 450) depending upon the size and working pressure required.

### 5.3.4 ANG storage technology

Adsorbed Natural Gas (ANG) is a technology in which natural gas is absorbed by a porous adsorbent material at relatively low pressures, 30 to 45 bar. When a natural gas storage vessel is filled with a suitable adsorbent material, the storage capacity will be greater than that of the same vessel without the adsorbent, when filled to the same pressure. When compared to CNG, ANG can store half to two-thirds the amount of gas, but at one-sixth the pressure (Ginzburg, 2006) as shown in Figure 27. In ANG systems, pressures of 30 to 45 bar allow designers to progress from the constraints of cylindrical-shaped containers currently used by CNG vehicles. Conformable tanks, similar to conventional petrol tanks, would not intrude upon or detract from on-board storage space (Judd and Law, N.D.) .

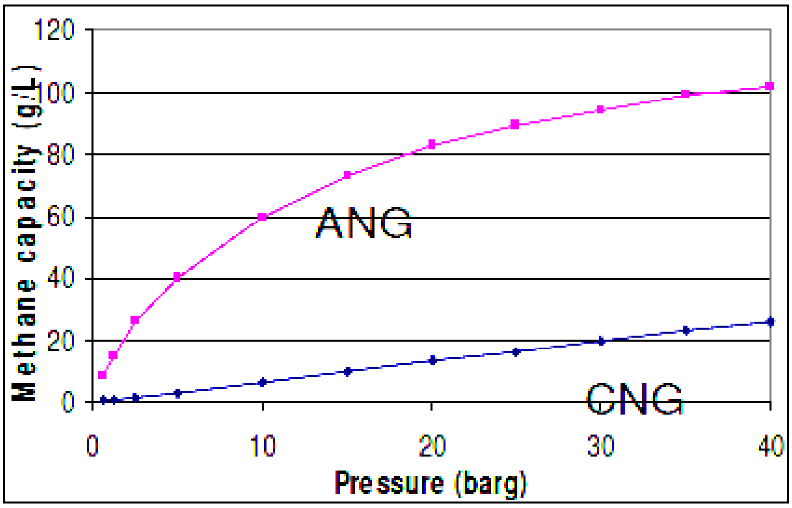



**Figure 27.** Methane storage capacity in CNG and ANG cylinders
(*Source: Judd R. et al, ANG Technology, Germanishar Lloyd, http://www.apinvest.co.in/inside/pdf_gas_glis.pdf*)

Commercial benefits of ANG technology include*:*

- Reduced operating pressures
- Safety benefits, lower fuelling pressure coupled with gas storage on carbon rather than in free space confer real safety benefits in most instances.
- Higher storage capacity for equivalent volumes (five to six times more storage volume at lower pressure**s**) during transport, in storage tanks and final usage as a fuel in vehicles
- Flexible Storage
- Possibly lighter storage systems can be installed
- Flatter shaped tanks can use space much more efficiently than CNG cylinders.
- The volumetric efficiency of ANG storage over more traditional CNG storage cylinders is typically more than 25%.

*Challenges in ANG Technology:* Till now commercialisation of ANG method did not succeed due to unsolved technological problems. Some of the problems are listed below (Starbuck, N.D.).

- Adsorption of gas into the cylinder releases heat which needs to be managed. Much of the gas is stored at relatively low pressures which needs to be discharged to as low a pressure as possible.
- The deliverability is not same as capacity, which needs to be configured so that there is minimum resistance to diffusion of gas.
- Due to this**,** ANG technology has not been applied in bottling of natural gas. The economics of ANG system depends critically on cost of activated carbon which increases disproportionately with performance.

In April 2007, a Kinetic Nova motor scooter was converted by Advantica using an extruded aluminium flat tank (Lay Y.L., 2008) as shown in Figure 28.

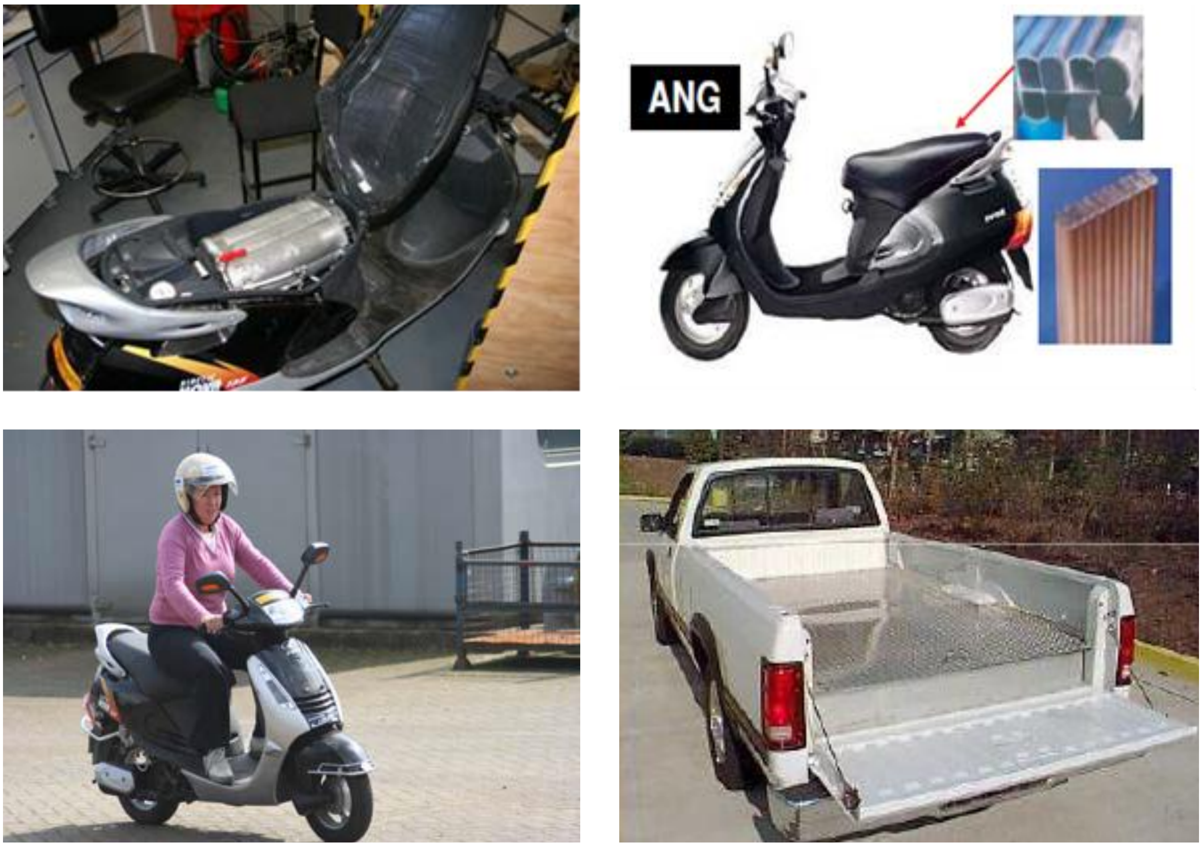



**Figure 28.** Two wheeler and four wheeler using ANG storage (*Source: Judd R. et al, ANG Technology, Germanishar Lloyd, http://www.apinvest.co.in/inside/pdf_gas_glis.pdf)*

