Biogas REPORT

FACILITATION OF LARGE-SCALE UPTAKE OF ALTERNATIVE TRANSPORT FUELS IN SOUTH AFRICA – THE CASE FOR BIOGAS

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Acronyms and abbreviations

AD	Anaerobic Digestion
AFD	French Development Agency
BFP	Basic Fuel Price
BRT	Bus Rapid Transit System
Capex	Capital Expenditure
CBG	Compressed Biogas as a Substitute for CNG
CNG	Compressed Natural Gas
CDM	Clean Development Mechanism
CEF	Central Energy Fund
CHP	Combined Heat and Power (Electricity)
CNG	Compressed Natural Gas
COD	Chemical Oxygen Demand
COP	Conference of the Parties
CPI	Consumer Price Index
DBSA	Development Bank of Southern Africa
DEA	Department of Environmental Affairs
DFID	Department for International Development
DLE	Diesel Litre Equivalent
DSM	Demand-side Management
DSML	Demand-side Management Levy
DM	Dry Matter
DoE	Department of Energy
DoT	Department of Transport
ESSAC	European Science, Support and Advisory Committee
EU	European Union
FOB	Free on Board
FTE	Full-time Equivalent
GDP	Gross Domestic Product
GEF	Global Environment Facility
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
GIZ	Gesellschaft für Internationale Zusammenarbeit
GJ	Giga Joule
GLE	Gasoline Litre Equivalent
GSI	Global Subsidies Initiative
GtL	Gas to Liquid
GW	Giga Watt
GWh	Giga Watt hour
HCV	Heavy Commercial Vehicle
IDC	Industrial Development Corporation
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
IMF	International Monetary Fund
IP	Illuminating Paraffin
IPPC	Intergovernmental Panel on Climate Change

KfW	Kreditanstalt für Wiederaufbau
KTBL	Association for Technology and Structures in Agriculture
kW	Kilo Watt
kWh	Kilo Watt hour
LCV	Light Commercial Vehicle
LFG	Landfill Gas
LfL	German Bayerische Landesanstalt für Landwirtschaft
LNG	Liquid Natural Gas
LPG	Liquified Petroleum Gas
MACC	Marginal Abatement Cost Curve
MCV	Medium Commercial Vehicle
MFMA	Municipal Finance Management Act 2003 (Act No.56 of 2003)
MJ	Mega Joule
MPA	Mitigation Potential Analysis
MSW	Municipal Solid Waste
Mt	Million Tonnes (megatonnes)
MW	Mega Watt
MWh	Mega Watt hour
MWW	Municipal Wastewater
NCCRWP	National Climate Change Response White Paper
NERSA	National Energy Regulator of South Africa
NG	Natural Gas
NGO	Non-governmental Organisation
Nm^3	Normal Cubic Metre.
OECD	Organisation for Economic Cooperation and Development
Opex	Operating Expense Operational Expenditure
PEG	Polyethylene Glycol
PM	Particulate Matter
PSA	Pressure Swing Adsorption
REIPPP	Renewable Energy Independent Power Producer Procurement
SABIA	Southern African Biogas Industry Association
SAPIA	South African Petroleum Industry Association
SANEDI	South African National Energy Development Institute
SASA	South African Sugar Association
SCPF	Strategic Climate Policy Fund
SMME	Small, Medium and Micro Enterprise
SUV	Suburban Utility Vehicle
SWOT	Strengths, Weaknesses, Opportunities and Threats
TS	Total Solids
UASB	Up-flow Anaerobic Sludge Blanket
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
VAT	Value-added Tax
v/v	Volume per Volume
ZAR	South African Rand

Definitions

Anaerobic	Oxygen-free
Biomethane	Biogas upgraded to natural gas quality.
Mesophilic digestion	Digestion at 25-40 °C. Usually around 35-37 °C.
Methane concentration	Amount of methane (CH_4) in the biogas, normally expressed as percentage by volume.
Methane yield	Amount of CH_4 produced, expressed in e.g. Nm^3 per tonne total solids.
Normal cubic metre.	Volume at normal conditions for which two standards are commonly used: - DIN1343: 273.15 K (0 °C) and 1.013 bar (atmospheric pressure) - ISO2533: 288.15 K (15 °C) and 1.013 bar (atmospheric pressure)
Thermophilic digestion	Digestion in the range of 50-60 °C, but usually in the range of 50-55 °C.
Total solids	The weight of the substrate after drying, normally expressed as a percentage of wet weight. Also called dry matter.
Wheeling	The 'free' movement of electricity or gas along interconnected transmission/transport (pipe-) lines of different owners for a certain transmission fee.

Chemical symbols

C	Carbon
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
H	Hydrogen
H_2O	Water vapour
H_2S	Hydrogen sulphide
$ktCO_2e$	Kilotonnes of carbon dioxide equivalent
$MtCO_2e$	Million Tonnes (megatonnes) of carbon dioxide equivalent
N_2	Nitrogen
NO_X	Nitrogen dioxide
O_2	Oxygen
So_x	Sulphur oxides

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Acknowledgements

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Executive summary

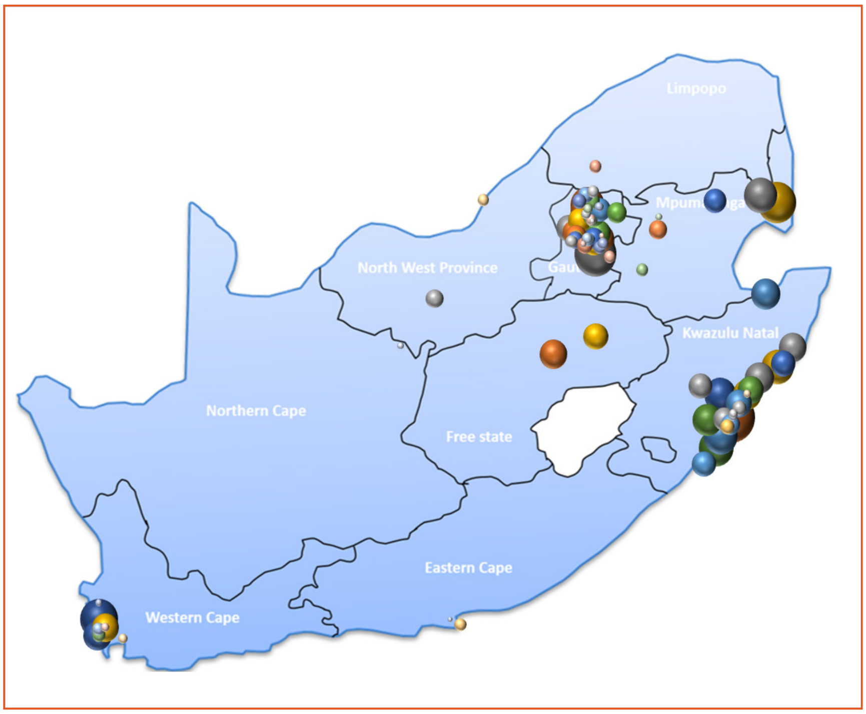
This study is part of a programme under the Strategic Climate Policy Fund (SCPF), established by the Department for International Development (DFID) of the United Kingdom (UK) government and managed by Cardno Emerging Markets (UK) Ltd on behalf of the Department of Environmental Affairs (DEA). The purpose of the fund is to translate the mitigation plans outlined in the National Climate Change Response White Paper (NCCRWP) (Republic of South Africa, 2011) into feasible mitigation actions.

The objective of this study is to establish an understanding of the economic and practical potential of compressed biogas (CBG) as an alternative transport fuel, thereby providing inputs to the potential further development of policies by the South African government. In support of this main objective, the study targeted the following results:

- The development of a national biogas inventory, including (as far as accessible and available) an indication of the quantity, quality and availability of biogas as a potential transport fuel.
- An assessment of the financial viability of the main CBG production processes, as well as the macro-economic effect and the national greenhouse gas (GHG) mitigation impact.
- The identification of opportunities for policy interventions by government in collaboration with business, with the aim of stimulating the application of CBG as an alternative transport fuel.

Potential of biogas for transport based on the relevant waste sources in the country

The total biogas potential from sources captured in the inventory is around three million normal cubic metres (Nm^3) per day, of which the majority can be found in the sugar and municipal solid waste (MSW) sectors. The majority of potential biogas sources are located in the proximity of South Africa's urbanised centres, along the KwaZulu-Natal coast, in Gauteng and around Cape Town. The following figure shows the geographic distribution of the potential biogas sources captured in the inventory. Each bubble represents a unique biogas source. The sizes of the different bubbles represent the relative biogas production potential between the sources.



It is worth noting that, with a share of 38% of the total volume, the MSW sector is the largest contributor to the country's biogas potential, and that these sources are all located in close proximity of urbanised areas. Several of the sources within this sector are among the ten largest point sources identified. From this, one can conclude that local governments in South Africa have the potential to control and/or operate a large share of the country's potential biogas-for-transport sources, making it ideally positioned to drive the large-scale uptake of biogas as a transport fuel.

Feasibility of transforming biogas to CBG as a transport fuel

Currently, the application of CBG as a transport fuel in South Africa is in its infancy. Biogas is mainly used to generate electricity and heat (combined heat and power), even though the analysis shows that processing biogas further into CBG, and using it as a transport fuel is economically the most attractive option. In spite of current market prices of petrol and diesel of around R11 to R14 per litre (ℓ), no material uptake of CBG as a transport fuel has materialised. Hence, it is evident that, under current conditions, market barriers prevent such uptake.

To a slightly lesser extent, the same can be said for compressed natural gas (CNG), which, when applied as a transport fuel, has very similar properties and technical requirements as CBG. Currently, the South African government supports the uptake of CNG as a transport fuel via an informal (i.e. not regulated) subsidy in the form of an implicit exemption on the fuel levies and taxes that are placed on petrol and diesel. In addition to this, the Industrial Development Corporation (IDC) provides a subsidy in the form of a soft loan for the conversion of petrol and/or diesel vehicles to CNG vehicles.

When comparing CNG with CBG from an economic perspective, CNG will probably remain more competitive, as gas from Mozambique is estimated by the Gas Users' Group to be imported by Sasol at only R20/GJ and sold at around R42/GJ on average, while at the pump, petrol is currently sold at a price higher than R309/GJ (R10/ℓ). Nevertheless, as petrol and diesel prices are largely governed by international markets, which are only influenced in a minor way by local alternatives, this will not be of importance. As long as petrol and diesel prices do not decrease further[1], the application of the same informal and formal subsidies for CBG as are currently being applied for CNG to counter market-entry barriers may make the application of CBG as a transport fuel viable if regulatory certainty is provided in this regard. Acknowledging the foregoing, the attractiveness for government to potentially stimulate biogas for transport would need to lie in the appreciation of the macro-economic effect, GHG mitigation impact and other co-benefits to government that the application of biogas as a transport fuel can make.

Gas in South Africa plays only a marginal role in the energy mix and, as such, there is very limited transport and retail infrastructure in place. While CBG can bring in the desired green content, CNG as a low-carbon fuel – if managed well – can provide the longer-term security and continuity of supply that this market needs to take off. The parallel emergence of CNG and CBG for the transport market therefore seems essential. Considering the latter, it is therefore crucial that government, in its overall policy framework, acknowledges the importance of CNG and CBG for transport, and facilitates the introduction of policies that should guarantee the security of supply and provide a stable environment for banks and investors to enter the industry. CNG and CBG, as alternatives to diesel and petrol, can only work if sufficient refuelling points are available. At the moment, only a handful of CNG fuel stations are operational, and a small number are under development, predominantly in Gauteng. Considering the limited range of CNG vehicles versus diesel- or petrol-powered vehicles, it is essential to focus on recurring transport patterns so as not to get intertwined in a 'chicken-and-egg' dilemma.

This report identifies three potential activity categories that could fit this profile: minibus taxis in many of South Africa's major cities, long-haul cargo transport routes between Gauteng and Durban, and CBG as a fuel for city bus transport systems that make use of the abundant waste streams of MSW and wastewater plants, also owned by cities. These categories once more indicate that municipalities are in the unique position of both controlling substantial resources and off-take.

Biogas for transport: benefits and barriers

In addition to high-level strategic benefits for the South African government resulting from the application of biogas as a transport fuel, such as reduced energy dependency and the diversification of the energy mix potential, benefits should be considered in relation to the currently prevailing practice of utilising biogas for the generation of electricity:

- *Economic/financial:* Appling biogas as a transport fuel creates a two- to three-times higher value, which would result in an increase in income from value-added tax (VAT) for government, as well as reducing

1. http://www.macrotrends.net/1369/crude-oil-price-history-chart

the country's foreign exchange (forex) requirements. On the other hand, utilising biogas for the generation of electricity could provide a 240- to 320-MW capacity to the strained South African electricity grid.
- *Environmental:* As a transport fuel, biogas would reduce the impact on air quality in urban areas, whereas the impact on air quality with the application of biogas in the electricity sector would be felt in more remote areas.
- *Socioeconomic:* The upgrading/compression of raw biogas for transport could result in one to two additional jobs per sizeable facility. When biogas is used for the generation of electricity, raw biogas is directly converted into electricity via a combined heat and power (CHP) installation.
- *Infrastructure development:* South Africa's electricity infrastructure is well developed, while the CNB/CBG infrastructure in South Africa is virtually non-existent. The skills that are available in the electricity sector are also much better developed than are skills related to the application of biogas in the transport sector.

In addition to the lack of economic viability, one of the main barriers brought forward by biogas project developers is the absence of a demand for CBG, certainly for the required longer term (a term of 10 to 15 years is essential to finance biogas projects). Therefore, most project developers still opt for biogas-to-electricity, as electricity for own use, wheeling agreements and delivery to third parties, as well as the delivery of electricity to the municipal grid, seem to provide better opportunities, regardless of certain difficulties (e.g. lack of wheeling regulations) encountered in realising this.

Regulations and related licences are also regularly mentioned as barriers to the implementation of biogas projects. Depending on the type of waste and size of the project, this can vary. In the case of abattoir waste, regulations are most strict, as one is dealing with potentially hazardous waste, for example pathogens, and the destruction of this waste needs to be ensured. Related licences need to be obtained on a national level. Moreover, the digestate is not always acknowledged as being safe (prion-free) and can still be considered waste, therefore limiting the opportunities to use and sell it.

Policy recommendations

Without government intervention, a positive business case for biogas in the national transport sector does not exist. The decision to support the business case should come from the overall benefits for the country as, in principle, CBG is currently not commercially competitive enough to overcome the barriers of implementation as a transport fuel. If government decides that these benefits justify support, it can be provided via three primary measures: subsidies, taxation and regulation.

When assessing opportunities for the application of these measures across the biogas-for-transport value chain, a wide-ranging mix of policy instruments can be considered. When looking at international experiences of government support for the uptake of different types of biofuels, it becomes apparent that most countries typically rely on a tax-incentive scheme, whereby biofuels are taxed at a lower rate than fossil fuels or are completely exempted from regular consumption/fuel taxes.

A mandatory blending requirement/quota system is the second-most relied on measure. When reviewing the effectiveness of these different measures, as applied internationally, using financial incentives, in combination with other policy measures, to promote biogas for transport is considered an effective option. There does not seem to be a compelling reason why this would be different in South Africa. As a result, it seems safe to conclude that government incentives can play a pivotal role in promoting the uptake of biogas for transport in South Africa.

In addition to identifying the optimal combination of measures and their location across the value chain, it is useful to identify the size of the financial incentive that could be applied. One rationale to determine the level of CBG-specific financial support (in comparison with support for CNG, which is gas-specific) is to look at domestic and international examples, as well as existing levels of support in relation to the different CBG-specific co-benefits, and to convert these into transport-related units of measure to allow for a comparison of 'apples with apples'. Considering three domestic and three international values (carbon tax, job creation and green fuel subsidies) that also apply to the case for biogas as a transport fuel, the level of support that the South African government could provide to the development of the biogas-for-transport sector could lie in the range of R1,80/GJ to R282,90/GJ when 'pegged' within the range of existing domestic or international measures, as illustrated in this study.

Summary overview of study findings and recommendations	
Findings derived from establishing an understanding of CBG as an alternative transport fuel	
FINDINGS	The total biogas potential from sources captured in the inventory is around three million Nm^3 per day.
	The majority of sources can be found within the sugar and MSW sectors, and most larger sources are in the proximity of urbanised centres along the KwaZulu-Natal coast, in Gauteng and around Cape Town.
	The development of CBG for transport is directly linked to and dependent on the development of CNG for transport by means of shared infrastructure and security of supply.
	CBG as a transport fuel in South Africa is currently not economically viable, despite benefitting from an informal subsidy provided by means of an exemption from fuel taxes and levies.
	Nevertheless, several strategic, economic, environmental, infrastructure development and socioeconomic benefits have been identified as benefits for the country.
	Main barriers standing in the way of the development of a biogas-for-transport sector include the absence of a stable medium- to long-term demand for CBG, the regulatory framework and licences.
Recommendations for the development of CBG as a transport fuel in South Africa	
RECOMMENDATIONS	If government considers the development of CBG as a transport fuel worthwhile, acknowledging the benefits for the country, a first step could be to formalise the current exemption from fuel taxes and levies for both CNG/CBG and put in place direct support (i.e. a subsidy for vehicle conversion) and support for CBG, as is currently the case for CNG, with regard to transport.
	Provide additional support for CBG as a transport fuel via the provision of subsidies or blending requirements in line with international practice.
	Specific support for CBG as a transport fuel based on its co-benefits could lie between R1,80/GJ and R282,90/GJ if linked to the domestic and international valuation of co-benefits, as illustrated in this study.
	Focus support towards the implementation of CBG for transport on sectors that control large biogas sources and fleets with fixed transport patterns, such as municipalities that own and/or operate large landfills and wastewater treatment plants, and own and/or operate public transport facilities.

Chapter 1: Introduction

This study is part of a programme under the SCPF established by DFID South Africa and managed by Cardno Emerging Markets (UK) Ltd on behalf of DEA. The purpose of the Fund is to translate the mitigation plans outlined in the National Climate Change Response White Paper (NCCRWP) to feasible mitigation action. The programme includes a range of studies covering several elements of the NCCRWP.

The main objective of this particular study is to establish an understanding of the economic and practical potential for CBG as an alternative transport fuel and GHG mitigation measure. This could provide the basis for the further development of policies promoting biogas for transport and the emergence of a national CBG industry.

1.1 Background

As identified in the National Climate Change Response Green Paper (Department of Environmental Affairs, 2010), transport systems form the backbone of South Africa's socioeconomic activities by enabling the movement of people and products. In the context of climate change, the transport sector is the fastest-growing source of GHG emissions in South Africa, and the second-most significant source after the energy sector (Department of Environmental Affairs, 2013). The latter implies that substantial mitigation potential may be found in the transport sector.

As reported by the Energy Research Centre (Dane, 2013), the transport sector consumes around 28% of final energy in South Africa, 97% of which is in liquid fuels, contributing to 13.1% of South Africa's GHG emissions. The sector is vital for economic development (Cohen 2011; Merven et al. 2012). According to the International Energy Agency (IEA) (2010), natural gas can play a significant role in cutting vehicle carbon dioxide (CO_2) emissions. Nevertheless, over the long term, there will need to be a commitment to transition to low CO_2 gas sources, such as biogas.

Biogas from organic sources needs to be cleaned, upgraded to a methane (CH_4) level similar to that of natural gas, and compressed in order to be used as transport fuel in the form of CBG. The combustion of CNG (or CBG for that matter) is much cleaner than the combustion of petrol or diesel. Because of the higher hydrogen (H):carbon (C) ratio of CH_4 versus conventional heavier fuels (petrol and diesel), it generates less CO_2 per energy equivalent of fuel[2].

Because of its clean combustion, CNG/CBG should have an additional advantage when applied in urban areas where air quality is generally an issue. For this reason, it can be a good fuel alternative for public fleets (i.e. public transport and waste removal service vehicles).

In the Mitigation Potential Analysis study (MPA) (Department of Environmental Affairs, 2014), CNG was identified as one of the opportunities to reduce emissions in the transport sector at a low cost (R1 360/kt CO_2e by 2050). The uptake of CNG vehicles has shown negative marginal abatement cost over all years. As such, it is an attractive measure to cut down road transport emissions. However, the large-scale uptake of CNG vehicles requires the necessary supporting infrastructure, along with the necessary supply of gas. This study aims to provide clarity on the potential of biogas as a transport fuel, as well as the question on how an emerging CBG industry could support the large-scale uptake of CNG- and CBG-powered vehicles.

1.2 Study objectives

Beneficiation of biogas can take different forms, from producing heat, electricity and CHP, to the production of transport fuel. The digester effluent resulting from biogas production can be used as a fertilizer. All these different forms contribute to diversifying the South African energy mix, which is currently dominated by local coal and (predominantly) imported transport fuels. Apart from a

2. Chemically, H atoms are converted into H_2O (water vapour) and C atoms are converted into CO_2. The higher the H:C ratio, the less CO_2 generated per energy equivalent of fuel.

positive environmental impact, fuel for transport and non-transport use can present a substantial positive socioeconomic impact, and should be assessed as a whole in respect of the overall biogas potential in the country. Nevertheless, the specific focus of this study is the use of CBG as a transport fuel, which is different from other uses, as it requires extensive cleaning, upgrading the CH_4 content to high levels similar to natural gas (NG), and compression.

As stated at the start of this section, the main objective of this study is to establish an understanding of the economic and practical potential of CBG as an alternative transport fuel and GHG mitigation measure, compared to the more common use of the gas to generate electricity, and thereby provide inputs to the potential further development of policies promoting biogas for transport and the emergence of a national CBG industry.

In support of this main objective, the study is targeted at the following results:

- The development of a national biomass inventory, including (as far as accessible and available) an indication of the quantity, quality and availability of biogas as a potential transport fuel.
- An assessment of the financial viability of the main CBG production processes, as well as the macro-economic effect and the national GHG mitigation impact.
- The identification of opportunities for policy interventions by government in collaboration with business, with the aim of stimulating the application of CBG as an alternative transport fuel.

1.3 Approach

To establish its practical potential, it was essential to determine a focus before being able to effectively map and assess biomass sources relevant to the production of biogas as an alternative transport fuel. The approach taken to determine this focus is the definition and application of four feasibility requirements, which will provide a basis for identifying potential biomass sources that could make an economically viable and practically achievable contribution to realising South Africa's potential for CBG as an alternative transport fuel, while:

- realising a low-cost measure to cut down road transport emissions;
- making a significant contribution to mitigation objectives; and
- achieving a positive socioeconomic impact.

1.3.1 Feasibility requirements

The set of feasibility requirements developed on the basis of the approach described above distinguishes between two application levels: a sector level and a project level.

Table 1.3.1: Feasibility requirements to be applied on sector and project level

Level	Feasibility requirement	Description
Sector	Commercially proven technology	Include only de-risked, proven technologies for commercial biogas production with clarity on economic, environmental and practical performance.
	Avoid negative socioeconomic and/or environmental impact	As a country in transition, it is important for South Africa that the Biogas for Transport Strategy is based on the premise that it has positive impacts from both a socioeconomic and environmental perspective.
Project	Critical mass for economies of scale	Point sources should be of sufficient size to convert and upgrade biomass, taking advantage of economies of scale.
	Avoid suboptimal usage of biomass for energy	Biomass sources currently used for lower-margin energy alternatives as heat and electricity have been included. If current market conditions and the regulatory environment become conducive to biogas for transport, these sources will become relevant again.

The first two feasibility requirements applied on a sector level result in a selection of sectors and relevant waste streams for the production of biogas for transport, as specified in Section 1.3.2. The second two feasibility requirements require project-specific information (e.g. quantity of waste produced at site) and will therefore be applied on a project level. The feasibility requirements summarised in the table above are further detailed below.

Commercially proven technology

The two main areas where innovation takes place and where the criterion of 'commercially proven technology' is relevant are production and upgrading technologies. The reason for applying this criterion is to focus on a practical potential that could be achieved in the short- to medium-term, rather than after completion of a research and development trajectory, including uncertainties. The latter could jeopardise the potential of targeted improvements as unexpected technical problems and technology costs may prevent implementation.

Production technologies

As shown in the analysis of the biogas-for-transport value chain (Figure 2.1.1 in Chapter 2), in particular, the two main mature technologies for processing biomass into biogas are:

- mesophilic anaerobic digestion (AD); and
- biogas collection from landfills.

Gasification of biomass, although potentially applicable to a large variety of biomass sources, is currently not common, and is generally not economically viable (IRENA, 2012). Moreover, the technology and required conversion of the synthesis gas, obtained through gasification, into biomethane is rather complex and costly. This introduces further risks and doubts with regard to the longer-term potential for biogas when produced using such gasification technologies.

Upgrading technologies

As described under Section 2.2.4, the following technologies are most commonly applied for the upgrading of biogas, and can be considered commercially proven:

- Water scrubbing
- Chemical and physical scrubbing
- Pressure swing adsorption (PSA)

Several studies, including Bauer, et al. (2013) and Valorgas (2011), have assessed these most commonly applied technologies with regard to economic performance and the scale at which they are applied.

Avoid negative socioeconomic and/or environmental impact

Potential biomass sources for biogas have only been considered if this application does not have negative socioeconomic or environmental impacts. Internationally, a range of studies proposes sets of rationales and guidelines that aim to ensure that these potential sources are not inadvertently considered (or only considered if certain mitigation criteria are met) as a source for the production of biogas. The most prominent issues to emerge are those around the impact of crop-to-fuel and the use of waste as fertilizer.

Crop-to-fuel

The National Academy of Sciences (2009), in its publication *Liquid transportation fuels from coal and biomass,* states that biomass production for liquid fuels should not compete for land on which an existing crop is produced for food, feed or fibre, or compete for pasture land that will be needed to feed a growing and increasingly affluent population. More generically, it has been concluded that biomass feedstock should first come from waste that would otherwise go to landfills (Johnson et al., 2006a; 2006b).

It is important to consider that growing crops for liquid or gas-based fuel does not only potentially compete with agricultural land use, but also with other agricultural resources, such as water, farming skills, infrastructure and capital. Following the latter rationale, the priority that should be given to waste streams, as well as the fact that fuel crops can, in principle, be grown on any piece of available land, making an inventory of crop-to-fuel sources impractical, this study excludes potential sources of biomass for biogas that that are not waste-based.

Use of waste as fertilizer

Waste streams are sometimes used to fertilize the land, e.g. fibre sludge from pulp mills (Rashid et al., 2006), thereby preventing the need for landfilling. Certain waste streams, pending their composition, can have advantageous effects by conditioning the soil, increasing its water- and mineral-holding capacity, thereby decreasing the need for mineral fertilizers. Nevertheless, this practice needs careful monitoring to prevent contamination in the longer term, with potentially undesired (trace) components like chemicals used in the production process from which the waste stems.

However, if the waste stream is used to generate biogas, the digestate is generally a superior concentrated mineral fertilizer, which can replace the raw waste stream as fertilizer. Moreover, the remaining organic matter is biologically more stable, which is suitable for soil improvement (Makádi et al., 2012).

Critical mass for economies of scale

Recent international studies (including Valorgas, 2011; Bauer et al., 2013) provide important insights into the appropriate scale of biogas production and upgrading. Results show that the central constraint in the biogas production, upgrading and compression cycle lies in upgrading biogas to biomethane. Although most biogas production in Europe comes from many small-scale digesters that produce small amounts of raw biogas (50 to 200 Nm^3 per hour), these sites are generally not economically suitable for upgrading and compression. In 2013, there were around 234 upgrading plants in operation in Europe, with a total upgrading capacity of 205 716 Nm^3 per hour of raw biogas equivalent to an average throughput of raw biogas of around 880 Nm^3 per hour. Most of these are located on large-scale biogas production sites.

The following figures show the cost of biogas production, upgrading and compression as a share of total cost for two categories waste: organic waste and sewage sludge (Valorgas, 2011). In both cases, the upgrading cost comprises a substantial part of the total cost. For the upgrading of biomethane from organic waste, this is 33%, whereas from sewage sludge, it is as much as 47%. This gives a good indication of the relative importance of upgrading in the whole production cycle.

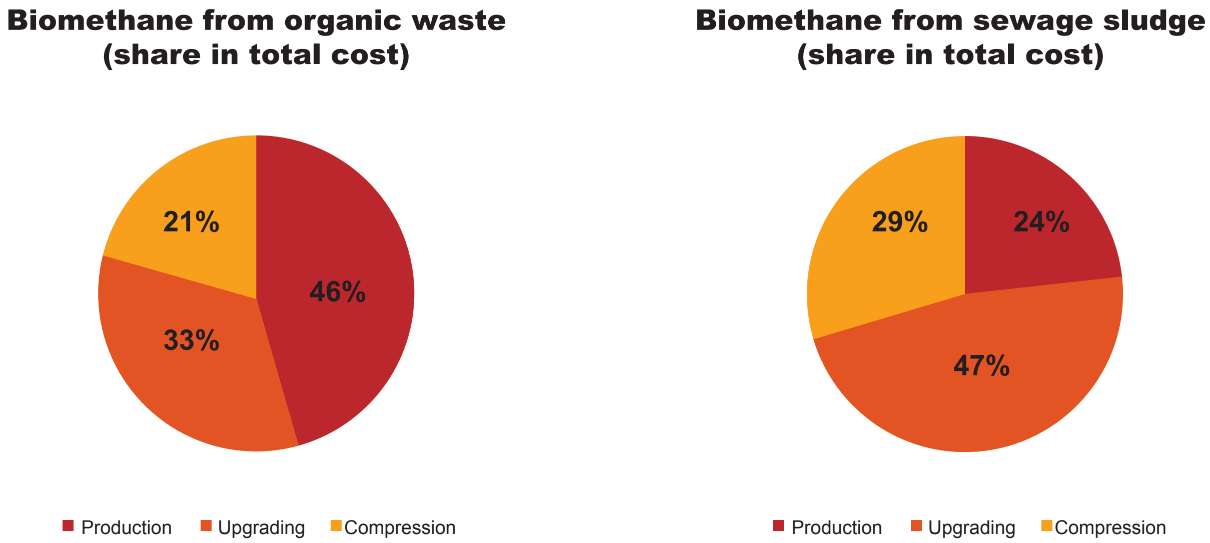


Figure 1.3.1: Costs of biogas production, upgrading and compression as a share of total cost

The costs of upgrading biogas to biomethane depend significantly on production plant size. In general, due to economies of scale, upgrading costs decrease with an increase in capacity. The next figure demonstrates the dynamics for different upgrading technolgies in terms of specific investment cost and total cost per kWh of biogas-based electricity produced, respectively, as a function of the biogas-processing capacity.

It shows that, with the current state of technology, an input of raw biogas of approximately 750 Nm^3 per hour is the minimum for economical investment in upgrading units. Furthermore, it is noteworthy that this result does not appear to depend much on the exact upgrading technology used, as the cost range between the technologies is relatively narrow.

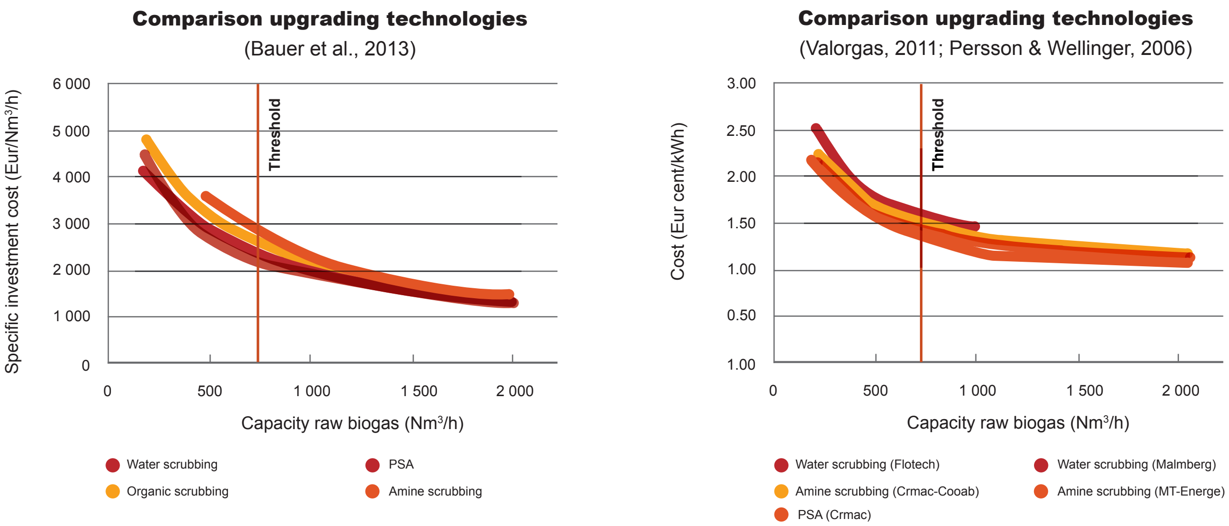


Figure 1.3.2: Costs of biogas upgrading and its dependency on installation capacity

Economics and related scale dependencies suggest focusing on single sources with a critical mass that corresponds to a minimum capacity of raw biogas production of 18 000 Nm^3 per day, equivalent to, for example, around 360 tonnes per day of MSW [3]. Furthermore, aggregating biomass from different sources to a central point for processing is significantly constrained by transportation and loading/unloading costs, which can accumulate to have a substantial impact on the cost of biomass feedstock in practice.

Avoid suboptimal usage of biomass

Organic waste may already be used to generate energy in some way or other. A simple, straightforward use is burning waste in a boiler to produce heat. More value-add can potentially be derived from waste when converted into biogas to produce electricity, CHP or to produce CBG. Although one option may, in theory, generate a higher monetary value per unit of energy than another, circumstances like familiarity with the technology, the demand on site for heat and electricity, no local off-take of CBG, and incentives like the Renewable Energy Independent Power Producer Procurement (REIPPP) Programme for renewable electricity may direct owners of biomass sources and project developers to other ways of producing electricity than the production of CBG.

Biomass sources that are currently being utilised in another form have been included in the inventory of biogas for transport sources. In principle, these sources could be utilised for the possibly more attractive production of transport fuels in the long run if market and regulatory conditions are changed to be conducive to the production of CBG. Section 4.1 of this report contains a comparison between electricity and CBG production.

3. Based on an organic fraction of around 50% (Kigozi, 2014) and a yield of 100 Nm^3 per tonne of organic MSW (Frankiewicz, 2014).

1.3.2 Sectors covered

The sectors covered in this study and the inventory of biomass for transport sources are presented in the table below. The table includes the focus on specific waste streams within the sector. The sectors mentioned were confirmed as being the main sectors of importance during stakeholder engagement and at the National Biogas Conference in March 2015.