### 5.3.5 Summary of storage options

**Table 9.** Summary of storage options for upgraded biogas

| Parameter | Types of Storage Options for Upgraded Biogas | | | | |
|---|---|---|---|---|---|
| | LPG Cylinders | CNG Cylinders | Composite Cylinders | Hydrogen Cylinders | Adsorbed Natural Gas Cylinders |
| Pressure | Domestic LPG cylinder - 14.2 bar | High-pressure cylinders - 200 to 250 bar | High-pressure cylinders - 200 to 250 bar | In hydrogen tanks at 350 and 700 bar CNG is stored | 30- 45 bar |
| Amount of gas stored | 0.35 kg of CNG at 14.2 bar pressure in domestic LPG cylinder (33 ltr. water capacity) | 8 -10 kg at 200 bar depending upon the ambient temperature and pressure | 8 -10 kg at 200 bar depending upon the ambient temperature and pressure | 8 kg at 200 bar and 15 kg 350 bar pressure | When compared to CNG, ANG can store half to two-thirds the amount of gas |
| Cost of empty cylinder | Approx Rs 1250/- (~ € 20) | CNG Cylinders come in the price range of Rs 10,000 – 20,000 (~ € 150 - 300). | Most expensive natural gas cylinder due to the light weight of the cylinder | Cylinders come in the price range of Rs. 20,000 - 30,000 (~ € 300 - 450) | Extremely High cost- due to unsolved technological issues. |
| Economic viability for small-scale bottling applications | Uneconomical - as the amount of gas stored in LPG cylinders is less. | Most economical and affordable are CNG type I cylinders for small-scale application. | Most expensive- INR 45,000- 90,000 (€ 650- 1300) | Less economical as compared to CNG cylinders | Economics of ANG system depends critically on cost of carbon which increases disproportionately with performance, therefore it is uneconomical at present for small-scale applications. |

## 5.4 Biogas dispensing system

Small-scale compressed upgraded biogas does not require any sophisticated infrastructure like metering devices, filling stations, piping, high capacity compressors and distribution system and can serve the needs of remote areas. A typical CNG pumping station consist of a high capacity CNG storage, a similar capacity high pressure CNG compressor and highly sophisticated CNG metering and dispensing system for filling gas in the vehicles. The above is not applicable for CBG due to the very small scale of operation. For small-scale applications, a dispensing system would consist of a two-cylinder cascade for compressed gas storage, a dispensing nozzle and hose.

Two types of dispensing nozzles are available in the market:

***New Zealand Standard (NZS)*** (AS/NZS 2229/2004)

This standard was prepared by a joint Australian / New Zealand committee. It specifies smaller nozzles of the type fitted with the CNG kit in auto rickshaws and cars, as shown in Figure 29. These were considered the cause of the long filling time due to their smaller size of inlet. The main cause of the long filling time is the low pressure supply which needs improvements in the nozzle. The NZS nozzle is inappropriate mainly because of the o-ring feature which can sometimes fail by cracking or getting loose.
(http://infostore.saiglobal.com/store/details.aspx?ProductID=364752)

a) CNG fill probes
*(Source: http://www.naveenvikas.in/cng-dispenser-components. html*)

b) CNG nozzle and dispenser
*(Source: http://daq.state.nc.us/motor/cng/crownvic.shtml)*

c) CNG nozzle and dispenser at IIT Delhi
*(Source: Authors)*

**Figure 29.** CNG Dispensing Nozzle to NZ Standard

***Natural Gas Vehicles – I (NGV-I)***

In 1994, the American National Standards Institute (ANSI, www.ansi.org/) published ANSI/AGA NGV-1-1994 in Canada applying to apply to CNG vehicles only (Jenks, 1998) For quick refuelling of heavy and light duty vehicles relatively big nozzles as compared to NZS nozzles are used, as shown in Figure 30. In most countries CNG vehicles are now fitted with *NGV – I German standard* nozzles to overcome the drawbacks of NZS nozzles. This standard addresses three types of nozzles, described as follows:

- **Type 1 Nozzle - High flow nozzles** –These are self-serve CNG fuelling nozzles for public stations. This type of nozzle is for quick refuelling of heavy and light duty vehicles from the same dispenser (bus refuelling in just few minutes). They have high flow capacity (Jenks, 1998). Figure 30 a and b show typical type 1 NGV1 nozzles.
- **Type 2 and 3** – these are basically used in time fill stations which fill vehicles over longer periods of time. Longer fill times can allow smaller and lower-cost compression and dispensing equipment. Time-fill systems often fill vehicles overnight when the cost of electricity used for the compression equipment is lower. Centrally fuelled fleets such as school buses, refuse trucks and utility service vehicles are excellent candidates for time-fill systems. The Type-2 nozzle is primarily intended to be used in fleet vehicle applications. The Type-3 nozzle is primarily intended for residential and fleet applications (Jenks, 1998; Staubli, 2012). Figure 30 c to g show typical type 2 and type 3 NGV1 nozzles for dispensing natural gas.

a) NGV 1 Type 1CNG Nozzle (*Source: http://www.staubli.com/en/connectors/quick-couplings/fuels/compressed-natural-gas/ngv-nozzle-gmv09/)*

b) NGV 1 Type 1 CNG Nozzle (*http://www.opwglobal.com/Product.aspx?pid=140)*

c) NGV 1 Type 2 CNG Nozzle *(http://www.globalfluid.com/c-global/Alternative_fuel.htm*

d) NGV 1 Type 2 CNG Nozzle *(http://www.opwglobal.com/Product.aspx?pid=138)*

e) NGV 1 Type 3 CNG Nozzle *(http://www.opwglobal.com/Product.aspx?pid=137)*

f) NGV 1 Type 3 CNG Nozzle *(http://www.oasisngv.com/products/c/54)*

g) NGV 1 Type 3 CNG Nozzle *(http://www.oasisngv.com/products/c/54)*

**Figure 30.** NGV – standard nozzles

## 5.5 Demonstration low cost small-scale compression and bottling unit at IIT Delhi

A demonstration small-scale system is in operation at IIT Delhi, consisting of a two-cylinder cascade for storage of upgraded biogas and a simple dispensing system with a nozzle for direct filling of gas in vehicles (Figure 31 a and b). The bottling part of the upgrading plant consists of a multi-stage high pressure compressor having suction at 0.5 bar, discharge pressure 200 bar and capacity 5 $Nm^3$ $hour^{-1}$; and a two-cylinder cascade as shown in Figure 31 c and d. Filters are used for moisture removal. The storage cylinders used are high pressure standard CNG cylinders to NZ standards with a water volume of 120 (2 x 60) litres capacity. A CNG dispensing cable and a nozzle to NZS standards is used for filling the gas into the vehicles. The typical cost of the small-scale dispensing system is € 3500. Figure 31 e and f shows the upgraded biogas dispensing system being used to fill a biogas vehicle.

a) Dispensing nozzle


b) Two-cylinder CNG cascade

c) Detail of dispensing system

d) Dispensing system

c) and d) upgraded biogas dispensing system being used to fill biogas vehicle

**Figure 31.** Simple low cost upgraded biogas dispensing system - demonstration system at IIT Delhi *(Source: Authors)*

# 6 Barriers and recommendations in promotion of biogas bottling in developing economies

## 6.1 Policies and regulations pertaining to biogas bottling in developing economies

At present most of the developing countries have no standards, norms or policies for biogas upgrading and bottling. Biogas policies pertaining to production do exist in developing countries like India, China, Nepal and Bangladesh. India and China are promoting biogas upgrading and bottling programmes, and are using bottled biogas as a vehicle fuel at demonstration level. For further promotion of biogas upgrading and bottling systems and to commercialise them, the governments of both countries are in the process of formulation of standards for upgraded biogas composition, and norms and policies for biogas bottling. The need of the hour is to introduce subsidies, tax incentives and bank loans for promotion of biogas bottling.