Table 1.3.2: Sectors covered and focus on specific waste streams

Sectors	Sector focus
Abattoirs	Slaughter waste of various types (bovine, porcine, poultry), consisting of rumen/stomach content, manure, condemned material/trimmings and blood
Agriculture	Waste from livestock held in cattle feedlots, chicken and pig houses, i.e. manure, litter and silage respectively
Brewery	Wastewater resulting from the beer-brewing process and the sludge derived from it in the wastewater treatment process
Fruit processing	Discarded waste fruit and pomace; pomace is the solid remains of grapes, citrus, legumes or other fruit after pressing for juice or oil
Municipal solid waste	Waste currently disposed at landfills, consisting mainly of household garbage and, depending on the circumstances, including green city waste and garden waste
Municipal waste-water treatment	Sludge produced in the process of cleaning wastewater can be anaerobically digested, thereby reducing the remaining sludge and producing biogas
Pulp and paper	Several types of (woody) solid wastes and sludge are generated in pulp and paper production; the main waste stream focused on is fibre sludge, which is produced during the wastewater treatment process
Sugar production	The main waste stream at sugar mills that process cane is bagasse; on the growers' side, waste concerns tops and leaves, which are generally left in the field

1.4 Guidance to the structure of this report

This study is geared towards providing recommendations for policies that could facilitate the uptake of biogas as a transport fuel. The following chapters provide an overview of the biogas-for-transport value chain, an assessment of the national potential, and the feasibility of biogas for transport. This is followed by a final chapter with conclusions and recommendations for potential policy interventions.

Chapter 2 provides an analysis of the value chain and the important characteristics when producing and implementing biogas for transport.

Chapter 3 gives an overview of the status of the development of biogas in South Africa and the potential of biogas for transport, based on the availability and location of the relevant waste sources. The latter data has been retrieved from an inventory of biomass sources, which has been developed as part of this study. The custodian of this inventory is SANEDI.

Chapter 4 focuses on the feasibility of transforming biogas to CBG as a transport fuel. This chapter informs policy makers about the financial performance and hurdles with regard to biogas for transport in the context of a competitive fuels-for-transport marketplace. Moreover, it includes an analysis of the potential environmental and macro-economic benefits, should a large-scale uptake of biogas for transport be realised.

Chapter 5 concludes this study with recommendations for policy interventions and projects, focusing on financial incentives that could be provided to enhance the uptake of biogas for transport. Moreover, a high-level perspective is provided of the barriers identified during stakeholder engagement. The following diagram provides a schematic overview of the report structure, which, for the convenience of the reader, is reflected throughout the report.

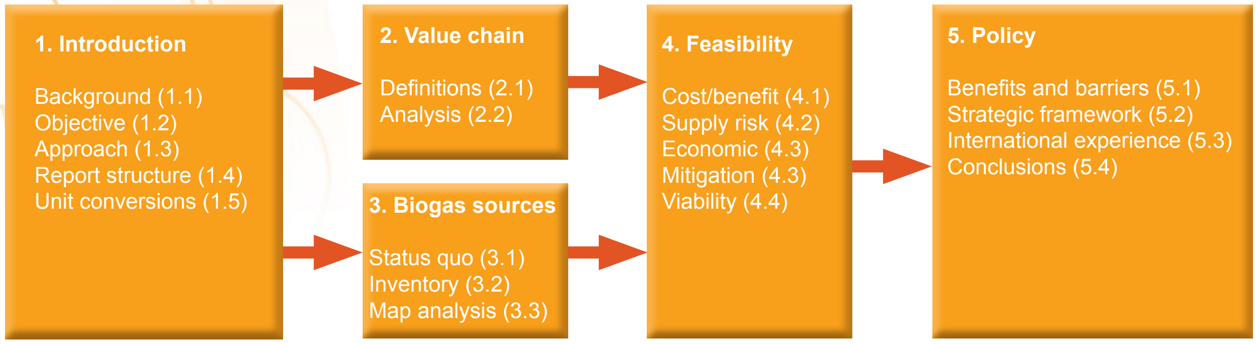


Figure 1.4.1: Report structure

1.5 Conversion between units

As guidance to the reader, Figure 1.5.1 and Table 1.5.2 below provide conversions of important units of measure used throughout the study, which should assist in interpreting values and their significance. The values in Figure 1.5.1 are calculated for dried raw biogas with 65% CH_4 content, starting with a biogas volume in Nm³/h as a basis, which is converted to MW of installed capacity, assuming a 100% (theoretical) conversion rate and subsequently GWh of energy produced during the year, based on a 100% (theoretical) availability.

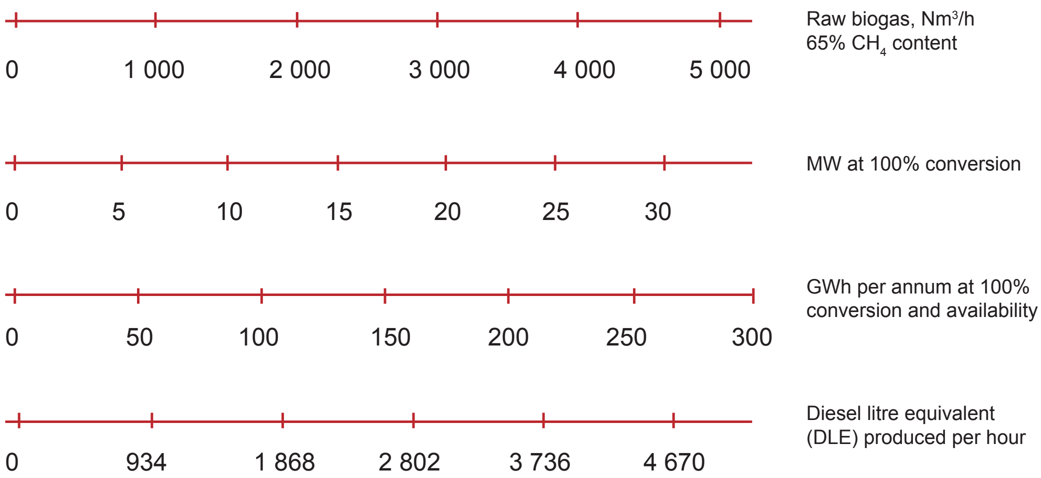


Figure 1.5.1: Units used for the analysis of biogas for the transport value chain

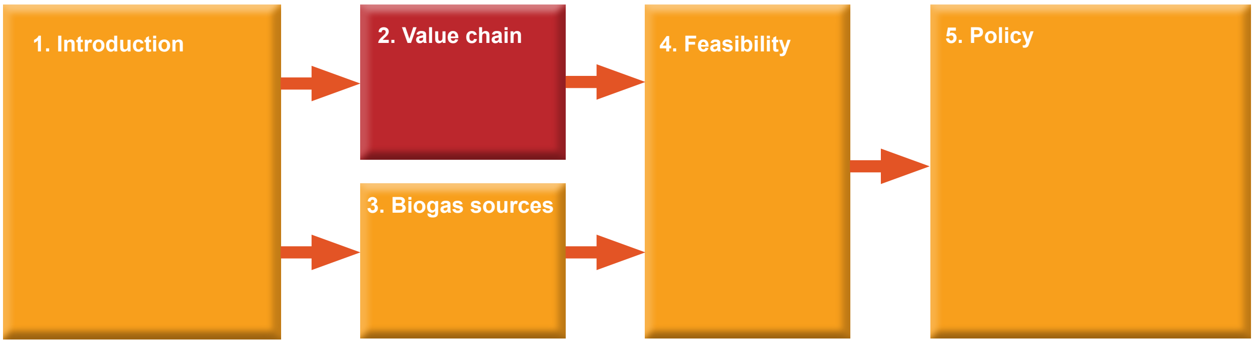
Conversion between several units and different forms of energy:

Table 1.5.1: Units of measure conversion table

Energy	kWh	MJ
1 kWh	1.0	3.6
1 MJ	0.28	1
1 Nm³ of biogas (65% CH_4)	6.4	23
1 litre of petrol	9.0	32.4
1 litre of diesel	35.8	35.8
1 litre of CNG/CBG at 250 bar	2.5	9.0

It becomes apparent from Table 1.5.1 above, that the energy density of a litre of CNG/CBG, although compressed to 250 bars, is only 9 MJ, which is significantly lower than that of petrol and diesel, which is 32.4 MJ and 35.8 MJ respectively. To achieve the same range, a transport vehicle therefore requires a larger CNG tank than the equivalent petrol or diesel fuel tank would.

Chapter 2: The biogas for transport value chain



This chapter provides the required technical context to the study by defining biogas for transport and providing insights obtained during an analysis of the value chain from the relevant biomass sources via production and upgrading to use biogas for transport.

2.1 Definition of biogas for transport

2.1.1 Definition of raw biogas

Biogas is generally referred to as a gas mixture derived from the decomposition of organic matter by anaerobic bacteria in the absence of oxygen. Biogas is typically composed of 65% CH_4 and 35% carbon dioxide, together with traces of contaminant gasses like hydrogen sulphide and ammonia. The exact composition depends on the type of feedstock and conditions of the fermentation process. Although biogas is the most valuable product, another product – the digestate – is a largely inert wet product with valuable plant nutrients and organic humus that can be used as soil conditioner (Redman, 2010).

The aforementioned typical definition of biogas (a gas derived from the bacterial decomposition of organic matter) is also used by the Southern African Biogas Industry Association (SABIA)[4]. As biodigestion is the most commonly applied and most commercially relevant type of biogas production, this study restricts itself to this definition.

Nevertheless, occasionally, biogas is also referred to as a gas mixture obtained from the gasification of biomass with or without further methanisation to achieve a composition comparable to that of natural gas. This type of technology is not included in this study as it is not commercially available, as further discussed in Section 2.2.3.

Biogas for transport

For use in transport, raw biogas needs to be cleaned and upgraded to a high-CH_4 content gas, also referred to as biomethane and compressed to CBG, which can be used as a substitute for or – mixed with CNG – used as vehicle fuel. As illustrated in the following table, this means the removal of more than 90% of the CO_2, small concentrations of nitrogen (N_2) and oxygen (O_2), as well as impurities like hydrogen sulphide (H_2S), siloxanes and ammonia.

4. http://biogasassociation.co.za/

Table 2.1.1: Comparison of the composition of biogas, biomethane and natural gas

Component	Biogas	Biomethane	Natural gas
	Content		
Methane	45–70%	94–99.9%	93–98%
Carbon dioxide	25–40%	0.1–4%	1%
Nitrogen	<3%	<3%	1%
Oxygen	<2%	<1%	-
Hydrogen	Traces	Traces	-
Hydrogen sulphide	<10 ppm	<10 ppm	-
Ammonia	Traces	Traces	-
Ethane	-	-	<3%
Propane	-	-	<2%
Siloxanes	Traces	-	-

Source: Kuczyńska & Pomykała (2012)

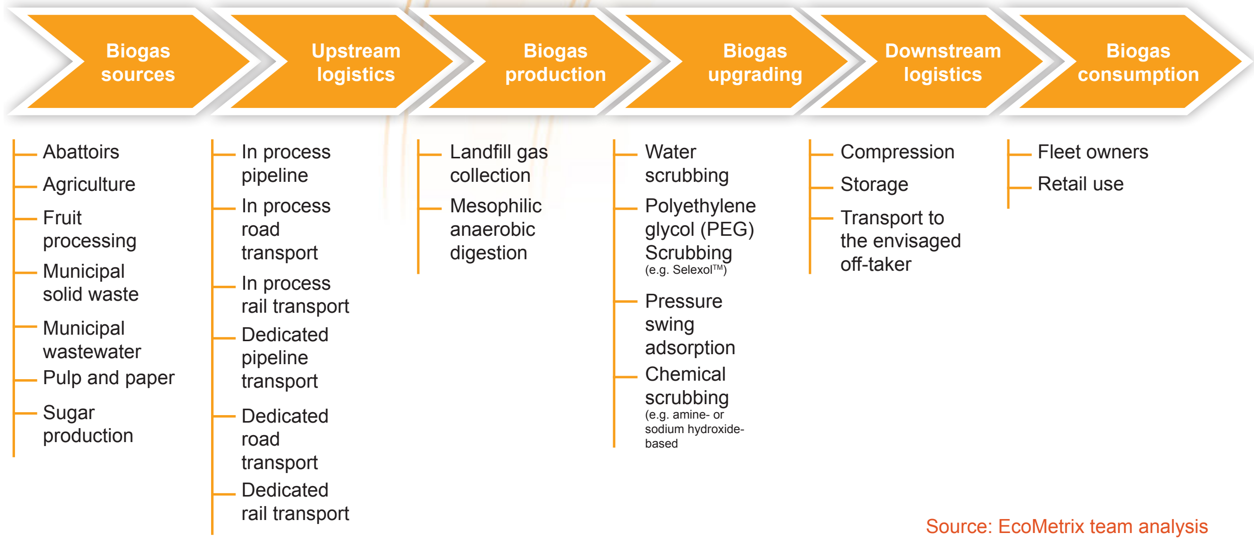
The CO_2 removed in the upgrading of biogas to biomethane is generally vented to the atmosphere and results in a GHG emission. However, from a carbon accounting perspective, it is important to realise that these emissions stem from short-cycle renewable waste sources and, moreover, that, in case the waste is not processed into biogas, uncontrolled aerobic or even anaerobic decomposition (the latter being most hurtful for the climate) will occur, resulting in emission to the atmosphere. Every avoided 1 000 Nm^3 release of biogas into the atmosphere equates to approximately 10 tCO_2e of GHG emissions. Nevertheless, this environmental benefit is not accounted for in this study, as the biomass may not decay anaerobically, or any CH_4 produced may be destroyed (e.g. flaring of landfill gas).

For use as transport fuel, natural gas or biomethane (upgraded biogas) is compressed to CNG and CBG respectively. In contrast to bottled butane and liquid natural gas (LNG), the compressed gas is not a liquid.

As illustrated in the table above, the composition of biogas can vary. The composition depends on multiple factors, such as the process design and operation, as well as the type of substrate. On average, the biogas produced by controlled AD has a 65% CH_4 content, which is significantly higher than that of biogas captured from landfills, which has an average 45% CH_4 content. These two average percentages are used throughout this study.

Biogas-for-transport value chain

The value chain of biogas for transport is complex, with various potential sources, potential ways of collecting the required biomass (upstream logistics), production and upgrading technologies, and ultimately the modalities of transport to get CBG to consumers. In line with the focus of the study, the value chain is illustrated in the following figure.



Source: EcoMetrix team analysis

Figure 2.1.1: The biogas-for-transport value chain

A unique step in the case of CBG for transport, as opposed to the use of biogas for electricity generation and heat with equipment designed to cope with a lower Methane content, is the upgrading step in which the Methane content is increased to levels comparable with natural gas. This step and others are described in the section that follows.

2.2 Value chain analysis

2.2.1 Biogas sources

The biogas-for-transport supply chain starts with biogas sources, also referred to as biomass or feedstock. Although there are various subdivisions, they are categorised according to the following key sectors with relevant organic wastes in line with the focus of this study: abattoirs, agriculture, fruit processing, municipal solid waste, municipal wastewater treatment, pulp and paper, and sugar production. Many of these wastes can be treated, used or disposed of in other ways that may not be without value. In that way, they can be in direct or indirect competition with biogas production. Examples include spreading to land, composting or incineration.

The following key sectors and focus on the relevant main organic waste types are defined:

1. *Abattoir*: Wastes generated include rumen/stomach content, manure and condemned material/trimming and blood. Except for blood, these types of waste have an attractive high biogas yield when anaerobically digested. A disadvantage of abattoirs is the applicable health and safety regulations with regard to the microbial quality. Slaughterhouse wastes can be contaminated with high numbers of microorganisms, including bacteria, viruses, prions, fungi, yeasts and associated microbial toxins (Urlings et al., 1992). Such wastes pose a potential risk to animal and human health, unless handled and treated properly.
2. *Agriculture*: Waste generated at farms includes animal manure (e.g. wet manure slurries) from intensive styles of livestock farming and dry animal manures (e.g. animal bedding). Although it has a relatively low biogas yield, large cattle feedlots and chicken broiler farms can produce sizable tonnages of waste and biogas.
3. *Brewery wastewater:* During the production process, wastewater accumulates from the various component processes (wort production, fermentation, storage, filtration, bottling). Anaerobic treatment is generally chosen for the first stage because of the higher chemical oxygen demand (COD). The volume of gas produced through the anaerobic digestion of the soluble organic matter is proportional to the mass of the organic matter.
4. *Fruit processing:* Although fruit processing is a seasonal business, discarded fruit and pomace (solid remains after pressing) are an interesting waste source with a high yield. However, seasonality can be a deal breaker as other biomass sources may be required to cover a period of up to eight months without production.

5. *Municipal solid waste*: This consists of all waste that is accumulated at landfills. Organic material is one of the largest constituents of municipal solid waste streams. The waste is either dumped without separating organic from non-organic waste streams, or the organic waste is separated from the non-organic waste (e.g. household, kitchen and garden waste). In practice, most municipal solid waste (including most food waste) in South Africa is dumped without separation, and has an organic fraction of around 48% (Department of Environmental Affairs, 2012).
6. *Municipal wastewater treatment:* Sewage sludge is produced as a by-product. Theoretically, all sewage sludge can function as biomass. However, in practice, issues may arise because of toxicity levels (especially in the case of the concentration of heavy metals). The remaining biosolid is more compressed than the original sewage sludge. It can be disposed of in a landfill (according to toxicity) or used as fertilizer/soil conditioner.
7. *Pulp and paper*: Waste streams are usually of substantial size due to the scale of operations. Depending on the process (i.e. chemical or mechanical pulping) and type of end-products (i.e. paper, newsprint or liner board), the content differs. Chemical pulping processes (i.e. Kraft and sulphite processes) are highly integrated and wastes are largely burnt in the boilers. The fibre sludge that remains in the wastewater can, however, be an interesting source of biomass with a high yield.
8. *Sugar production*: In South Africa, sugar production is based on sugar cane grown in large quantities in KwaZulu-Natal. Although tops and leaves left in the field are too distributed and low in yield, the bagasse produced after pressing the cane can be a useful feedstock. Although generally burned in the boilers of the sugar mill, the production of biogas may be an attractive alternative. In the case of sugar production, seasonality also plays a role.

The graph below provides an overview of the biogas yields for solid and semi-solid waste streams as used in this study. These yields are based on a number of scientific studies, including Fachagentur Nachwachsende Rohstoffe (2010), the feedstock atlas of the European Association for Technology and Structures in Agriculture (KTBL)[5] and research on the website of the German Bayerische Landesanstalt für Landwirtschaft (LfL)[6], as well as the analysis of the EcoMetrix team, and are expressed in GJ per ton of wet waste.

5. http://daten.ktbl.de/euagrobiogasbasis/startSeite.do;jsessionid=6673083D64CB29E2EA6734F-35C03F044
6. http://www.lfl.bayern.de/iba/energie/049711/?sel_list=32%2Cb&anker0=substratanker#substratanker

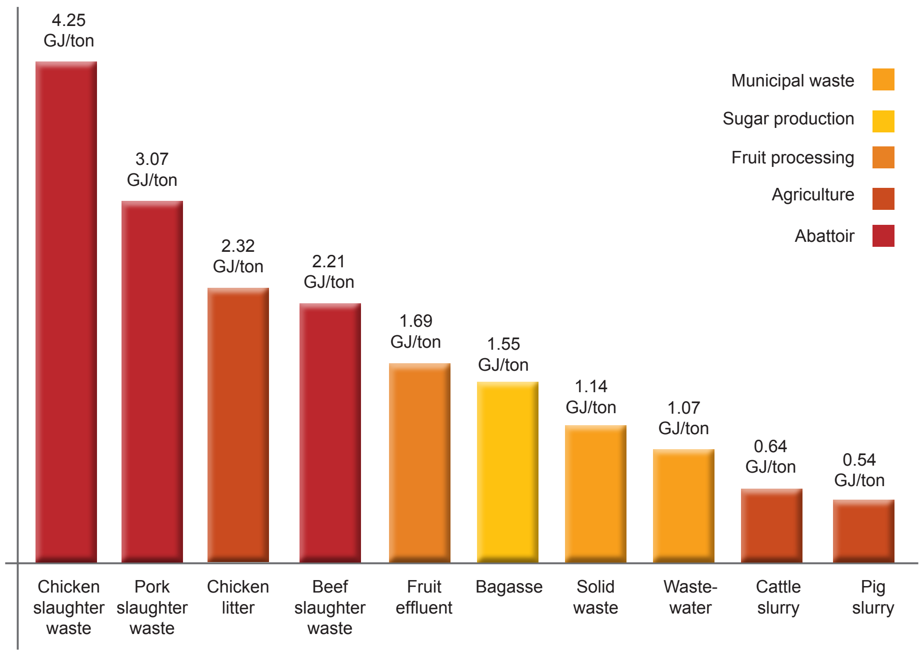


Figure 2.2.1: The relative biogas yield per source per sector (GJ/ton)

The diagram shows the relative distribution of the yield per source across and within the different sectors captured within this report. It is important to consider that, while the yields reflected in Figure 2.2.1 are based on both practical and theoretical in-depth studies, yields can vary from project to project, based on the unique characteristics of a specific project. The latter may include the dry matter content, storage and handling of feedstock, as well as the specific digester operation.

2.2.2 Upstream logistics

The second step in the biogas-for-transport supply chain is upstream logistics. This stage captures the transportation system in place to get biomass from the point source to the processing facility or production plant. A main consideration in the viability of biogas production is cost, a significant part of which is incurred in the course of transportation. Various generic modes of transport can be identified, which may or may not be relevant, depending on the type of biomass and the configuration of existing infrastructure in a region or country. On the whole, the following categories in upstream logistics are distinguished in the biogas value chain: in-process pipeline, road and rail transport, and dedicated pipeline, road and rail transport.

In this regard, a key distinction needs to be made between point sources that are large enough independently to sustain biogas production on an economically viable scale, and those that are not. In the first case, the biomass will already have been amassed on a sufficiently large scale through existing commercial processes (e.g. landfills or manure at feedlots). Otherwise, the case for biogas rests on developing an efficient transport system that collects feedstock from a number of smaller sources and carries it to a centralised biogas production plant for processing (e.g. small-scale farming).

As such, important factors to take into consideration include the following:

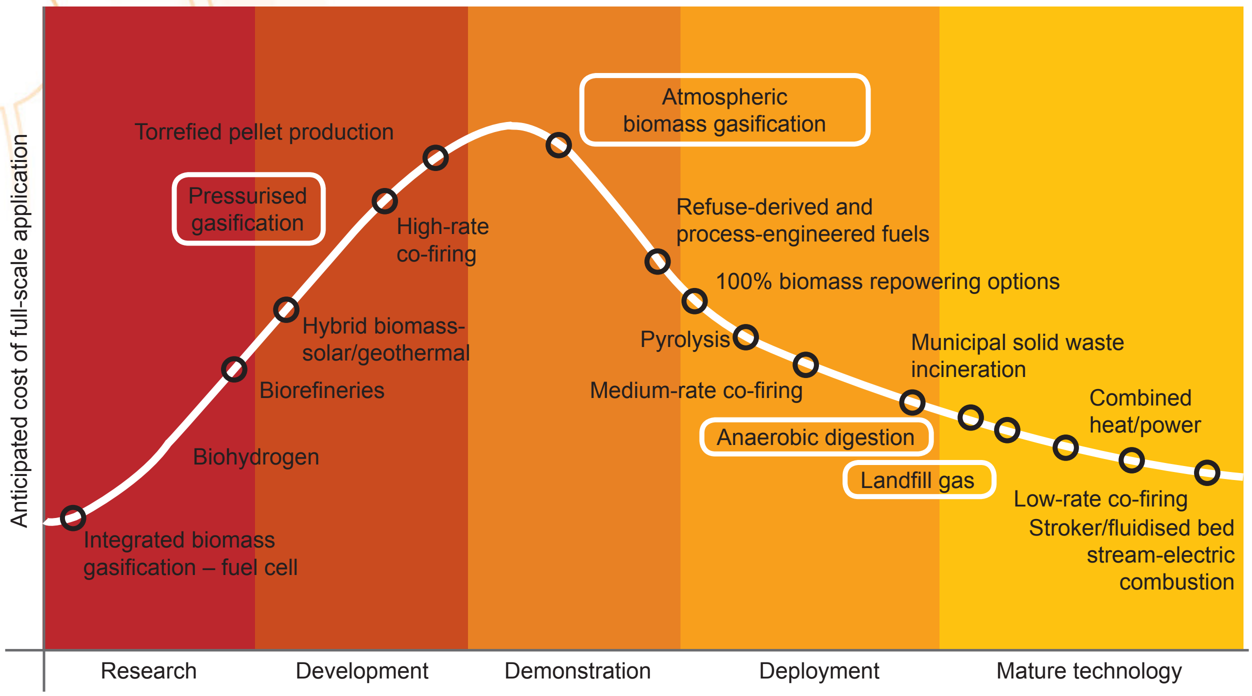
- Costs of on-site and off-site collection and transportation (so-called first transport and processing, and transport to destination)
- Distance/concentration of sources
- Relative size of biomass sources
- Gate fees
- Cost of waste stream handling in the absence of alternatives

Obviously, the share of transportation in the total production costs will depend substantially on country- or region-specific conditions and economics. Several international studies already exist on the economics of biomass collection and transportation. Most of these studies show a relatively high cost of transport for biomass fuel and related handling, even within relatively developed regions with advanced transportation networks (Junginger et al., 2011; Brechbill et al., 2011; Nielsen & Hjort-Gregersen, 2002; Wamisho et al., 2010).

As a general rule, confirmed by project developers during this study, one should not go beyond a radius of 10 to 15 km collecting biomass. On specific occasions (e.g. close range, high yield) sizable sources can be combined. However, these are exceptions rather than the rule.

2.2.3 Biogas production

In respect of biogas production, one generally refers to anaerobic digestion, which can take different forms and shapes, like industrial biodigesters, capped and controlled landfills with biogas collection or capped lagoons. In some cases, however, one also refers to biogas when gasifying biomass into a synthesis gas, which can be converted into CH_4 using a methanisation technology. However, biomass gasification is not a commonly used option. When looking at biomass-to-electricity application (biogas burned to generate electricity), it is still regarded as a technology in the demonstration phase. LFG and AD, on the other hand, are recognised mature technologies that are included in the scope of this study.



Source: IRENA (2012), EcoMetrix team analysis

Figure 2.2.2: Biogas technology maturity status

Anaerobic digestion

Anaerobic digestion is a naturally occurring process that concerns the decomposition of organic matter by bacteria thriving under low-oxygen (anaerobic) conditions. The organic decomposition under anaerobic conditions results in the generation of CO_2 and CH_4. See Table 2.1.1 for typical compositions.

Three main categories of anaerobic digestion can be classified by means of the temperature regimes under which the process takes place (Duff, n.d.):

1. Psychrophilic: <20 °C (68 °F):
   a. Covered lagoons
   b. Slow process dependent on ambient temperatures
   c. Large area requirements
2. Mesophilic: 35 °C to 40 °C (95 °F to 105 °F):
   a. Industrial and farm digesters
   b. Faster process
   c. Well controllable
3. Thermophilic: 50 °C to 60 °C (125 °F to 140 °F):
   a. Industrial and farm digesters
   b. Fastest reaction kinetics and shortest residence time
   c. Sanitises pathogen-bearing feedstock, but more complex to control

Most common is mesophilic anaerobic digestion, as the process is relatively easy to operate and control. Although thermophilic processes operated at a higher temperature produce more biogas in a shorter time, it requires higher input energy (more stringent feedstock requirements) to obtain the desired operation temperatures and may, moreover, generate free ammonia, which can act as an inhibitor (ISAT/GTZ 1999).

Anaerobic digester reactor systems can be designed using a number of different process configurations, depending on the desired operation and feedstock:

- Continuous or batch
- Mesophilic or thermophilic, determined by temperature range
- High solids or low solids (plug-flow or mixed reactor)
- Single-stage or multistage

Landfill gas collection

LFG is created by microorganisms that act on the organic waste within a landfill. This process is continuous, so that over time, the pressure within the landfill builds up and the gas is released into the atmosphere. Landfill gas typically contains between 40 and 60% CH_4, where the exact quality depends on the waste composition and landfill geometry.

Landfill gas can be captured through an LFG collection system of vertical wells or horizontal trenches. In this way, the gas can be syphoned off to a central collection header downstream. Here, it is either flared to prevent the relatively harmful CH_4 from entering the atmosphere, or it is used to generate energy. In the latter case, the biogas from the landfill is directly transformed into electricity and heat through CHP, or it can be upgraded to biomethane.

2.2.4 Biogas upgrading

Biogas upgrading consists of increasing the CH_4 content to a level similar to that of natural gas, removing water vapour and several impurities. The CH_4 level is increased by removing CO2 from the gas mixture. It is important to get the biomethane composition close to the composition of regular natural gas in order to realise a similar calorific value and burning characteristics. This allows for the shared use of equipment and infrastructure originally designed for natural gas. Moreover, as biomethane needs to be compressed to CBG, no energy is wasted by compressing non-burnable components.

Besides small amounts of N2 and O2, impurities generally concern contaminants like sulphur in the form of H2S, a highly poisonous gas, and siloxanes (R-Si-O-Si-R), which, when burned, are usually converted into silicon dioxide particles. These particles are chemically and physically similar to sand and can cause significant internal damage to turbines and/or engines (McCarrick, 2012).

Depending on the upgrading technology, impurities are removed from the biogas in the process of removing CO_2 in a separate pre-treatment step or within the digester. The removal of water can be done in several ways, but this does not generally pose a challenge.

Several sources in literature, including Petersson and Wellinger (2009), confirm that the most widely used technologies for biogas upgrading are PSA, water scrubbing, organic physical scrubbing and chemical scrubbing. These technologies are derived from common petrochemical process technologies and have matured for the application to biogas upgrading over the years. Generally speaking, these technologies benefit significantly from economies of scale (Bauer et al., 2013). Brief descriptions of these most widely used technologies, largely taken from Niesner et al. (2013), are as follows:

- *Water scrubbing:* This represents a process based on physical absorption, employing water as a solvent for dissolving CO_2. The solubility of CO_2 in water is many times higher than the solubility of CH_4 in water, and therefore selectively absorbs CO_2 from the raw biogas mixture.
- *Chemical scrubbing:* Like water scrubbing, it is based on selectively dissolving CO_2 from biogas in a solvent. However, absorption is associated with a chemical reaction (between CO_2 and the solvent). The most employed solvents are monoethanolamine, diethanolamine or diglycolamine, which, in comparison to water, can dissolve considerably more CO_2 per unit volume.
- *Physical scrubbing:* Like chemical scrubbing, it is an absorption process, however without a chemical reaction. The most-employed commercial solvents are Selexol™, Rectisol™ and Genosorb™. The technological arrangement is similar to chemical scrubbing. However, the energy requirement for regeneration at a higher temperature is lower than for chemical scrubbing. Pretreatment of H_2S is not required (Beil & Hoffstede, 2010).
- *Pressure swing adsorption:* This is based on adsorption. Adsorbent materials are able to selectively retain specific compounds of a mixture by molecular size. CO_2 molecules are smaller than CH_4 molecules, and are therefore selectively captured from the CO_2/CH_4 biogas mixture in the adsorbent material. Process efficiency depends mainly on temperature, pressure and adsorbent type. The

pressure of the process is varied to load/unload the adsorbent material. Commercial adsorbents can include molecular sieves, zeolites and activated carbon (Grande, 2011).

2.2.5 Downstream logistics

Once upgraded to the required specification, the biogas, in essence, has become natural gas (which is mainly composed of CH_4). Like natural gas, biogas can then be compressed to either CNG or LNG. While both are forms of gas ready for storage and long-distance transportation, the key difference is that CNG, albeit its high density, is still a gas and is stored at ambient temperature, while LNG is a liquid stored at very low temperature. The table below provides a generic comparison between LNG and CNG (National Renewable Energy Laboratory, 1991).

Table 2.2.1: Generic comparison between CNG and LNG

Comparison	CNG	LNG
Physical state	Gas	Liquid
Temperature when stored	Ambient	-162 °C
Typical pressure when stored	172–248 bar	0.7–3.4 bar
Typical energy density (lower heating value)	6 500–9 500 MJ/ℓ	5 250–21 000 MJ/ℓ

The downstream logistical step of the biogas-for-transport value chain can be separated into three components:

- Compression or liquifaction
- Storage
- Transport to the envisaged off-taker

CNG has a lower cost of production and storage compared to LNG, as it does not require an expensive cooling process or cryogenic storage tanks. As a consequence, LNG is generally only used for transporting natural gas over large distances by sea where pipelines do not suffice. As this study focuses on the local generation and utilisation of biogas, LNG transport and storage application is excluded.

Biogas upgraded to biomethane and compressed to CBG requires compression equipment and energy. Commercial technologies for the compression of natural gas can be used and are readily available. However, it is important to consider that the investment costs for the equipment and the ongoing costs of operating the equipment (e.g. energy, maintenance) have to be recuperated from the commercialisation of the biogas at the end of the value chain. To compress biogas to between 250 and 270 bar, the estimated cost for compression lies at around 0.1 Eur/Nm^3 (Valorgas, 2011).

In case of on-site use, CNG storage is principally used to meet load variations. Gas is injected into storage during periods of low demand and withdrawn from storage during periods of peak demand. As CNG is stored under high pressure, this mostly happens in cylindrical storage vessels that are designed to withstand high pressures.

In situations where CNG is not used on location (either internally or via commercialisation at the gate), the CNG can be transported from the storage facility to the end-user in a number of ways, including pipeline, rail and road transport. The selection of the transport medium is dependent on the existing infrastructure in the vicinity of the storage facility (e.g. whether there is a suitable gas line or railroad station nearby) and/or the costs of additional infrastructure. If volumes are limited and pipelines and railroads are not easily accessible, which is often the case as South African gas infrastructure is very limited, the most practical flexible solution is transport by road to any off-taker of choice, pending demand.

2.2.6 Biogas consumption

Biogas upgraded and compressed has a wide range of applications. Within the confines of this study, only the application as transport fuel is considered. An existing petrol vehicle can be converted to a dual-fuel (petrol/CNG) vehicle. However, even in its compressed state, CNG's volumetric energy density is only 25% that of diesel (Eberhardt, 2002). Therefore, the required tank in a vehicle for CNG is larger, and due to its pressured containment requirement, costlier than a conventional fuel tank. The aforementioned benefits and compromises are illustrated in the example of the Honda Civic provided in Box 2.2.1.