In India during 2008-2009, the Ministry of New and Renewable Energy (MNRE) undertook an initiative to demonstrate an integrated technology-package in entrepreneurial mode on medium size (200-1000 $Nm^3$ $day^{-1}$) biogas fertiliser plants (BGFP) for generation, purification/enrichment, bottling and piped distribution of biogas. A 50% subsidy of the total project cost for compressed biogas plant (Biogas Bottling) was extended for another 6 months by the MNRE, Government of India. The available term loan was up to 30% from financing institutions with a 20% entrepreneur's share (MNRE, 2011, http://www.mnre.gov.in/mnre-2010/schemes/decentralized-systems/schems-2/). 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 stationary and motive power, cooling, refrigeration and electricity generation needs in a decentralised manner through establishment of a sustainable business model in this sector. The purified 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 (PESO, 2011) A 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). Standards for biogas composition have also been developed, and are being processed through Bureau of Indian Standards (BIS) and likely to be finalised during the year 2012.

The purpose of these standards and policies is to provide general guidelines for the upgraded biogas composition, and its filling into CNG cylinders. In the proposed standards, the composition of purified biogas suitable for filling in CNG cylinders (at 200 bar) is as shown in Table 10.

**Table 10.** Suggested standards for biogas composition in India

| No. | Biogas Component | Percentage |
|---|---|---|
| 1 | Methane ($CH_4$) | ≥ 90 % |
| 2 | Carbon Dioxide ($CO_2$) | ≤ 4 % |
| 3 | Hydrogen Sulphide ($H_2S$) | ≤ 20 ppm |
| 4 | Moisture | ≤ 0.02 g $m^{-3}$ |

In China, even though current policies for promoting renewable energy indicate the future trends for biogas utilisation, at present there are no specific regulations and laws to promote the utilisation of upgraded biogas. A clear statement of intention to build up biogas plants in rural areas in a short time is considered as the current guideline in China. All decisions come from the central government, thus, how to utilise resources properly and how to put them work together smoothly are the questions for China's Biogas policy makers to solve (Wang D et al., 2006).

The Sri Lanka Standards Institute (SLSI) is a relevant body for the formulation of biogas standards. At present standards related to biogas upgrading and bottling do not exist but the government is keen to formulate standards for bottling keeping in view the Indian and other European standards (Alwis, 2012)

The cost barrier towards upgrading biogas to biomethane is still significant, and may constrain further implementation of the technology, in the developed world. This does not mean that there are no opportunities. The economic barriers towards further use of upgraded biogas could partly be overcome by for example, biogas production in some cases (for example landfills) which decrease methane emissions, making such projects eligible for CDM credits.

## 6.2 Main barriers to promotion of biogas bottling

It is evident that there is a conducive situation for the adaption of biogas upgradation and bottling in developing countries as stated in the text above. But the main barriers in developing countries in the promotion of bottling can be attributed to many factors as listed below. Awareness, high cost, scale of the technology contributes to the slow adoption of the technology but the main factor is the non-existence of standards for particularly biogas bottling. At present the standards and regulations which are being followed for biogas bottling are quite stringent because high pressure gas is involved hence all the existing standards for natural gas compression and bottling being followed. The main barriers to the promotion of biogas bottling are listed below:

(i) The high costs of biogas upgrading systems.
(ii) The relatively large scale required for upgrading, as systems above 50 $m^3$ $hour^{-1}$ upgrading capacity are economically viable.
(iii) The lack of widespread availability of simple low cost bottling technologies.
(iv) In most of the developing countries, standards and policies for use of upgraded biogas in vehicles as a transport fuel like CNG either do not exist or are in the formulation stage.
(v) Presently there are no existing norms for uses of high pressure compressed biogas gas like CNG for bottling and for use in vehicles. For example, in India norms and rules have to be followed conforming to BIS standards for high pressure cylinders, upgraded biogas composition, rules of PESO (Petroleum and Explosives Safety Organisation) for bottling, Motor Vehicle Act for use of biogas in vehicles as a fuel.

*(Sources: Alwis, 2012; MNRE, 2011; AEBIOM, 200; Wang, 2006)*

## 6.3 Models for promotion of biogas bottling

Biogas upgrading offers various entrepreneurship models which can be adopted in both rural and urban areas. These models can help in employment generation, waste minimisation, energy saving, pollution reduction and sustainable development.

In developing countries the following models can be assessed options are possible:-

***Model I:*** In many developing economies, the majority of households in rural areas have cattle. If a village has 100 families with cattle, then the total number of cattle may be around 200-300 and the manure available would be sufficient to operate a digester with a production biogas capacity of 100-120 $Nm^3$ $day^{-1}$. After removing impurities such as $CO_2$, $H_2S$, moisture etc, a yield of about 50-60 % of upgraded biomethane can be achieved. Entrepreneurship models can designed based on a centralised waste collection system in which people in rural areas put all their waste including animal dung, human waste and agricultural wastes in a centralised collection place. From here the waste is mixed and shredded and fed into the digesters also called community biogas plants (Exnora Green Pammal News, 2010). Raw biogas is then purified using low cost small-scale upgrading technologies and can be sold to local people at nominal prices. This model is shown in Figures 32 and 33. The upgraded biogas can be:

a) Bottled and filled in a cascade of biogas cylinders for transportation in remote rural areas and or used in cylinders for cooking or filling in vehicle cylinders for transport.

b) Used for generating power using 100 % biogas engines.

The biomanure generated by these biogas plants can also be used to promote organic farming in agriculture.