Generically speaking, two main types of direct off-takers for CNG can be distinguished in the transport environment:

- *Fleet owners:* These are owners of a fleet of vehicles operated collectively with fixed routes and/or stopover points in most cases. Fleets can be owned and/or operated by the private sector (e.g. trucking companies) or public sector (e.g. city bus service, public waste collection agencies).
- *Retailers:* Retailers offer individual vehicle owners the services of refilling their CNG-converted vehicles at commercial on-demand refuelling stations, which are commonly part of an existing fuel distribution system (i.e. an additional CNG pump at an existing petrol station).

In addition, there may be direct off-take by individual users with one vehicle or a limited number of vehicles using CNG in use. However, investment in individual filling stations is generally much less attractive economically, and individual off-takers are therefore rare.

Box 2.2.1 : The Honda Civic on natural gas

Since 2008, when the car was introduced in the USA, Honda has sold around 1 000 to 3 000 CNG vehicles a year. An important influence on sales is the cost advantage of CNG over petrol and diesel. With fossil fuel prices having dropped significantly in 2014, sales came down as well.

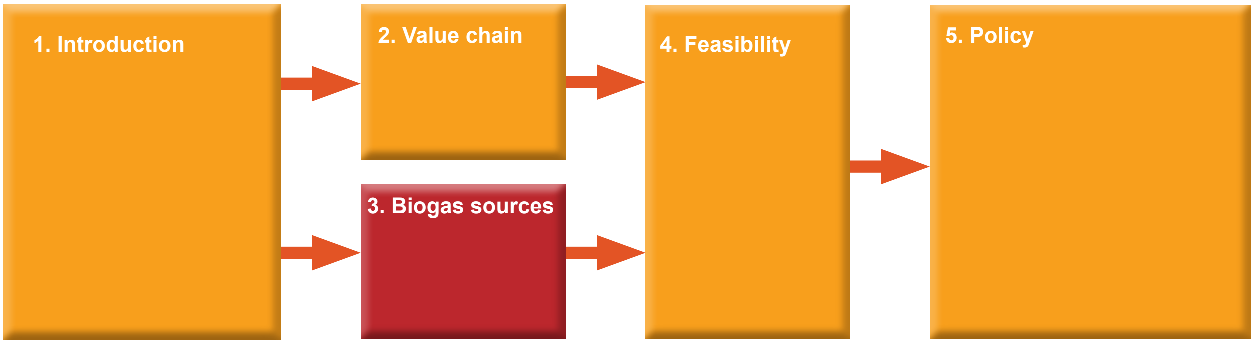
Lower fuel costs, better air quality and lower GHG emissions are substantial benefits that the natural gas option brings. On the other hand, disadvantages are the limited range, reduced trunk space and limited availability. An overview of pros and cons, as reported in reviews* are presented in the table below.

Honda Civic at a public natural gas fuel station.

Benefits	Compromises
Fuel cost: About 30% versus 50% lower fuel cost for commercial versus home fuelling.	Trunk space: Roughly half the trunk capacity is given over to the tank, while range anxiety remains.
Clean and climate-friendly fuel: When compared with gasoline, 90% less CO_2 and 16 to 91% less nitrogen dioxide (NO_x), fewer carcinogenic pollutants, little or no particulate matter, 13 to 18% less GHG emissions, according to Natural Gas Vehicles for America.	Purchase cost: The Civic on natural gas is about 40% more expensive than a gasoline equivalent (before incentives). A home-fuelling station could add another 27%, compared to a gasoline equivalent.
Reducing reliance on foreign oil: Domestically sourced natural gas reduces reliance on imported oil.	Availability: CNG stations are not available in some areas, and some are only open to fleet owners

*ConsumerReports.org (2014): http://www.consumerreports.org/cro/2012/03/the-natural-gas-alternative/index.htm; USA Today (2011): http://usatoday30.usatoday.com/money/autos/reviews/healey/story/2011-11-10/civic-cng-test-drive/51159408/1; Forbes (2015): http://www.forbes.com/sites/michaelkanellos/2015/01/19/sales-of-hondas-natural-gas-civic-plummet/2/; and NVG America: http://www.ngvamerica.org/natural-gas/environmental-benefits/.

Chapter 3: Biogas-for-transport sources in South Africa



This chapter captures the results of the Inventory of Biogas for Transport Sources, providing a perspective on the most relevant biogas-for-transport sources, the main contributing sectors and their locations. Before looking at the inventory itself, the current status quo of the sector is provided below.

3.1 Status quo of the South African biogas sector

To ensure that an objective view can be developed around the feasibility of CBG for transport, this section provides an overview of the current status quo of the biogas sector in South Africa.

It is estimated that there are currently several hundred biogas digesters scattered across South Africa. Most of these are accounted for by small domestic units and a few initiatives driven by non-governmental organisations (NGOs). In comparison, there are 12 million biogas digesters in India and 17 million in China (Ruffini, 2013). Although these numbers might give the impression that South Africa does relatively well when it comes to the total digesters per capita, considering the large populations in India and China, the table below provides some additional insight into South Africa's position in relation to Germany and China.

Table 3.1.1: Digesters per country

Country	No digesters	Population	Number per capita
Germany	6 800	82 000 000	0.000 083
China	17 000 000	1 357 000 000	0.012 528
South Africa	200	52 000 000	0.000 004

An ESI-Africa article entitled 'SA not using its biogas potential'[7] provides a number of reasons for this limited number of biogas digester plants in South Africa. These include public apathy (other sources of electricity are much less of a hassle), cheap electricity, limited grants or government incentives and no local technology providers.

An overview of existing biogas projects in South Africa was presented at the first SABIA Biogas Conference (Munganga, 2013). The following three types of biogas installations are distinguished:

- *Type 1: Domestic and residential digesters:* These are used for cooking, lighting or sanitation in rural residential areas (e.g. villages and schools). In South Africa, the most common of these installations is a digester made of PVC, concrete and plastic bags (i.e. a biobag digester).
- *Type 2: Small-scale and medium commercial digesters:* These are defined as biogas systems with an installed capacity of between 25 and 250 kWe, where the gas is used directly for heating purposes or indirectly for the generation of electricity (e.g. conference and community centres, small commercial facilities, such as abattoirs, as well as dairy factories and farms).
- *Type 3: Large-scale installations:* These are installations where large-scale digesters (with a capacity larger than 250 kWe) utilise the biogas from large sources, such as abattoirs, farms, MSW and wastewater treatment facilities.

The table below provides an overview of the existing biogas projects for Type 2 and Type 3 as defined above.

7. http://www.esi-africa.com/sa-not-using-its-biogas-potential/

Table 3.1.2: Overview of existing biogas projects in South Africa

Size	Name	Electrical capacity
Small-scale and medium-scale commercial digesters	Humphries Boerdery (outside Bela-Bela)	30 kW
	Jan Kemdorp Abattoir (iBERT)	100 kW
	Cullinan	190 kW
	Robertson	150 kW
	Jacobsdal	150 kW
Large-scale installations	Mariannhill (Durban)	1 MW
	Bisasar Road (Durban)	6.5 MW
	Chloorkop landfill gas project (EnviroServ)	unknown
	Ekhurleni landfill gas project	unknown
	Robinson Deep (City of Johannesburg)	19 MW
	Alrode/up-flow anaerobic sludge blanket (UASB) (brewery)	unknown
	Newlands/UASB (brewery)	unknown
	Rosslyn (brewery)	unknown
	Prospection (brewery)	unknown
	Ibhayi (brewery)	unknown
	Cape Flats biogas digester-dewatering sludge	unknown
	Ceres fruit farm-UASB digester (Veolia)	unknown
	PetroSA (Biotherm)	4.2 MW
	Northern Wastewater Treatment Works – Biogas-to-electricity Project	1.1 MW

Most of the biogas projects listed above use the biogas for the generation of electricity or direct use, and in some cases for a combination of heat and power. No active projects have been identified that upgrade biogas to CNG for use in transport services.

3.2 The Biogas for Transport Sources Inventory

To determine the national potential of biogas-for-transport, this study includes the development of a waste biomass inventory and map. It is important to note that the biogas inventory and map are developed without a predetermined pro-biogas-for-transport view, and therefore cover sources from which biogas can be applied within the transport sector, but also for other applications. However, to ensure that the inventory and map provide relevant information from a biogas-for-transport application, as per the mandate of this study, the inventory and map contain information relating to the biogas potential and the quality of the underlying biomass source from a qualitative and quantitative perspective. The table below provides an overview of the quantitative and qualitative details captured per source.

Table 3.2.1: Biogas inventory qualitative and quantitative criteria definitions

Type	Characteristic	Definition	Unit of measure
Quantitative	Biogas quantity	Provides an indication of the biogas potential per biomass source and is expresses as annual average biogas potential in cubic metres per day	Nm^3 per day
Qualitative	Yield	Expresses the potential to convert the biomass from a particular source into biogas in cubic metres of biogas per tonne of biomass at the source	Nm^3 per ton of fresh material
	Remaining lifetime	Captures the expected lifetime over which the biomass from a specific source will remain available in years	Annum
	Seasonality	Indicates the availability of the biomass at a specific source within a year, and is expressed in months, where 12 months indicates that the biomass is available at the source on a continuous basis	Months

In addition to these quantitative and qualitative criteria and the physical location of each potential source, which is required to map the geographic location of the sources, the inventory captures additional specific information on the biomass source. The additional information does not only allow the user to better identify the source (e.g. plant name, plant owner, etc.), but also enables the user to develop a better understanding of the origin of the biomass waste stream, for example, via a description of the underlying process from which the waste stream materialises.

This additional detail captured within the inventory, in combination with the quantitative and qualitative criteria per source, allows the user to identify individual sources that meet specific requirements set for the development of a biogas-for-transport generation facility within a specific geographic region.

The biogas-for-transport viability per source depends heavily on the individual requirements of a biogas-for-transport project developer, which in practice means that this level of analysis of the inventory cannot be done from a national biogas-for-transport potential perspective. For this reason, the next section provides a holistic analysis of the inventory and map to provide insight into the biogas-for-transport potential within the country as a whole, rather than on a source-by-source basis.

3.3 Main sectors and potential

The inventory captures potential biogas distributed over eight different sectors, and distinguishes between 12 different biomass types. The figure below provides an overview of the potential biogas volumes per sector.

Sector	Biogas potential (relative per sector)	Biogas potential (Nm³/day)
Fruit processing	0.21%	6 360 Nm³/day
Brewery	0.36%	10 615 Nm³/day
Abattoir	1.27%	38 050 Nm³/day
Pulp and paper	6.91%	206 400 Nm³/day
Municipal waste water	7.27%	216 911 Nm³/day
Agriculture	13.77%	410 989 Nm³/day
Sugar production	32.35%	965 736 Nm³/day
Municipal solid water	38.07%	1 136 450 Nm³/day
Total		**2 985 150 Nm³/day**

Figure 3.2.1: Biogas potential per sector (Nm³ per day)

It becomes apparent from the table above that the total biogas potential from sources captured in the inventory is around three million Nm³ per day, of which the majority can be found in the sugar and MSW sectors. Although the remaining lifetime of the source and the seasonality of the source, among other things, are relevant considerations when assessing the biogas-for-transport potential of a range of sources, the total potential volume of a source, in most cases, provides a first indication of the potential of the sources from a biogas-for-transport perspective. The figure below provides an overview of the ten largest biogas-for-transport sources captured in the inventory.

Sources	Biogas potential (Nm³/day)
Bisasar Road landfill	175 000 Nm³/day
Karan Beef feedlot	138 146 Nm³/day
Komati Mill	116 008 Nm³/day
Vissershoek (south/north)	108 050 Nm³/day
Sezele Mill	93 296 Nm³/day
Sappi Saiccor Mill	89 600 Nm³/day
Onderstepoort landfill	88 800 Nm³/day
Malalane Mill	86 972 Nm³/day
Flexton Mill	81 872 Nm³/day
Noodsberg	79 696 Nm³/day
Total	**1 057 440 Nm³/day**

Figure 3.2.2: Biogas potential per source (Nm³ per day)

It is interesting to note that, among the ten largest sources, a wide range of sectors is represented, such as MSW, agriculture, pulp and paper, and sugar production. In addition to that, it is worth considering that the ten largest potential sources (as listed in the figure above) make up over one-third of the total identified potential.

3.4 Conclusion

Even though the biogas inventory and map itself were developed with an independent and open view as to the type of use of the biogas, the analysis of the inventory focuses on the potential application within the transport sector. Due to the downstream logistical complexities (e.g. limited range of CBG/CNG vehicles), the geographic location of potential biogas sources in relation to potential customers, and the current and future CNG infrastructure are of importance when assessing the national potential of CBG for transport purposes. For this reason, the biogas-for-transport inventory was used to visually represent the different potential sources on a map of South Africa.

The figure below shows the geographic distribution of the potential biogas sources captured in the inventory. Each bubble has a unique colour and represents a unique biogas source. The sizes of the different bubbles represent the relative biogas production potential between the sources.

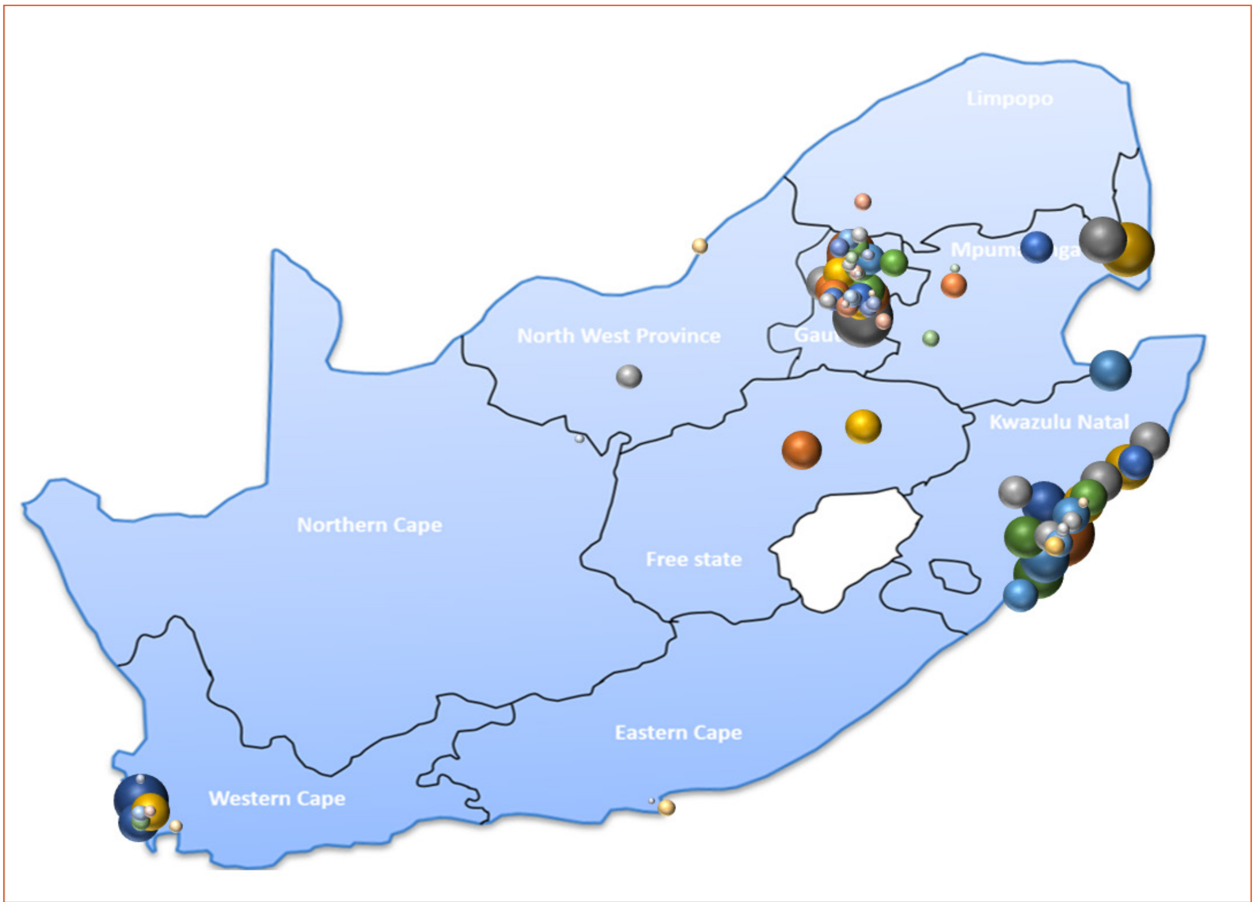
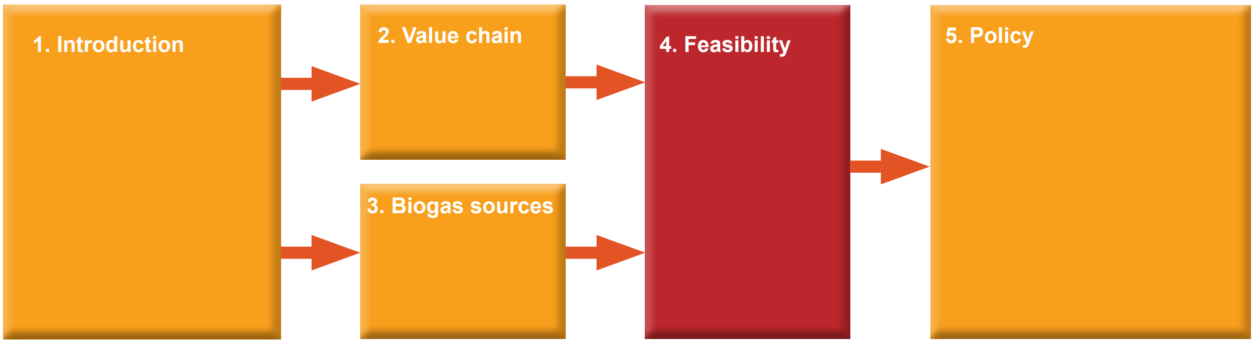


Figure 3.4.1: Geographic distribution of potential biogas sources

As can be seen from the map above, the majority of potential biogas sources are located in the proximity of South Africa's urbanised centres: along the KwaZulu-Natal coast, in Gauteng and around Cape Town. This, in combination with the material total potential, as captured in the Biogas for Transport Sources Inventory, of around three million Nm^3 of raw biogas per day, provides sufficient grounds to conclude that, from a potential biogas availability perspective, a material volume located within well-accessible areas and close to consumers has been identified.