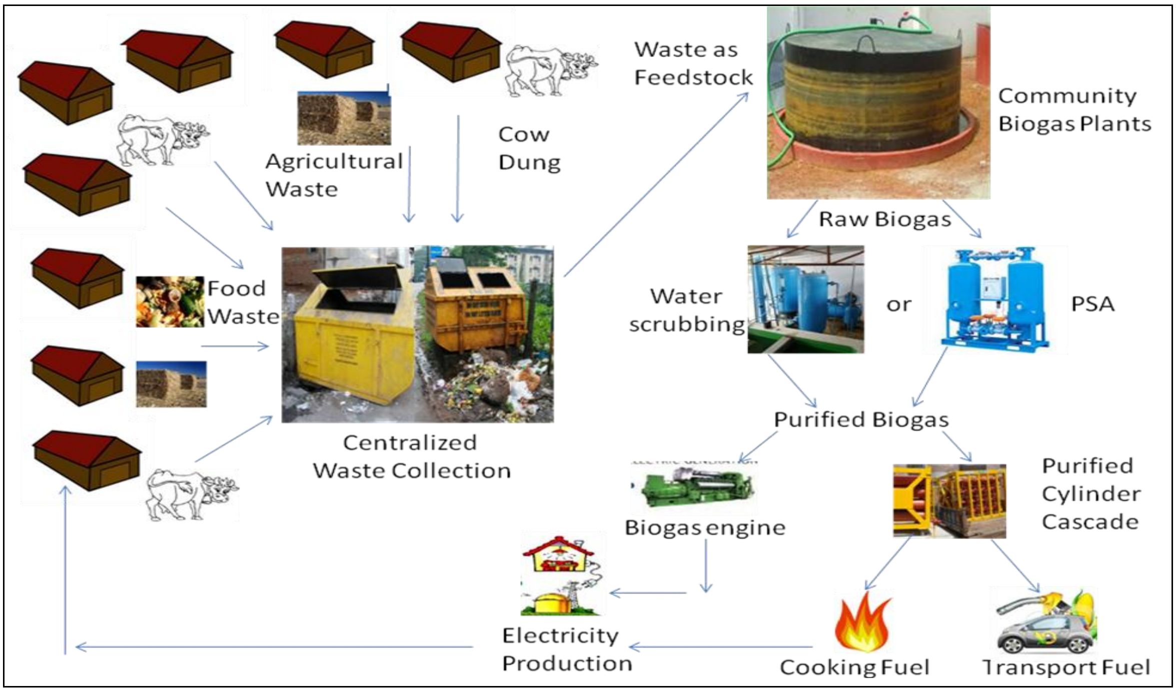



**Figure 32.** Schematic diagram of Biogas Entrepreneurship Model I (Source: Author).


**Figure 33.** Community biogas plant *(Source: Exnora Green Pammal News,2010)*

***Model II:*** The second option for entrepreneurship is a mobile biogas upgrading unit. In this option the upgrading unit is mounted on a trolley attached to a vehicle. Because of this, the mobile biogas unit can service more than one biogas plant within a cluster. The trolley mounted machine (Figure 34) can be transported to digesters in different locations where raw biogas is kept in a storage vessel. The raw biogas can be upgraded by these mobile units and can fill CNG cylinders for storage at high pressure then transported to the required place, giving an uninterrupted supply of upgraded biogas (Leonard et al., 2006).

Two possible options for a mobile biogas upgrading system serving a cluster of biogas plants in nearby villages could be: (a) a mobile unit collects the raw biogas from various small-scale biogas plants and transports it to a centralised unit for upgrading and bottling. (b) the mobile unit is mounted with an upgrading system for upgrading and bottling gas at the site itself. The scenario can be site specific depending on the local situation.

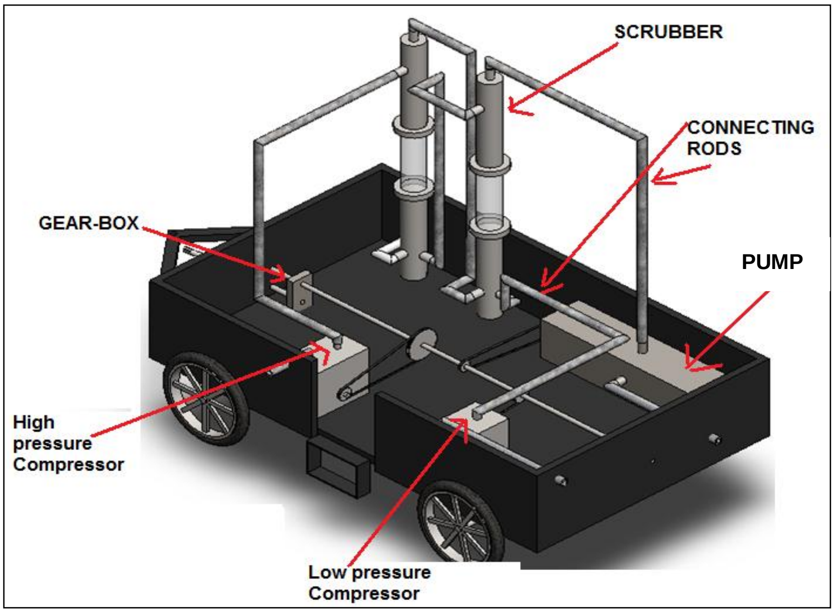



**Figure 34.** View of the Mobile Unit (*Source:Author*)

***Model III:*** In urban areas organic wastes, high population densities mean that sewage sludge, wastewater, waste from food processing industries, food and organic waste from restaurants and other commercial operations, household kitchen and garden waste, vegetable and fruit market waste and even farmyard waste can all be used for biogas generation. This biogas can be upgraded and either injected in the natural gas grid if available or filled in a cascade of cylinders. It can be sold for vehicles use or cooking fuel in large gas consumption places.

Urban areas are densely populated and have large scope for such systems. If residential colonies can be grouped in 20,000-25,000 households, then waste from these households can be collected at a centralised place by an entrepreneur / company. The company can generate biogas and upgrade and sell it to consumers for various applications. For example, if on an average one household gives 250 g of biodegradable waste, then a small community of 25000 households will be able to generate approximately 6.5 tonnes $day^{-1}$ of waste. This quantity of waste can generate approximately 500 $Nm^3$ of biogas, which is sufficient for running a small-scale biogas upgrading system in entrepreneurial mode. Such systems are a need of the time and in future may become reality everywhere.

## 6.4 Recommendations for promotion of biogas bottling systems

For the promotion of biogas bottling systems in developing countries the following recommendations are suggested:

a) Bank loans and central subsidies should be provided for the promotion of biogas upgrading and bottling plants.
b) Formulation of upgraded biogas standards and policies for use in vehicles as a transport fuel like CNG.
c) The government should provide turn-key job fee linked with free maintenance warranty,
d) Central Financial Support (CFA) should be provided to support biogas bottling.
e) Training, workshops and dissemination activities for users, manufacturers and entrepreneurs.
f) It has also been suggested that norms for small-scale biogas bottling systems should be eased for small-scale biogas bottling systems.
g) Subsidies should be provided for application of biogas bottling systems in rural areas.
h) Development of a system for manure management.
i) Government should make biogas projects eligible for funding for efficient rural development.
j) 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, which has led to a favourable development in some countries of Europe.
k) Public transportation should run on biogas, and there should be provision of incentives for biogas taxis and buses. Bus fleets with steady and regionally bound fuel consumption are a perfect first step to introduce upgraded biogas and filling stations to urban areas as was done for CNG public buses in India in 1998 (Roychowdhury A., 2010).

# 7 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 either in small or large scales. The bottled biogas can cater to numerous applications like a supplement to CNG in vehicles, domestic and commercial cooking, power generation via engines. Low cost small-scale biogas upgrading and bottling technology is thus a step towards achieving financial stability for the common man. The present technologies available for bottling are evaluated on cost basis and viability in small-scale applications. Bottling systems give 2-5 yrs of payback period if bottled biogas is used as a cooking fuel and as a vehicle fuel. 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 first level biogas upgrading unit using water scrubbing technology and based on this development and pilot scale setups in the field, government has initiated to provide financial support to any such commercial projects in India. Right now, there are no national standards available for use of biogas in vehicles; however, they are still in the formative stage. Different government agencies are contemplating protocols and standards to be adopted for biogas upgrading and bottling for vehicular applications in India. Hence it can be concluded that:

1. Policy and financial support from the government are necessary for promotion of biogas upgrading in the developing countries.
2. Above 50 $Nm^3$ $hour^{-1}$ biogas upgrading unit are economically viable.
3. Biomethane standards should be developed according to the need of the countries.
4. Involvement of more industries/companies is required in this sector to bring down the capital investment in the technology.
5. Mobile biogas upgrading unit may be useful in developing economies for centralised biogas upgrading and bottling.

## References

Adnan, I. (2011). Biogas, an Answer to Pakistan's Energy Crisis, Pakistan Today,.

AEBIOM (2009). A Biogas Road Map for Europe, European Biogas Association, October, 2009.

AEIC (2010). Afghan Energy Information Centre. Biogas. Available http://www.afghaneic.org/biogas.php, last accessed June 2012.

Aguas, A. (2012). Aguas Andinas y Metrogas inauguran planta de biogas. http://www.aguasandinas.cl/la-empresa/novedades/aguas-andinas-y-metrogas-inauguran-planta-de-biogas?CodTemplate=20120213120706. Accessed August 2012.

Ahman, M. (2010). Biomethane in the Transport Sector - An Appraisal of the Forgotten Option. Energy Policy, 30 (1), 208–217.