It is also interesting to consider that, with a share of 38% of the total, the MSW sector, as a whole, is the largest contributor to the country's biogas potential, and that these sources are all located in close proximity of urbanised areas. Several of the sources in this sector are among the ten largest sources identified. From this, one can conclude that local governments in South Africa have the potential to control and/or operate a large share of the country's potential biogas-for-transport sources, making them ideally positioned to drive the large-scale uptake of biogas as a transport fuel.

Chapter 4: Feasibility of transforming to CBG as a transport fuel

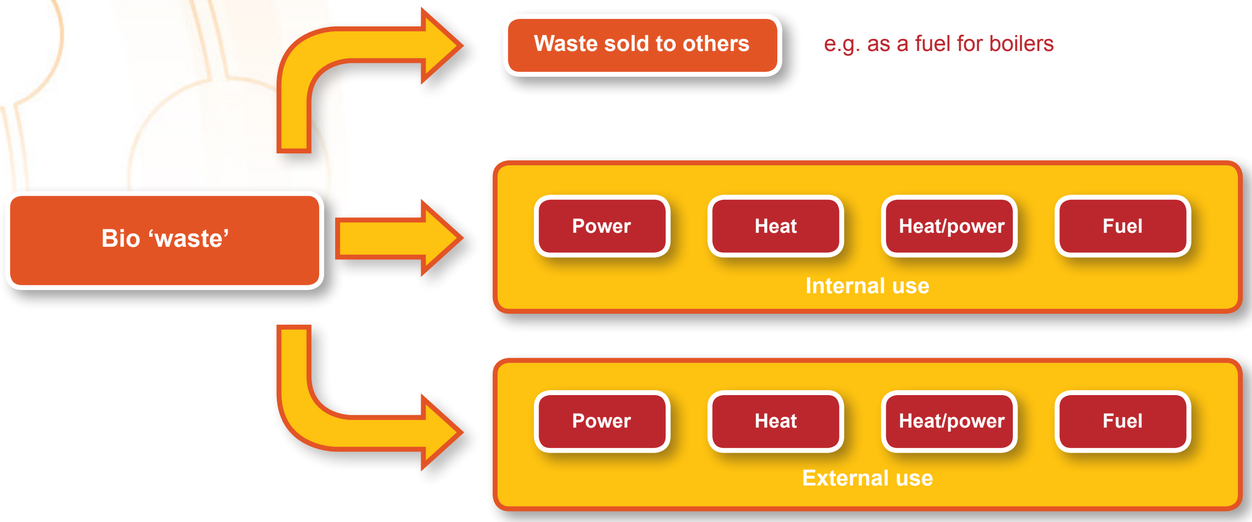


This chapter provides a feasibility assessment of the biogas-for-transport value chain and its potential to be introduced in South Africa as a transport fuel, given its competitiveness, available local infrastructure and benefits for the country.

4.1 Cost-benefit analysis: biogas-to-fuel versus biogas-to-electricity

In South Africa, the most common commercial non-residential use of biogas is for the generation of electricity either for own consumption, to be sourced to the municipal/national grid, or in exceptional cases to 'wheel' electricity across the grid to a dedicated off-taker. The use of biogas as a transport fuel has been tested on a few occasions in the country. For example, NOVO Energy demonstrated a CBG-dispensing station at a landfill site near OR Tambo International Airport. Nevertheless, biogas as a transport fuel has not emerged as yet.

However, the competition between wastes is wider than just fuel versus electricity. Heat is also an option, and before any conversion can take place, the waste may already have been used for other purposes, like animal feed or as a soil conditioner. In this sense, waste often already has a purpose or value diverting it from landfilling, the last-resort alternative for which a cost would be incurred.



Source: EcoMetrix team analysis

Figure 4.1.1: The use of waste in different ways and modalities

Although the main subject of the analysis is the comparison between electricity and transport fuel, an analysis has also been done on the value in terms of primary energy in R/GJ for the different energy carriers, i.e. electricity, heat (in terms of coal) and fuel (in terms of petrol). For electricity, this means that one calculates the electricity energy value back to the rand value of the amount of energy in terms of fuel that was required to generate the electricity. For coal, one can use the direct heating value that, in the case of thermal coal traded at Richard's Bay, is 6 000 kcal/kg. For petrol, an energy content of 32.4 MJ/ℓ has been used. The results are presented in the table below.

Table 4.1.1: Prices of energy of different carriers compared

Energy carrier (unit of measure)	Regular price R/unit of measure		Price per unit of energy R/GJ	
	Low	High	Low	High
Coal – heat (R/kg)[1]	0.65	0.83	26	33
Electricity (R/kWh)[2]	0.89	1.54	98	171
Petrol – transport (R/l)[3]	10	12.89	309	398

[1] Richard's Bay free on board (FOB) prices thermal coal low/high for the period April 2014 to Aprl 2015. A rand-dollar exchange rate of 11 is assumed.

[2] The price per unit of primary energy for electricity is calculated on the basis of a 40% electrical efficiency[8].

[3] The petrol price from R10/ℓ (low) up to the average pump price on 21 May 2015 (high).

8. A 40% electrical efficiency is at the top of the range (30 to 40%). However, new generator designs claim efficiencies around 40% as an MWM biogas-optimised generator, for example, claimed to have an efficiency of 42.8%. See: http://www.mwm.net/mwm-chp-gas-engines-gensets-cogeneration/press/press-releases/optimized-tcg-2016-c-genset-with-improved-efficiency-for-biogas-operation/

As becomes aparent from Table 4.1.1, the lowest value per unit of energy (R/GJ) is paid for coal. After this comes electricity, while by far the highest monetary value per GJ is generated by a transport fuel, which in this example is petrol. Although indicative, this order in value is not conclusive, as one needs to take into account the investments required to convert primary energy, in this case biogas, into the respective energy carrier.

In the next sections of this chapter, we focus on the pricing of both petrol and electricity, assess the additional cost incurred when going for one energy carrier or the other (i.e. the cost of converting raw biogas into electricity or a transport fuel) and make a comparison by subtracting the additional cost for converting to the specific energy carrier from the raw biogas. This should provide the net benefit when choosing one above the other.

Other indirect financial/non-financial benefits and barriers are also taken into account. In this way, a full comparison of both economic/financial, socioeconomic and environmental benefits is provided, which are all important factors for government to take an informed decision on whether and to what extent it might support and promote the uptake of biogas as a transport fuel.

4.1.1 Biogas to fuel

The potential for biogas in the form of CBG as a transport fuel should be considered in relation to the currently prevailing fuel alternatives within the country. As is the case globally, in South Africa the primary fuels used for transport are petrol and diesel. In some parts of the world, CNG is also a material transport fuel, but as indicated, the CNG for the transport market in South Africa is still in its infancy.

To be able to make a realistic comparison between the economics of the different fuels and to determine the potential competitive position of CBG in relation to other transport fuels, this study compares the sales price at the point of off-take (i.e. at the refuelling station) of the energy content of the different fuels in R/GJ. Since the predominant transport fuel in South Africa at the moment is petrol, the sales prices of diesel and, to some extent, CNG are positioned in such a way that they are competitive to the price of petrol.

When looking at the composition of the petrol price in South Africa, it is important to consider that South Africa does not hold oil deposits within its borders. As a result, it imports crude oil, as well as petrol and diesel, as needed. According to the South African Petroleum Industry Association (SAPIA), the petrol retail price is regulated by government and changes monthly. The calculation of the new price is done by the Central Energy Fund (CEF) on behalf of the Department of Energy (DoE). The petrol pump price is composed of a number of price elements, which can be divided into international and domestic elements. The international element, or basic fuel price (BFP), is based on what it would cost a South African importer to buy petrol from an international refinery and to transport the product to South African shores. The BFP is influenced by[9]:

- international crude oil prices;
- the international supply and demand balances for petroleum products; and
- the rand-dollar exchange rate.

The BFP, quoted in US$ per barrel or US$ per ton, is converted to US cents per litre by applying the relevant international conversion factors. It is then converted to South African rand and cents per litre by applying the applicable rand-dollar exchange rate. To arrive at the final petrol pump price in the different fuel-pricing zones (magisterial district zones), domestic costs, import costs, levies and margins are added to the BFP.

Although no VAT is raised on petrol or diesel, the DoE specifies the following other components that make up the domestic portion of the final fuel price:

- *Inland transport costs:* Refined petroleum products are transported by road, rail, pipeline or a combination of these from coastal refineries to inland depots.
- *Wholesale margin:* The margin is a fixed maximum monetary margin. The formula used to determine the wholesale margin is based on a set of guidelines – the Marketing of Petroleum Activities Return. The level of this margin is calculated on an industry average basis and aims to grant marketers a benchmark return of 15% on the depreciated book values of assets, with allowances for additional

9. http://www.energy.gov.za/files/esources/petroleum/petroleum_fuelprices.html

depreciation before tax and payment of interest. Should the industry-aggregated margin be between 10 and 20%, no adjustment is made to the margin. If it is below 10% or above 20%, the margin is adjusted to a level of 15%.

- *Retail profit margin:* The retail profit margin is fixed by the DoE and is determined on the basis of the actual costs incurred by the service station operator when selling petrol. In this cost structure, account is taken of all proportionate retail-related costs, such as rent, interest, labour, overheads and entrepreneurial compensation.
- *Equalisation Fund:* The Equalisation Fund levy is normally a fixed monetary levy, determined by the Minister of Minerals and Energy in concurrence with the Minister of Finance. The levy income is mainly utilised to equalise fuel prices. The levy is currently zero.
- *Fuel tax:* A fuel tax is levied on petrol and diesel. The magnitude of this levy is determined by the Minister of Finance.
- *Customs and excise duty:* A levy is collected in terms of an agreement with the Southern African Customs Union.
- *Road Accident Fund:* A Road Accident Fund levy is applicable on petrol and diesel. The magnitude of this levy is determined by the Minister of Finance. The income generated from this levy is utilised to compensate third-party victims of motor vehicle accidents.
- *Slate:* A slate levy is applicable on fuels to finance the balance in the so called ‘slate account’ when the slate is in a negative balance. The slate account and how the balance on the slate account is determined is described as follows: The BFP of petrol, diesel and illuminating paraffin (IP) is calculated on a daily basis. This daily BFP is either higher or lower than the BFP reflected in the fuel price structures at that time. If the daily BFP is higher than the BFP reflected in the fuel prices, a unit under recovery is realised on that day. When the BFP is lower than the BFP reflected in the price structures, an over-recovery is realised on that day. An under-recovery means that fuel consumers are paying too little for the product on that day, while in an over-recovery situation, consumers are paying too much for the product on that day. These calculations are done for each day in the fuel price review period, and an average for the fuel price review period is calculated. This monthly unit over-/under-recovery is multiplied by the volumes sold locally in that month, and this is recorded on a cumulative over-/under-recovery account (the slate account).
- *Demand-side management on 95 unleaded petrol:* A demand-side management levy (DSML) is applicable to 95 unleaded petrol consumed in the inland area. This levy was implemented in the price structure of 95 unleaded petrol in January 2006 when 95 unleaded petrol was introduced into the inland market for the first time. Most vehicles in the inland market do not need to run on 95 unleaded petrol and its unnecessary use in the inland area would result in ‘octane waste’, with negative economic consequences. A DSML was introduced to curtail the demand of 95 unleaded petrol in the inland area.
- *IP Tracer Dye levy:* To curtail the unlawful mixing of diesel and illuminating paraffin, a tracer dye is injected into illuminating paraffin. An IP Tracer Dye levy was introduced into the price structures of diesel to finance expenses related to this.
- *Petroleum Pipelines levy:* The annual budget of the Petroleum Pipelines Regulator is approved by the Minister of Energy and the Minister of Finance. In terms of the Petroleum Pipelines Levies Act (Act No 28 of 2004), a levy of 0.19 c/ℓ was added to the price structures of petrol and diesel on 7 March 2007.

The table below provides an indicative price breakdown of the petrol price at a refuelling station of approximately R12,89/ℓ (as on 21 June 2015).

Table 4.1.2: South African petrol pricing structure breakdown

Price components	Type	Price per litre (R/ℓ)
Basic fuel price	International	6,16
Inland transport costs	Domestic	0,35
Wholesale margin	Domestic	0,34
Retail profit margin	Domestic	1,51
Equalisation Fund	Domestic tax or levy	-
Fuel tax	Domestic tax or levy	2,55
Customs and Excise Duty	Domestic tax or levy	0,04
Road Accident Fund	Domestic tax or levy	1,54
Slate account	Domestic tax or levy	-
DSML on 95 unleaded petrol	Domestic tax or levy	0,10
IP Tracer Dye levy	Domestic tax or levy	-
Petroleum Pipelines levy	Domestic tax or levy	0,00
Total		**12,59**

The table above shows that, as is common in many places around the world, a portion of the price of petrol in South Africa at the pump is made up of a range of taxes and levies. Depending on the type of fuel and its detailed composition, the energy content of a fuel can vary. When comparing the price breakdown of different energy sources used in the transport environment, it is useful to make a conversion into R/GJ, so that one can compare costs on an equal basis. In this study, a standard energy content of 32.4 MJ/ℓ of petrol is applied. The diagram below provides a schematic breakdown of the international, domestic and domestic tax or levy components of the price of 95 unleaded petrol per MJ.

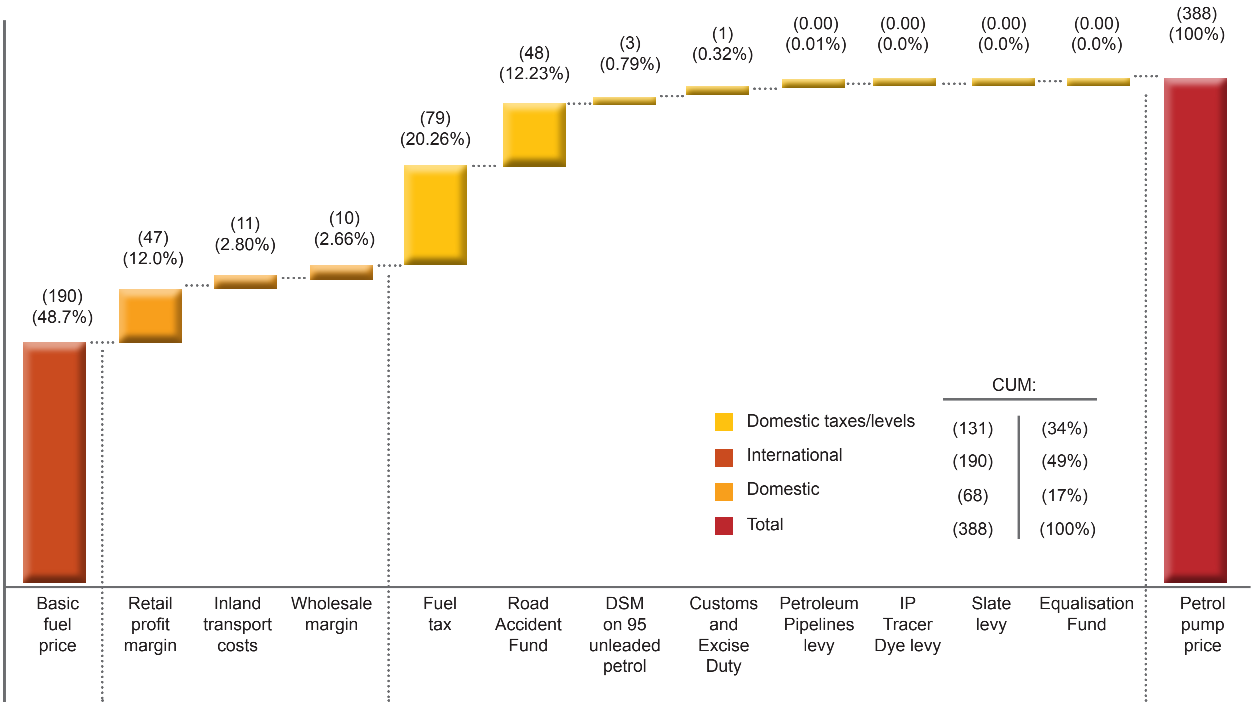


Figure 4.1.2: Cost breakdown of 95 unleaded petrol price per MJ

As a result of fluctuations over time, for example, in the rand-dollar exchange rate, and changes in the global market price of crude oil, it is important to consider that Figure 4.1.2 and Table 4.1.2 above are based on indicative numbers, and should be seen as an illustration of the components and dynamics that make up the petrol price at a refuelling station only. When looking at the taxes and levies on CNG for transport in South Africa, a very different picture emerges, as only CNG carries 14% VAT at the pump. The reason for this is that CNG for the transport sector in South Africa is still in its infancy, and National Treasury still needs to determine how the taxing structure should work[10].

One of the objectives of this study is to make recommendations regarding potential financial incentives to facilitate the large-scale uptake of CBG as a transport fuel. Taking into consideration the fact that the development of the CNG infrastructure is of substantial importance for a successful uptake of CBG in the transport environment, and that for CNG to be a viable alternative transport fuel, it needs to be price-competitive with petrol and diesel. The current absence of fuel taxes and levies on CNG, but applicable to petrol and diesel, can be considered an 'informal tax incentive' for CNG.

The diagram below provides a schematic overview of the price structure for CNG in the transport environment without this 'informal tax incentive'.

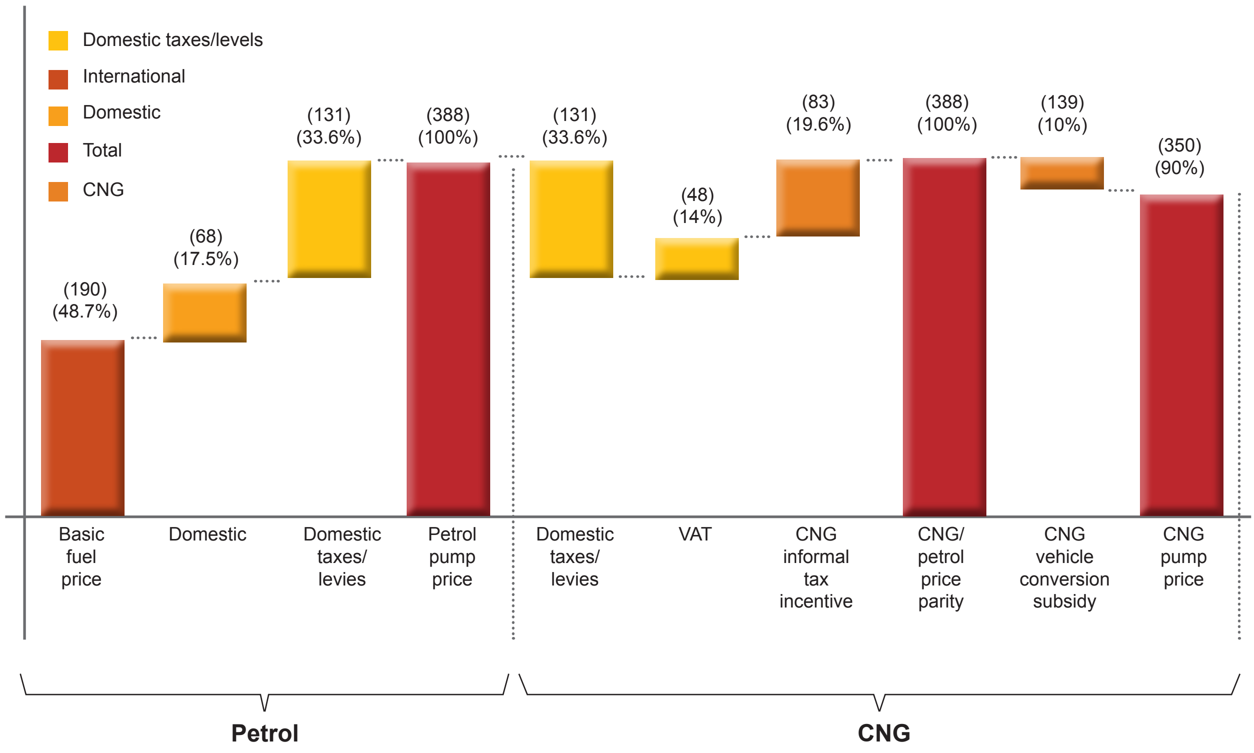


Figure 4.1.3: The price parity breakdown of 95 unleaded petrol as opposed to CNG[11]

What becomes apparent from the figure above is that the 'informal tax incentive', which results from the absence of the taxes and levies applied to petrol minus the VAT of 14% that is currently levied on CNG for transport (but not on petrol) is close to 20% of the price parity between petrol and CNG. The figure also includes a different discount embedded in the conversion of a petrol vehicle to a CNG vehicle, since an additional investment is required to fit a CNG system into a petrol vehicle.

10. http://citizen.co.za/148482/cng-filling-stations-arrive-in-south-africa/

11. In line with Figure 4.1.2, the domestic component of the petrol cost breakdown consists of the retail profit margin, inland transport costs and wholesale margin, as determined by the South African government.

Due to the early-stage maturity of CNG for the transport market, this saving on the CNG pump price that is required to repay the investment on the conversion kit is difficult to assess. However, assuming that a conversion kit costs R20 000 for a standard minibus taxi and that a vehicle drives 20 000 km a year at a petrol price of R12,59/ℓ, the additional investment can be recovered within 12 months at a discounted CNG price of 10%, including payback, interest and potential loss of income/use of the vehicle during the period it is being converted. This translates to a 'vehicle conversion subsidy' of R0,039/GJ.

As part of the roll-out by CNG Holdings, CNG refuelling stations provide an incentive for taxi drivers (supported by the IDC) in the form of a reduction in the CNG pump price. Although the incentive is structured slightly different to the example above, in essence it indicates that such a subsidy is required to develop a competitive market for CNG as a transport fuel. This kind of incentive, together with the 'informal tax incentive', should also be considered when looking at potential policy measures by government to kick-start the large-scale uptake of CBG as a transport fuel.

4.1.2 Biogas to electricity

Electricity rates in South Africa vary substantially, with different rate schemes for urban, residential and rural areas. Eskom, as the national utility company, proposes annual price increases for blocks of three years, which need to be approved by the National Energy Regulator of South Africa (NERSA). The last 10 years were characterised by periods of a shortage in supply and substantial price increases, which do not appear likely to subside. As illustrated in the table below, since 2009, average electricity price increases accumulated to over 100%.

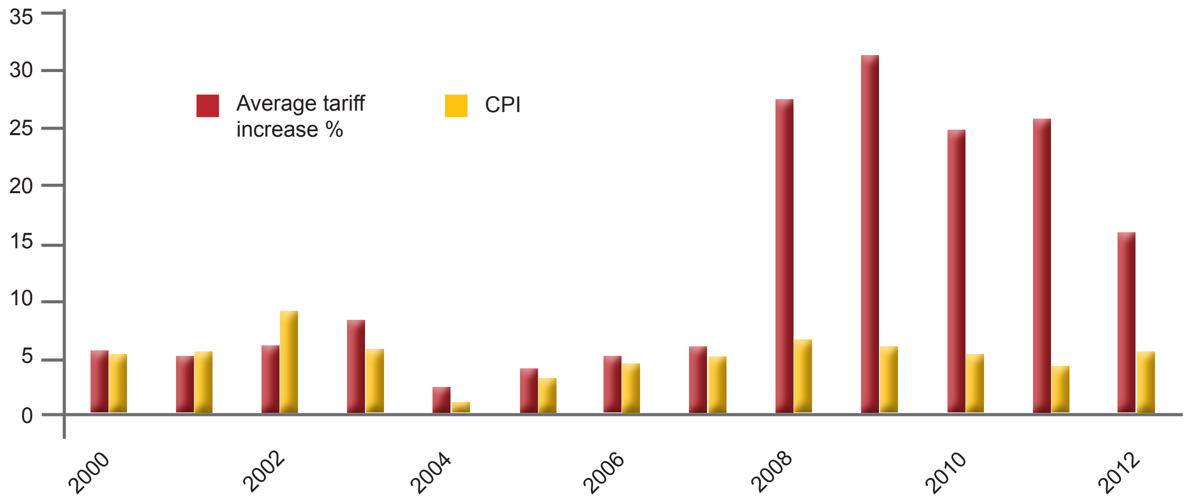


Figure 4.1.4: Average NERSA-approved price increase and consumer price index (CPI) since 2000[12]

Not surprisingly, managing security of supply and becoming less exposed to further electricity price increases has been a strong driver for project developers to develop electricity for their own use. The relevant prices in this regard mostly concern prices in urbanised areas, as these are the areas where waste is available for conversion into biogas (see Section 3.3).

Prices that have been taken into account in our analysis stem from large user domestic rates, which are the highest potentially achievable rates in urban areas like Johannesburg, regardless of whether the user is connected to the national or the municipal grid.

12 Eskom Tariff History: http://www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Tariff_History.aspx

Table 4.1.3: Domestic electricity prices of City Power versus Eskom (May 2015)

	City Power	City Power	City Power	Eskom	Eskom	Eskom	Eskom
Monthly kWh	60A prepaid	60A credit	80A credit	20A prepaid	60A prepaid	60A credit	80A credit
1 000	1 148	1 532	1 563	1 016	1 379	1 379	1 506
1 500	1 803	2 168	2 200	1 558	2 295	2 295	2 425
2 000	2 459	2 805	2 836		3 210	3 210	3 337
3 000	3 939	4 148	4 179		5 042	5 042	5 168
4 000	5 544	5 557	5 594		6 873	6 873	7 000

Other preferential rates can be obtained when participating in the REIPPP Programme. However, the number of biogas projects participating in REIPPP Programme has been close to zero, with only one qualifying project, the Johannesburg Landfill Gas-to-energy Project, which is anticipated to deliver 18 MW of electricity.

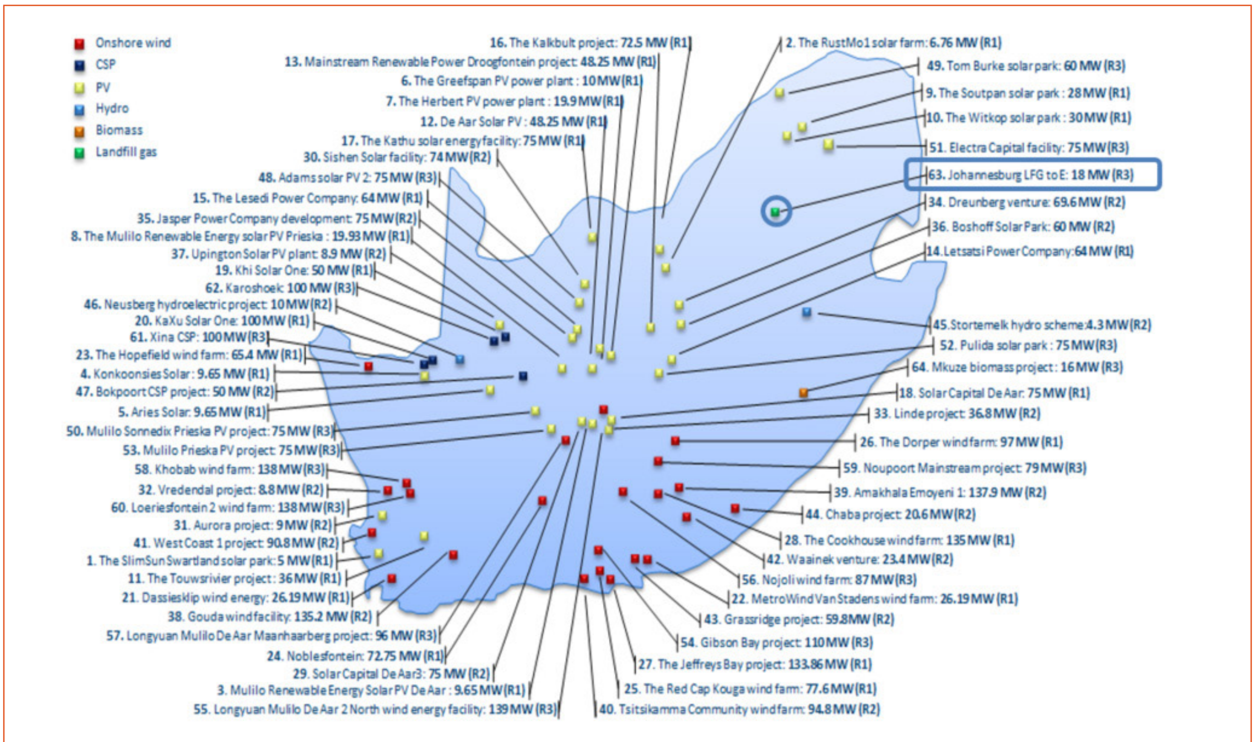


Figure 4.1.5: The 64 projects awarded under REIPPP Round 1–3, accumulating to 3 916 MWe

The price that the biogas projects participating in the REIPPP Programme obtained in this case was R1 108/MWh partially indexed (Rycroft, 2013), and is lower than what would be potentially achievable when selling to customers within urbanised areas. Another observation is that the location of the majority of solar and wind projects in the REIPPP Programme are outside urbanised areas. In that sense, electricity projects running on biogas could complement the current REIPPP Programme's renewable energy projects by geographically balancing (remote versus urban) the renewable feed into the grid to some extent.

4.1.3 Net price benefit: biogas-to-fuel versus electricity

Although fuel as a product seems to be more attractive, one needs to take into account the additional effort that is required to produce fuel over electricity. In order to compare 'apples with apples', one needs to distinguish between how the raw biogas is converted into the energy carrier of preference, whether it is being a CHP generator in case of electricity or an upgrading, compression, storage and dispensing system in case of CBG.

On the basis of inputs from local and international stakeholders, as well as data from biogas studies, an indicative cost range has been derived for a CHP unit, and for upgrading and compression. These costs are indicative for sizable projects of around 2 MWe or 18 000 Nm³ per hour of raw biogas and larger. The net price benefit is calculated by subtracting the 'additional cost' from the price one can obtain by selling the energy either as electricity or as a fuel respectively. In line with Section 4.1.1, we have chosen 95 unleaded petrol as a fuel and, in line with Section 4.1.2, the electricity domestic price range as charged in urban areas like Johannesburg. For purposes of comparison, CBG as a substitute for CNG has been added, showing prices when final use (heat or fuel) is still to be determined.

	Electricity from biogas	CBG as a substitute for CNG	CBG as a substitute for petrol
PRICE	**R98–171/GJ** Based on electricity rate: R0.89–1.54/kWh-e	**R238–249/GJ** Based on rates known from Egoli/CNG license	**R309–398/GJ** Based on petrol price of: R10–12.6/ℓ
COST	**R71–79/GJ** Based on CHP cost: R900–1,100/kWe	**R91–116/GJ** Upgrading + compression cost of biogas	**R91–116/GJ** Upgrading + compression cost of biogas
MARGIN	**R19–100/GJ** Available for production of raw cleaned biogas and additional cost	**R122–158/GJ** Available for production of raw cleaned biogas and additional cost	**R193–307/GJ** Available for production of raw cleaned biogas and additional cost

Figure 4.1.6: Comparing net price benefit between energy carriers when using biogas-based substitutes

The figure above shows that producing a fuel is the most attractive option, since the higher cost for upgrading and compression is more than compensated for by the higher price of energy. It is acknowledged that the assessment includes some simplifications as it does not include all detailed (often project-specific) costs related to the establishment of a gas or electricity grid connection, for example, neither does it include the costs related to upstream logistics. Nevertheless, considering the substantial difference in net price benefit of one energy carrier versus another, this will not change the perspective that, in monetary terms, the value of biogas as a fuel is a factor two to three higher than when it is converted to electricity, while at this stage it is taxed equally by VAT at a rate of 14%.

In the following section, the monetary advantages, other socioeconomic and environmental benefits, as well as infrastructural requirements regarding biogas-based electricity versus biogas-based fuel are assessed.

4.1.4 Benefit analysis of fuel versus electricity

In this section, we discuss the main benefits and requirements of biogas-to-fuel versus biogas-to-electricity per main benefit category: economic/financial, environmental, socioeconomic and infrastructural.

Economic/financial

Biogas-to-fuel has a number of advantages over biogas-to-electricity in economic/financial terms. Being superior in monetary terms by a factor two to three with respect to market value, as was demonstrated in Table 4.1.1, this will reflect equally in tax revenue for the country as both electricity and CBG/CNG are currently subject to VAT (no fuel levies are charged on CBG).

Electricity is a local commodity, while for the provision of transport fuels, South Africa is highly reliant on the import of crude oil. The benefits related to the improvement of the trade balance and decrease of forex expenditure will therefore only materialise when biogas is converted into a transport fuel, which reduces the reliance on crude imports.

From a strategic economic perspective, one could argue that biogas-to-electricity has the strongest benefits as South Africa is struggling with its security of electricity supply. Biogas generators may provide relief for own use, as well as feed some additional capacity into the grid. While being reliant on crude oil imports and the conversion of coal into liquid fuels, no supply constraints are experienced in the case of fuels. For obvious reasons, it is difficult to forecast how both the local electricity market and international oil and gas markets are going to develop in the future.

With regard to security of supply, one has to take into account that the relevant biogas-for-transport sources, as identified in the biogas sources inventory, are focused at sources of 18 000 Nm^3 per day or larger. There may be many smaller sources, which do not qualify for biogas for-transport, but might make a meaningful aggregated contribution, similar to biogas-for-transport in terms of electricity.

Environmental

Whether biogas is used to displace petrol or diesel, or to produce bioelectricity, displacing coal-based grid electricity, both result in a reduction of net GHG emissions. Although one might think that replacing dirty coal-based electricity from the grid has by far the largest mitigation effect, this is largely dependent on the efficiency with which the biogas is converted into electricity. The efficiency of generators generally lies within the range of 30 to 40%.