Ahmed, A. (2010). Bio-gas Cylindering: Managing Process of City Wastage with Business; Evidential Study from Bangladesh. Social Science Research Network. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1625035

Akshay, U. (2011). Ministry of New and Renewable Energy, 4(6).

Alwis, A.A.P. (2012). Tool for Sustainability: A Case for Biogas in Sri Lanka, de Alwis/Journal of Tropical Forestry and Environment 2(01), 1-9.

Amjid, S.S. (2011). Biogas, Renewable Energy Resource for Pakistan, Renewable and Sustainable Energy Reviews, 15(6).

Arevalo, W., and Ortiz, L.S. (2011). Single Cylinder Engine System using LPG: An Investigation to Set a Baseline for Future use with Biogas, Department of Mechanical Engineering, Kun Shan University, Taiwan.

Bamboriya, M.L. (2012). Biogas Bottling in India, Akshay Urja, 5(5). http://www.indiaenvironmentportal.org.in/files/file/biogas%20bottling.pdf

Baron, D., Leginski, J., Malek, A., Murphy, T., Smith, A. (2008) Biogas Compressor Project. Department of Mechanical Engineering, University of Michigan, Ann Arbor. Available http://deepblue.lib.umich.edu/bitstream/2027.42/58672/1/me450w08project29_report.pdf. Last accessed August 2012.

Biogas Energy Solutions (2012). See the Idea Through. Available http://www.sirim.my/web/core/research/renewable/biogas-energy, Accessed August, 2012.

Biogas News (2010) http://biogasnews.blogspot.in/2010/12/billion-rand-biogas-saving-for-taking.html. Accessed June 2012.

Biotec, (2012). Research and Development: Biogas as vehicular combustible. http://www.bio-tec.net/en.php?id_menuppal=3&id_menusec=18, Accessed August 2012.

Brown. V. (2006) Biogas: A Bright Idea for Africa. Environmental Health Perspectives 114(5), 300-303.

Buffetoblog (2011) A motorcycle fueled by poop, Nov 2011**.** Available http://buffetoblog.wordpress.com/2011/11/09/a-motorcycle-fueled-by-poop/. Last accessed August 2012.

CDM (2006). Executive Board: Clean Development Mechanism Project Design Document Form (CDM-PDD): Biogas use in Town Gas Factory in Santiago. (2006). http://cdm.unfccc.int/filestorage/8/G/J/8GJ9LPX4F5M36ADYURKTVZSCW1N7B0/4037_PDD.pdf?t=U3V8bTh1cWh6fDBgkLkMtXJMe7QYd-4iTN46. Accessed August 2012.

CNG Cylinders (2012). High-Tech for Storage, Transportation and Power, International GmbH, Germany. Accessed March 2012. http://www.mcs-international-gmbh.de/downloads/mcs_cng01_engl.pdf

Compressed Natural Gas. (2011). http://en.wikipedia.org/wiki/Compressed_natural_gas. Last accessed February 2012.

Exnora Green Pammal News. (2010). http://greenpammalchennai.wordpress.com/page/2/. Accessed March 2012.

Farming and Agriculture (2011). http://pakagri.blogspot.in/2011/11/biogas-answer-to-pakistans-energy.html). Last accessed August 2012.

Flotech News (2010). Greenlane Biogas confirms new project in Hitachi, Japan, Auckland. http://www.flotech.com/flotech-news/greenlane-biogas-confirms-new-project-in-hitachi-japan.

Garwood. A. (2010). Network for Biodigesters in Latin America and the Caribbean: Case Studies and Future Recommendations. Inter-American Development Bank Sustainable Energy & Climate Change Unit Infrastructure and Environment Sector. Technical Notes http://ideas.repec.org/p/idb/brikps/31818.html. Accessed 16 August 2012.

Ginzburg, Y. (2006) ANG Storage as a Technological Solution for the “Chicken-and-Egg” Problem of NGV Refueling Infrastructure Development. 23rd World Gas Conference. Amsterdam.\ http://biogasapplication.blogspot.in/2010/03/new-perspective-in-biogas-technology.html. Accessed March, 2010

Good Returns (2010). http://www.goodreturns.in/news/2010/09/29/24-biogas-plants-dompok.html. Accessed June 2012.

IEA Task 37 (2011) http://www.iea-biogas.net/_download/Up-grading_Plant_List.pdf. Accessed March 2012.

IEA Task 37 (2012) http://www.iea-biogas.net/_download/newsletter/2_11%20 Newsletter _Task37.pdf. Last Accessed August 2012.
IEA Task 37 (N.D.) 100% Biogas for Urban Transport in Linköping. Available http://www.iea-biogas.net/_download/linkoping_final.pdf.Last accessed July 2012.
ISO 11439 FAQ (2012) http://www.iso11439.com/index.php. Last accessed August 2012.
Jang, J. (2009) Exploring Opportunities for Biogas as a Vehicle Fuel in South Korea: Learning from Sweden. Master of Science in Environmental Sciences Thesis. Lund University. Sweden.
Jenks, C.W. (1998). Research Results Digest. Technology Assessment of Refueling-Connection Devices for CNG, LNG, and Propane. Transit Cooperative Research Program.
Jönsson, O., Persson, M., (2003). Biogas as transportation fuel. http://www.fvee.de/fileadmin/publikationen/Workshopbaende/ws2003-2/ws2003-_02_04.pdf.
Judd, R., Law, C.Y. (N.D.) ANG Technology, Germanishar Lloyd, http://www.apinvest.co.in/inside/pdf_gas_glis.pdf, Accessed April 2012.
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.
Kapdi, S., Vijay, V.K., Rajesh, S., Prasad, R., (2006). Upgrading biogas for utilisation as a vehicle fuel. As. J. Energy Env. 7(04), 387-393.
Kranert, M., Fischer, K., Huang, J. (n.d.). Development of Biogas Plants in Latin America and Africa. Slideshow presentation, University of Stuttgart. http://www.cetesb.sp.gov.br/userfiles/file/mudancasclimaticas/biogas/file/cursos_seminarios/jingjing2011/vortrag_180311.pdf . Accessed August 2012.
Krich, K., Augenstein, D., Batmale, J.P., Benemann, J., Rutledge, B., Salour, D. (2005). Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California. Available http://suscon.org/cowpower/biomethaneSourcebook/biomethanesourcebook.php. Last accessed August 2012.
Lay, Y.L. (2008). New Approach to Natural Gas Storage –Advances in Adsorbed Natural Gas (ANG) Technology, Advantica Ltd, International Gas Union Research Conference, Paris.
Leonard, T., and Massie, C. (2006). Mobile Biogas Processing System and Method. US Patent Application 2006/0213370. Minneapolis. MN (US).
Mail & Guardian. Africa's Best Read. Billion-rand Biogas Saving for the Taking, 2010. http://mg.co.za/article/2010-12-07-billionrand-biogas-saving-for-the-taking. Accessed August 2012.
Mittal K.M., Biogas Systems: Principles and Applications. New Age International (P) Limited, New Delhi, 1996.
MNRE (2001). Annual Report. Renewable Energy in India and Business Opportunities. MNRE (Ministry of New and Renewable Energy). Government of India, New Delhi.
MNRE (2010a) Ministry of New and Renewable Energy, http://www.mnre.gov.in/mnre-2010/schemes/decentralised-systems/schemes-2/. Accessed December 2011,
MNRE, Ministry of New and Renewable Energy (2010b), http://mnre.gov.in/mnre-2010/related-links/r-d/rd-projects/. Accessed November 2011
Mshandete, A. M., and Parawira, W., (2009). Biogas technology research in selected sub-Saharan African countries – A review, *8*(2), 116–125,.
Murphy, J.D. (2005). Anaerobic digestion and biogas. Cork Institute of Technology. Composting Conference (Cré). http://www.cre.ie/docs/09_jerry_murphy_ad_biogas.pdf

NBI (2010) National Biogas Implementation, Biogas Capture and CDM Project Implementation for Palm Oil Mills, 2010. http://www.e-kilangmpob.com.my/National_Key_Economic_Areas.pdf.

NGV Global (2012) http://www.naturalgasglobal.com/?p=508. Accessed August 2012

NGV Journal. http://www.ngvjournal.com/pt/mercados/item/9600-metrogas-chile-to-start-producing-natural-gas-to-power-vehicles-from-2014. Accessed August 2012

NGVA Europe (2012) (http://www.ngvaeurope.eu/worldwide-ngv-statistics). Last accessed August 2012.

Pakistan Today (2012). http://www.pakistantoday.com.pk/2012/03/23/news/profit/4000-bio-gas-plants-installed-across-pakistan/. Accessed August 2012.

Parawira, W. (2009). Biogas Technology in Sub-Saharan Africa: Status, Prospects and Constraints, Reviews in Environmental Science and Bio/Technology. 8(2),187-200.

Perry, R.H. and Green, D.W. (Editors) (2007). *Perry's Chemical Engineers' Handbook* (8th ed.). McGraw Hill.

PESO (2011). Annual Report. (2010-2011) Petroleum and Safety Organisation (PESO). http://peso.gov.in/PDF/AR2010_11.pdf.

Petersson, A., Wellinger, A. (2009) Biogas upgrading technologies – developments and innovations, Task 37 - Energy from Biogas and Landfill Gas, IEA Bioenergy.

Power, G. (2011) Potential of small to medium scale transport biomethane development in Ireland, Proceedings of the Irish Transport Research Network Conference.

RedBioLac. (N.D.). Red de Biodigestores Para America Latina y El Caribe (Biodigestors Network for Latin America and the Caribbean). http://redbiolac.org/. Accessed August 2012.

Reinforced Plastics (2012) CNG Cylinder Manufacturers Test Basalt Fibre,. http://www.reinforcedplastics.com/view/1138/cng-cylinder-manufacturers-test-basalt-fibre/. Accessed August 2012.

Renewable Energy Magazine. (2011). http://www.renewableenergymagazine.com/article/rural-areas-start-to-tap-huge-biogas, Accessed August 2012.

Renewables. (2010). Global Status Report. REN21. Annual Publication. Revised Edition. Paris. http://www.ren21.net/REN21Activities/Publications/GlobalStatusReport/GSR2010/tabid/5824/Default.aspx.

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

Sakulin, C. (2010). Country Specific Conditions for the Implementation of Biogas Technology Comparison of Remuneration. Biogas Regions. http://www.biogasregions.org/feed_in_tariffs.php

Salomon, K.R., and Silva Lora, E. E. (2009). Estimate of the electric energy generating potential for different sources of biogas in Brazil. Biomass and Bioenergy, 33(9), 1101–1107. doi:10.1016/j.biombioe.2009.03.001

Schenker, J., (2008) Cows to Kilowatts: A Bounty from Waste. Bloomberg Business Week. http://www.businessweek.com/stories/2008-12-03/cows-to-kilowatts-a-bounty-from-wastebusinessweek-business-news-stock-market-and-financial-advice. Accessed August 2012.

Singbua, P., and Suntivarakorn, R. (2011) A study of Compression and Utilisation of Biogas in Motorcycle. (In Thai). Available http://intranet.gs.kku.ac.th/e-journal/index.php/gs/article/viewFile/287/289. Last accessed August 2012.

Sri Lanka Domestic Biogas Programme (2011). People in Need. Member of Alliance. June 2011. http://www.snvworld.org/sites/www.snvworld.org/files/publications/20110901_pin_biogas_concept_note_sri_lanka.pdf. Accessed March 2012

Starbuck, J.M. (N.D.) A Lower Cost Composite Material for CNG Storage. Oak Ridge National Laboratory. www.ornl.gov/~webworks/cpr/misc/104060.pdf. Accessed April, 2012.

Staubli (2012) http://www.staubli.com/en/connectors/quick-couplings/fuels/compressed-natural-gas/ngv-nozzle-gmv09/. Accessed June 2012.

Su, J.J., (2011). Biogas Utilisation and Policies for Establishing Green Livestock Farming in Taiwan, Dept. of Animal Science and Technology, National Taiwan University, September 2011.

SuperNGV (N.D.) http://www.superngv.com/cylinderstandard.php. Accessed April 2012.

Svensson, M. (2011). Biomethane Powered Transport in EU27 - Potentials and Challenges NGV 2011, the 2nd NGVA Europe International Show & Workshops. Berlin. http://www.ngvaeurope.eu/members/presentations/SGC-Mattias-Svensson.pdf

Tanzania Domestic Biogas Programme (2012). History of Biogas in Tanzania, Accessed August, 2012, http://www.biogas-tanzania.org/index.php/tdbp/about/category/history_of biogas in_tanzania/

Tempo (2011). News in Flash. http://www.tempo.com.ph/2011/biogas-motorcycle/. Accessed August, 2012.

Trudgeon, M., (2005) An overview of ngv cylinder safety standards, Production and in-service requirements, July. http://www.apvgn.pt/documentacao/overview_of_ngv_cylinder_safety_standards.pdf. Accessed May 2012.

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

Wang, D., Wen, T. (2006). Feasibility of Biogas as Transportation Fuel in China - Implications for the Policy Makers in China, Master of Science Thesis, Chalmers University of Technology , Göteborg, Sweden.

WASH Technology. (2009). Biogas: Chilean water utility inaugurates largest plant in South America. http://washtech.wordpress.com/2009/06/05/biogas-chilean-water-utility-inaugurates-largest-plant-in-south-america/ . Accessed August 2012.

Wellinger, A. (2012). Staying in the Course and Realizing Potential, Growing the Margins. Canadian Farm and Food Biogas Conferences. European Biogas Association.

Widodo, T.W, Hendriadi A. (2005) Development of Biogas Processing for small scale cattle farm in Indonesia, International Seminar on Poverty Reduction and sustainable Development, China.

Widodo, T.W, Hendriadi, A. (2005). Development of Biogas Processing for small scale cattle farm in Indonesia. International Seminar on Poverty Reduction and sustainable Development, China.

Wikipedia (2012) Gas compressor - diaphragm compressor. Available http://en.wikipedia.org/wiki/Gas_compressor#Diaphragm_compressors. Last accessed August 2012.

Worldwide NGV Statistics (2012). Natural and Biogas Vehicle Association, Europe. http://www.ngvaeurope.eu/worldwide-ngv-statistics. Accessed April 2012.

Yong, S.K., Young, M.Y., Chang, H.K., Jens, G. (2012). Status of biogas technologies and policies in South Korea. Renewable and Sustainable Energy Reviews. 16, 3430– 3438.

Zalosh, R. (2008), CNG and Hydrogen Vehicle Fuel Tank Failure Incidents, Testing, and Preventive Measures, Spring Meeting and 4th Global Congress on Process Safety, Conference Proceedings.

**Appendix A: Energy analysis of $20m^3$ $hour^{-1}$ biogas upgrading and bottling plant operating for 10 hours**

| | | |
|---|---|---|
| **Assumptions** | | |
| | Biogas Production | 200 $Nm^3$ $day^{-1}$ = 230kg |
| | Biogas upgrading plant capacity | 20 $Nm^3$ $hour^{-1}$ |
| | Calorific Value of raw biogas | 21MJ $m^{-3}$ |
| | Calorific Value of upgraded biogas | 36MJ $m^{-3}$ |
| | 1Nm3 of raw biogas | 6 kWh |
| | 1 Nm3 of upgraded biogas | 10 kWh |
| | Density of upgraded biogas | 0.72 |
| | Purified biogas obtained | 11 $Nm^3$ |
| | Number of working hours | 10 |
| | Purified biogas obtained after 10 hours | 80 kg (~ 110 $Nm^3$ ) |
| | Gas capacity of 60 l water capacity cylinder at 200 bar | 12 $Nm^3$ = 9 kg |
| | Gas capacity of 35 l waster capacity cylinder at 200 bar | 7 $Nm^3$ = 4.2 kg |
| **Energy Required for Purification** | | |
| 1) | For water pumping and pressuring at 10 bar pressure | 2 kW |
| 2) | For pressuring gas at 10 bar | 3 kW |
| | Total power required for upgrading 20 $m^3$ raw biogas | 5 kW |
| | Power consumption | 0.25 kWh $Nm^{-3}$ of raw biogas |
| | Energy content of 20 $m^3$ raw biogas required for upgrading per hour | 17.5 MJ |
| | Energy content of 200 $m^3$ raw biogas required for upgrading biogas | 175 MJ |
| **Energy Required for Compression And Bottling** | | **3 kW** |
| **Energy Required for Controls and Valves** | | **0.25 kW** |
| | Total energy required for bottling of 11 $m^3$ of upgraded biogas per hour | 3.25 kW |
| | Energy content of upgraded biogas per hour | 110 kW |
| | Power consumption | 0.3 kWh $Nm^{-3}$ of upgraded biogas |
| | Energy content of 11 $m^3$ upgraded biogas required for bottling per hour | 11.88 MJ |
| | Energy content of 110 $m^3$ upgraded biogas required for bottling | 118.8 MJ |
| | **Total energy required for upgrading and bottling of 20 $m^3$ $hour^{-1}$ of raw biogas** | **2 + 3+ 3+0.25 = 8.25 kW** |
| | **Total power consumption** | **8.25 kW** |
| | **Power requirement per $Nm^3$ / raw biogas** | **0.4125 kWh** |
| | **Hence power requirement for upgrading 200 $Nm^3$ / raw biogas** | **82.5 kW** |
| | **System energy requirement as a percentage of raw biogas** | **6.88 % of raw biogas energy** |
| | **System energy requirement as a percentage of** | **4.125 % of upgraded and** |

| | upgraded and bottled biogas | bottled biogas |
|---|---|---|
| **Bottling System** | | |
| | Net purified gas available for compression and bottling in a day | 110 $Nm^3$ = 80 kg |
| | Number of 60 ltr. cylinders filled in one day at 200 bar<br>Number of 35 ltr. cylinders filled in one day at 200 bar | 9<br>19 |
| | Weight of gas in each cylinder at 200 bar | 9 kg (in 60 l cylinder)<br>4.2 kg (in 35 l cylinder) |
| | **Energy stored per cylinder at 200 bar** | **450 MJ (in 60 l cylinder)**<br>**210 MJ (in 35 l cylinder)** |
| | **Number of hours required for filling the cylinder at 200 bar** | **1 hour 59 min (60 l cylinder)**<br>**1 hour 30 min (35 l cylinder)** |

**Economic viability of 200 m$^3$ day$^{-1}$ biogas production and 20 m$^3$ hour$^{-1}$ upgrading plant**

| | | |
|---|---|---|
| **Biogas Plant:** | | |
| | Waste Required | ~5 tonnes day$^{-1}$ cattle dung |
| | Water requirement in Biogas Plant: | ~ 5 tonnes day$^{-1}$ |
| | Biogas Production | 200 Nm$^3$ day$^{-1}$ |
| **A.** | **Cost:** | **Rs. 2 million (~ €30,000)** |
| **Biogas Upgrading and Bottling System (20 m$^3$ hour$^{-1}$)** | | |
| | Purified Gas Quantity | ~ 80 kg day$^{-1}$ |
| | Purified Gas Composition | $CH_4$: 95 %, $CO_2$: 3, $H_2S$: < 25 ppm, Moisture: < 20 ppm |
| | **Cost of biogas upgrading system** | **Rs. 4.5 million** |
| | **Cost of biogas bottling system** | **Rs. 0.5 million (including high pressure compressor system, cylinders for gas storage and gas dispensing system)** |
| **B.** | **Total cost of biogas upgrading and bottling system** | **Rs. 3.5 million (~ € 75,000)** |
| **Slurry Management System** | | |
| | Slurry Production | ~ 1.5 tonnes (50 % solid) |
| **C.** | **Cost:** | **Rs. 1million (~ € 15,000)** |
| **D.** | **Other Costs :** Land preparation, Civil work, High pressure gas storage cylinders taxes, Logistic etc. | **Rs. 1million (~ € 15,000)** |
| | **Total Initial Cost of Project (A+ B+ C+D)** | **Rs.9 million (~ € 1,35,000)** |
| **Revenue: if upgraded biogas is sold as a vehicle fuel** | | |
| | Purified Gas: as vehicle fuel | (Rs. 35 kg) * (80 kg) = Rs. 2800 day$^{-1}$ |
| | Slurry: | (Rs. 3 kg$^{-1}$) * (1500 kg) = Rs. 4500 day$^{-1}$ |
| | Total Revenue | Rs. 7300 day$^{-1}$ |
| **E.** | **Annual Revenue:** | **(Rs. 7300 day$^{-1}$) * (350 day) = Rs. 2.6 million (~ € 39,000)** |
| | Cost of Dung | (Rs. 250 tonne$^{-1}$) * (5 tonnes day$^{-1}$) = Rs. 1250 day$^{-1}$ |
| | Annual cost of dung | (Rs. 1250 day$^{-1}$) * (365) = Rs. 0.45 million |
| | Annual cost of water and electricity | Rs. 0.15 million (Annual) |
| | Annual cost of manpower | Rs. 0.2 million (Annual) |
| | Annual Maintenance cost | Rs. 0.15 million |
| **F.** | **Total Recurring cost** | **Rs. 0.95 million (~ € 14,200)** |
| | **Annual Profit:** | **Rs. 1.65 million (~ € 25,000)** |
| | Subsidy (Power Equivalent) | Rs. 1.6 million |
| | Beneficiary Expenditure | Rs. 7.4 million **(~ € 1,10,000)** |
| | Payback Period | 4.625 years |
| **Revenue: if upgraded biogas is sold as a cooking fuel** | | |
| | Purified Gas: as cooking fuel Commercial gas cost @ 72 kg | (Rs. 70 kg$^{-1}$) * (80 kg) = Rs. 5600 day$^{-1}$ |
| | Slurry: | (Rs. 3 kg$^{-1}$) * (1500 kg) = Rs. 4500 day$^{-1}$ |
| | Total Revenue | Rs. 10,100 day$^{-1}$ |
| **G.** | **Annual Revenue:** | **(Rs. 10,100 day$^{-1}$) * (350 day) = Rs. 3.56 million (~ € 52,000)** |
| | **Total Recurring cost** | **Rs. 0.95 million (~ € 14,200)** |

| | | |
|---|---|---|
| | **Annual Profit:** | **Rs. 2.61 million (~ € 39,000)** |
| | Subsidy (Power Equivalent) | Rs. 1.6 million |
| | Beneficiary Expenditure | Rs. 7.4 million **(~ € 1,10,000)** |
| | Payback Period | 2.84 years |

** The above calculations provide only a very rough idea for the complete project and are for discussion purposes only, while the actual figures vary on a case by case basis.*

## Appendix B: Compressors

| **JSC "Ural Compressor Plant",6, Estonskaya St, Ekaterinburg, 620 007, Russia** | **Compressors of 6GSh1.6-2/1.1-200 type** |
|---|---|
| The compressors are provided with water cooling and electric motor drive. | |
| Capacity, $m^3 min^{-1}$ | 2 |
| Initial pressure, MPa (bar) | 0.110.005 (1.1±0.05 |
| Outlet pressure, MPa (bar) | 20 (200) |
| Power consumption, kW (max) | 43 |
| | |
| Technical specifications | AGSh-5/1.1-250, AGSh-8/4-250 ,AGSh -9/7-250, AGSh-10/13-250 |
| Capacity, $m^3 min^{-1}$ | 5, 8, 9, 10 |
| Initial pressure, MPa (bar) | 0.01 (0,1)<br>0.3 (3)<br>0.6 (6)<br>1.2 (12 |
| Outlet pressure, MPa (bar) | 25 (250) |

| **Indian Compressors Limited, India** | |
|---|---|
| Capacity | 5 - 50 $m^3 hour^{-1}$ |
| Working Pressure | 200 bar |
| Cooling method | Air cooled (5 $m^3 hour^{-1}$), water cooled (above 10 $m^3 hour^{-1}$) |
| No. of stages | 4 |

| **Shanghai Davey Machinery Co., Ltd., China** | |
|---|---|
| Construction: | Vertical type |
| Compressed stage: | 4 |
| Rated capacity (suction): | 10 $m^3 hour^{-1}$ |
| Inlet pressure: | 0.1 |
| Exhaust pressure | 200 bar, |

| **Model: DMC-3/200** | |
|---|---|
| Suction Volume Displacement: | 3.0 $Nm^3 hour^{-1}$ |
| Cooling Mode: | Air-cooled |
| Intake Pressure: | 0.017-0.035 bar |
| Discharge Pressure: | 200 bar /250bar |
| Stages: | 4 |

| **Model: DMC-5/200** | |
|---|---|
| Suction Volume Displacement: | 5.0 $Nm^3 hour^{-1}$, 3.0 cfm |
| Cooling Mode: | Air-cooled |

| | |
|---|---|
| Intake Pressure: | 0.017-0.035 bar |
| Discharge Pressure: | 200 bar / 250bar |
| Stages : | 4 |
| **Coltri Compressors(Nuvair)**<br><br>**Coltri –MCH 5 CNG** | |
| Charging rate | 5 $m^3$ $hour^{-1}$ |
| Working Pressure: | 200 Bar |
| No of Stages and Cylinders: | 3 |
| Lubricant | Nuvair Oil |
| **Coltri -MCH10 CNG** | |
| Charging Rate: | 10 $m^3$ $hour^{-1}$ |
| Working Pressure: | 200 bar |
| No of Stages and Cylinders: | 3 |
| Lubricant | Nuvair Oil |
| | |
| Charging Rate: | 20 $m^3$ $hour^{-1}$ |
| Working Pressure: | 200 bar |
| No of Stages and Cylinders: | 4 |
| Lubricant | Nuvair Oil |
| **J.A Becker and Sohne**<br>**SV 225/300 NG** | |
| Free air delivery | 16 $m^3$ $hour^{-1}$ |
| Suction pressure (min) | 0.022 bar |
| Maximum. pressure | 350 bar |
| Stages | 3 |
| Cooling method | Air cooled |
| ***SVC 450/300 NG*** | |
| Free air delivery | 32 $m^3$ $hour^{-1}$ |
| Suction pressure (min) | 0.3 bar |
| Maximum. pressure | 350 bar |
| Stages | 4 |
| Cooling Method | Air cooled |

## Appendix C: Madhav Govigyan Anusandhan Sansthan, Nogaon, Bhilwara

### About the Dairy farm:

The dairy farm where medium size biogas plants had benn installed is Madhav Govigyan Anusandhan Sansthan, Nogaon, Bhilwara. It is a registered society under society registration act of Govt. of Rajasthan, India (Registration no. 94/BHL/2002-03). It has five large cattle sheds for 500 cows, 65 and 45 cum two biogas plants, biogas engine – generator (20 kW), vermin -compost pits, chaff cutting system, grazing field, bull house, veterinary care unit, central office, panchgavya products making lab etc. The orgainsation has dedicated team of volunteers and people working for improving rural economy through cows, organic agriculture and decentralized energy system. It is 500 km (approximately) far from Delhi.

### Biogas production and Utilisation

There is no grid supply in the dairy hence all the electricity.supply is from the biogas generator.
There are two biogas production plants;

1. one having capacity is 65 $Nm^3$/day and
2. other one is 45 $Nm^3$/day.

Hence total biogas production plant capacity is 110 $Nm^3$/day and at 80% plant efficiency, total biogas production is about 88 $Nm^3$/day.
About 13 $Nm^3$/day of raw biogas is utilized for cooking, medicine preparation in the laboratory and water heating. About 75 $Nm^3$/day of raw biogas is available for upgrading and about 37 $Nm^3$/day of upgraded biogas is obtained from the water scrubbing system. About 31 $Nm^3$/day upgraded biogas is utilized in Natural Gas generator set for electricity generation without bottling; upgraded biogas about 6 $Nm^3$/day is bottled for running CNG auto luggage carrier about 125 km/day.

### Description of the installed set-up at the dairy.

**Biogas Enrichment Plant (Plant for Purification of Biogas)** - Water Scrubbing System, gas scrubbing tower, gas storage pressure vessel (capacity of 16 m3/hr )

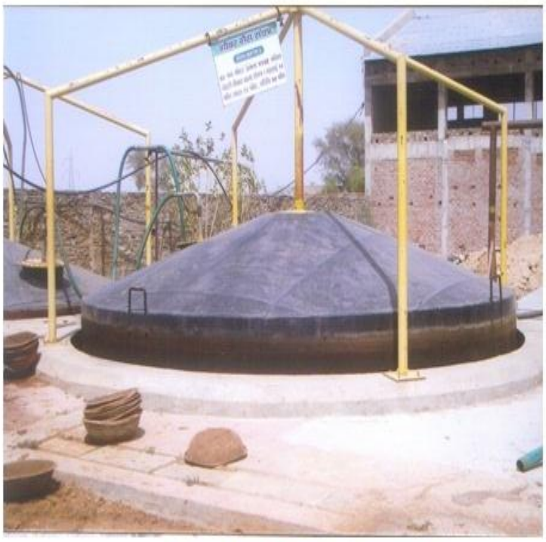
**Bio-CNG Cylinder Filling and Dispensing to CNG Vehicle** having cascade to two CNG Cylinders of 49 litre capacity (250 bar)

**Bio CNG Compressor Model BG 5 with Standard Accessories (Didwania made)** for filling in the range of 200 bar

**Bajaj CNG GC Max Auto Luggage Carrier (DL 1VB 5830) Three Wheeler Model 3W RE GC 1000 CNG (High Deck with Door),** Power: **5.4 KW (7.2 BHP),** Type: **Water Cooled 4 Stroke**, **Single Cylinder, SI, Petrol/CNG**, Body Type: **III Deck**.

## Pictures of Biogas Production and Upgarding System at Madhav Govigyan Anusandhan Sansthan, Nogaon, Bhilwara

Bhilwara Gaushala, Rajasthan



Biogas Plant at Bhilwara Gaushala

Biogas Enrichment Plant

High Pressure Compressor

Upgraded Biogas Dispensing System


CNG auto luggage carrier


Upgraded biogas being dispensed into biogas vehicle