Table 4.1.4 illustrates the assessment of the net mitigation effect for the substitution of petrol with CBG, and coal-based electricity with biogas-based electricity, taking into account the different energy contents and emission factors. The assessment shows that the net mitigation effect per Nm^3 of raw biogas (65% CH_4 content) is significantly higher in the case of a generator-efficiency of 40% electrical (i.e. 0.002504/0.001702 = 47%), while in the case of a generator efficiency of 30% electrical, the net mitigation effect becomes comparable with only a 10% net mitigation advantage (i.e. 0.001878/0.001702) of bioelectricity versus biofuel.

Table 4.1.4: Comparison return on mitigation: bioelectricity versus biofuel

Substitution of petrol	Value	Unit of measurement
1 litre of petrol - Nm^3 of biogas equivalent	1.41	Nm^3
Gasoline emissions factor	0.000074	tCO_2e/MJ
GHG avoided per litre of petrol replaced	0.002398	$tCO_2e/ℓ$
Net mitigation effect per Nm^3 raw biogas[2]	**0.001702**	**tCO_2e/Nm^3 biogas**

Substitution of coal-based electricity	Value	Unit of measurement
1 000 kWh-e grid electricity, CO_2e emissions	0.98	tCO_2e[1]
1 000 kWh-e grid electricity, energy content	3,600	MJ
1 000 kWh-e, Nm^3 of biogas equivalent (at 40% efficiency)	391	Nm^3
1 000 kWh-e, Nm^3 of biogas equivalent (at 30% efficiency)	522	Nm^3
Net mitigation effect per Nm^3 raw biogas[2]	**0.002504**	**tCO_2e/Nm^3 biogas**
Net mitigation effect per Nm^3 raw biogas[2]	**0.001878**	**tCO_2e/Nm^3 biogas**

1 Grid emission factor derived from Eskom's inputs in its 2013 annual report.
2 Raw biogas with a CH_4 content of 65% has been assumed.
3 Gasoline emission factor as stated in the Mitigation Potential Analysis (Department of Environmental Affairs, 2014).

While on the basis of the net mitigation benefit, one might favour bioelectricity over biofuel as an option for biogas, this will to a large extent depend on the choice of generator by the project developer. It is important to note in this respect that, as may be expected, lower-efficiency generators are generally less expensive.

Although important, climate change mitigation is not the only environmental benefit to take into account. Air quality and the effects on respiratory health are of importance as well, and are particularly an issue in urban settings with high population densities. South Africa has had new air quality legislation since 2004, with new national standards for the monitoring of ambient air pollutants. It acknowledges the fact that the effects of fossil fuel burned by electricity plants and cars is a major factor that influences air quality outdoors. As gas burns cleaner compared to diesel, petrol or coal, with little soot and very low sulphur oxides (SO_x), nitrogen dioxide (NO_x) and CO_2 emissions, it can make a contribution to improve air quality.

At point sources like large-scale coal-fired electricity plants, it is in principle possible to treat flue gasses so that low emission levels (similar to the combustion of gas) are reached. This is to some extent planned to happen at the new electricity plants of Kusile and Medupi (currently under construction), which include NO_X burners and wet flue gas desulphurisation processes. Within the transport sector, the cleaning of flue gasses is much harder because of its distributed nature, with millions of vehicles of different makes and models, while the areas where a large number of vehicles come together are the highly populated areas where people are affected by deteriorating air quality. In this sense, the benefits of air quality improvement may be regarded as substantially more significant in the case of biogas as a transport fuel.

A third, more strategic consideration is the value of the individual GHG mitigation measure of biogas for transport or electricity, as part of a portfolio of GHG mitigation measures. Of importance is to realise what options the different sectors of application have.

Table 4.1.5: GHG mitigation options: electricity versus transport sector

Electricity sector	Transport sector
Electricity plant efficiency	Fuel efficiency
Consumer efficiency	Passenger transport efficiency
Demand-side management	Passenger demand reduction
Solar heating	Shift to public transport
Gas heating	Hybrid vehicles
Solar electricity	Biofuels for transport
Wind	Biogas for transport
Hydro-electricity	
Biomass-to-electricity	
Biogas-to-electricity	

As the table above illustrates, the number of mitigation measures that can be applied to achieve GHG mitigation is largest in the electricity sector. Moreover, the improvement in the energy efficiency of vehicles may be hard to achieve as most vehicles are designed and manufactured outside South Africa. However, more important may be that several policies already successfully drive mitigation measures in the electricity sector. Most prominent in this regard is the REIPPP Programme, which is designed to contribute towards a target of 3 725 MW of renewable electricity, the Energy Efficiency Demand-side Management (DSM) Policy and the 12ℓ Energy Efficiency Tax Incentive.

With regard to biofuels in the transport sector, the Mandatory Blending Regulations are only envisaged to commence on 1 October 2015 at the earliest (if no delays occur). The blending regulation will require all licensed petroleum manufacturers to purchase a blend of biofuels from licensed biofuels manufacturers with a minimum of 5% volume per volume (v/v) of biodiesel (a blend with diesel), and between 2 and 10% v/v of bioethanol to petrol. Biogas and ‘blending’ into CNG as a transport fuel is currently not included in this legislation.

Socioeconomic

Job creation is the first and foremost desired socioeconomic impact in a developing country like South Africa. In this regard, we have to consider, as illustrated in the figure below, that the value chain of biogas-to-electricity is shorter than the value chain of biogas for transport. Moreover, considering the fact that the electricity grid is existing infrastructure and that gas infrastructure (transport, fuel stations and vehicles) is new infrastructure, investment in this new infrastructure was triggered as a result of an emerging gas market, which may include an additional indirect job creation potential.

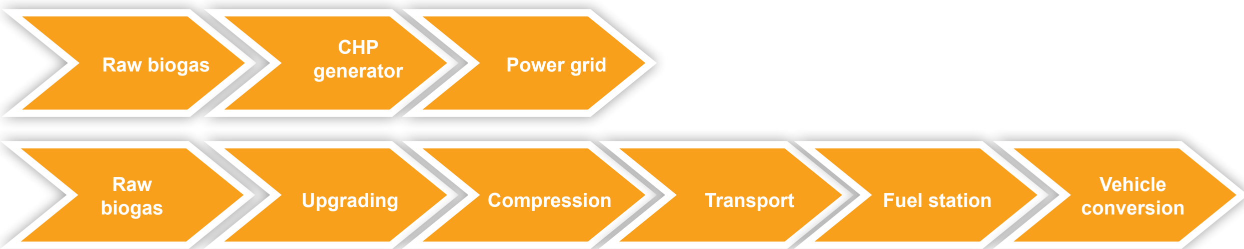


Figure 4.1.7: Value chain of biogas-to-electricity compared with biogas for transport

The upgrading and compression of biogas may require two additional persons compared to the operation of a CHP unit per sizable installation (say 2 to 4 MWe equivalent). The further indirect employment benefit will emerge from the investment in the new infrastructure that is required for gas, while the direct jobs in transport and retail (fuel stations) will probably largely replace jobs in the transport industry and the distribution of regular fossil fuels. A further analysis of the job creation potential of biogas for transport is provided later on in this report.

4.1.5 Infrastructural requirements

Although infrastructural requirements for biogas-to-electricity or biofuel are – in essence – similar, there are differences as the existing electricity transmission infrastructure is substantial, while the gas transportation grid only exists in certain parts of the country. Moreover, biogas for transport will, in addition to anaerobic digestion facilities, require expertise and skills regarding the upgrading and compression of biogas. When comparing biogas-to-electricity with biogas to-fuel, one should also take into account infrastructural requirements and differences in this regard.

Electricity versus gas grid

Although there is an almost national coverage by the electricity grid, 'wheeling' of electricity is not common practice. Project developers in general express their concern about the long and complex regulatory processes one needs to go through in order to arrange for wheeling agreements in collaboration with the municipality and/or Eskom. There are, however, a few examples of project developers who have succeeded in doing so. One such development is the Bronkhorstspruit Biogas Plant, which has an allowance to connect to the Eskom grid and a wheeling agreement with the City of Tshwane. One of the main hurdles indicated is the Municipal Finance Management Act (Act No. 56 of 2003), which limits the freedom of municipalities to enter into long-term commercial agreements.

At this point in time, there are no examples of biogas projects that have connected to the gas grid. Although NERSA has been mandated with this task, no specific regulations have been developed as yet to facilitate the opening up of the few long-distance pipelines and urban fine grids in Gauteng. However, as an alternative to a gas grid, CBG can be transported by truck to fuel stations dispensing CNG. Fuel stations dispensing CNG are currently still limited (see Section 4.2).

Supporting skills and the service industry

The biogas industry in South Africa is only emerging. However, there are several first-mover biogas system vendors and project developers with regional and/or international experience (see the website of SABIA[13] for examples), who are able to deliver projects, whether it is biogas-to-electricity or biogas-to-fuel. Nevertheless, it has to be said that although several local biogas-to-electricity projects are up and running, no biogas-to fuel projects are currently operational.

Experiences in Europe show that farmers, for example, are able to operate biogas projects at their farms with the support of expert service providers. On-farm workers are required to focus on collecting waste and feeding the digester, while the remainder of the process can be handled by semi-skilled operators working with the support of expert service providers.

4.2 Risks of supply using CBG

This section assesses the risk of supply using CBG and the potential of integration between the current CNG supply network and CBG production facilities. The first part of this section looks at the different components of CBG risk of supply, and provides an overview of the potential solutions to address this supply risk. This is followed by a more in-depth analysis of how alignment of CBG with the current and future CNG infrastructure in South Africa could work and how this can be structured. The concluding part of this section looks at the development of the potential CBG customer base and the importance of integrating CNG and CBG for transport infrastructure for the successful large-scale uptake of CBG as a transport fuel.

4.2.1 Risk of supply using CBG

As opposed to first-generation biogas production using crops as feedstock, second-generation biogas production, by definition, is dependent on the supply of organic waste, which – within the scope of this study – is converted into biogas using an anaerobic digester or landfilling. The organic nature of the production of

13. http://biogasassociation.co.za/membership/members/

biogas creates a CBG supply risk in that the volume of biogas produced can vary over time. Holistically, this variation can be contributed to the following components:

- *Variation in the volume of biomass supplied:* Variations in the biomass volume supplied can be caused by a range of natural phenomena, such as drought, but can also be the result of operational considerations, such as harvesting cycles.
- *Variations in the biogas volume generated:* The anaerobic digestion process in both a digester and a landfill can slow down or accelerate the generation of biogas, depending on a number of variables, such as temperature and the detailed composition of the biomass, which causes the bacteria to increase or decrease the natural process of anaerobic decay.
- *Variations in the CH_4 concentration:* During the biogas upgrading process, one of the activities that takes place is the separation of the CH_4 used for the production of CBG from the other components in the biogas. Variations in temperature and humidity, for example, can increase or decrease the CH_4 concentration within the biogas supply, which, in turn, increases or decreases the produced volume of CBG.

Although the above list of CBG supply risk components is not exhaustive, such risks can materialise independently or in combination. This makes managing the supply risk from within the CBG production process very complex. To manage the CBG supply risk, a study entitled 'Accelerating the transition to green municipal fleets' (Linkd Environmental Services, 2015) looks outside the CBG production process itself and identifies two layers of security that can serve as back-up to the supply of CBG:

- *First-generation agricultural biogas*: In countries where there is existing production capacity of CBG from first-generation agricultural biogas, this serves as a back-up and first level of supply security in case the CBG supply risk from second-generation biogas production capacity materialises.
- *Compressed natural gas*: In this case, the existing CNG production capacity and infrastructure serves as a back-up and second level of supply security to CBG production from second-generation biogas facilities in the event that the existing first-generation agricultural biogas capacity cannot substitute the shortfall in supply.

When looking at the second point, it is apparent that this back-up would, in essence, substitute fossil fuel for biofuel (CBG with CNG) in situations where second- and first-generation biogas production is unable to sustain a stable supply. However, a fuel switch from petrol to CNG always results in substantial GHG emission reductions (25%) (Kreditanstalt für Wiederaufbau, 2012). In practical terms, this means that, in the event that the CBG security of supply is provided by CNG, this would still result in a substantial reduction of GHG emissions in comparison to petrol, even though CNG is a fossil fuel.

4.2.2 Potential for integrating CBG with the CNG infrastructure

Before being able to assess the possibility of integrating the current and future CBG and CNG infrastructure, it is important to get a good understanding of the current CNG infrastructure in the country. South Africa presently imports natural gas from its neighbouring country, Mozambique, via an 865 km-long pipeline. The gas is predominately used in industrial processes and conversion into diesel fuel, for among others, transport applications via the gas-to-liquids (GtL) process. Some of the natural gas is redirected into the Gauteng distribution grid, which supplies parts of the greater Johannesburg area.

The limited CNG infrastructure is a concern when it comes to the large-scale roll-out of CNG and CBG for transport across the country. Globally, CNG infrastructure build-up is considered a concern whenever CNG vehicles are introduced into a market from scratch, and must go hand in hand with natural gas demand to avoid sunken costs. A different manner in which this shortcoming can be addressed is by the application of the so-called 'virtual pipeline' concept (trucking in CNG), where expansion of the natural gas grid may not be economically justifiable (Kreditanstalt für Wiederaufbau, 2012).

Internationally, and to some extent domestically, the concept of 'blending' biofuels with fossil fuels at the upstream section of the supply chain is implemented either via the provision of government subsidies to do so or because governments have set a minimum biofuel blending level for biofuels. During this study, no legislation was identified (neither internationally nor domestically) regarding CBG blending requirements for CNG. Table 4.2.1 therefore only provides a snapshot of the regulations for other biofuels in this regard.

Table 4.2.1: Biogas-for-transport GHG emission mitigation policies and regulations

Jurisdiction	Fuel type	Status	Summary of legislation
South Africa	Liquid fuels (petrol and diesel)	Scheduled for implementation from 1 October 2015	Regulations regarding the mandatory blending of biofuels with petrol and diesel, promulgated in terms of the Petroleum Products Act (Act No. 120 of 1997) (Mandatory Blending Regulations) will require that all licensed petroleum manufacturers purchase biofuels exclusively from licensed biofuel manufacturers, so long as the volumes can be blended with the petroleum manufacturer's petroleum within the minimum concentration of 5% v/v biodiesel added to diesel, and between 2 and 10% v/v bioethanol added to petrol.
European Union (EU)	Liquid fuels (petrol and diesel)	Implemented	Via its Renewable Energy Directive of 2009, the EU currently has a 5.75% mandate directive in place, which was scheduled to increase to 10% by 2020. However, in September 2013, the European Parliament voted to cap first-generation ethanol consumption at 6% of fuel demand by 2020, rather than the 10% originally mandated by the Renewable Energy Directive
Brazil	Petrol	Implemented	A minimum ethanol content of 25% is currently mandated by government, which was increased to 27.5% in September 2014.
	Diesel	Implemented	A blending requirement for biodiesel of 5% is in place. The Brazilian senate voted to raise the biodiesel limit from 5% to 6%, but President Roussef had yet to approve the legislation.

When looking at the existing natural gas infrastructure and where in the South African economy natural gas is utilised, it becomes clear that CBG blended into the natural gas infrastructure would currently almost never end up as a transport fuel, except maybe via the GtL process as diesel or petrol. From this perspective, it is also important to consider that, as became clear from one of the interviews with stakeholders at Sasol, including additional supply to the existing natural gas network might not be possible in the short term due to capacity constraints on most of the pipeline system (excluding some of the capacity around Gauteng), as well as concerns around the ability to maintain safety standards for relatively small sources added to the pipeline system.

When considering CNG supply as a back-up to address potential CBG supply risks, a number of possible combinations from a refuelling-station perspective can be derived from the above understanding of the CNG infrastructure:

- *Refuelling station at CBG source and CNG pipeline:* An example of this kind of setup would be a refuelling station that is located at a landfill from which it extracts biogas and upgrades it to CBG for transport application, while connected to the CNG grid to provide an increased security of supply. Although this combination would be the most economical with the current limited CNG infrastructure, the chances of a biogas source being located next to an existing CNG pipeline are very limited. It is conceptually feasible to extend the CNG network to the location of biogas sources or vice versa, but this would depend on economic comparison with a virtual CBG or CNG supply.

- *Refuelling station at CBG source with virtual CNG back-up:* In this setup, the refuelling station is located at the biogas source, and CNG is trucked in and stored at the refuelling station for back-up purposes. This setup would be the most 'pure' form of CBG for transport application in the sense that the CNG provided to the refuelling station serves to provide security of supply by addressing the CBG supply risks.
- *Refuelling station at CNG pipeline with virtual CBG pipeline:* In this situation, the refuelling station is located near a CNG pipeline to provide it with a reliable source of CNG. CBG is trucked in and stored on site. In the early stages of the development of the upstream CBG infrastructure, it is reasonable to assume that the majority of supply will initially come from CNG and that, over time, the CBG share of supply to the refuelling station will increase.
- *Refuelling station with virtual CBG pipeline and virtual source and CNG pipeline:* In this setup, the refuelling station is supplied virtually with both CNG and CBG being trucked in. Although this increases the logistical complexity and potentially also the transport costs, it also increases the flexibility of where the refuelling station can be located. In practice, this means that the refuelling station can be positioned closer to its potential customer base.

Considering the range of options above, it is apparent that several options exist where CNG supply as a back-up to address potential CBG supply risks can be utilised. The next section considers how the potential CBG for a transport customer base can be defined and developed over time.

4.2.3 CBG/CNG integration

In addition to CNG providing a security-of-supply backstop for CBG, making the alignment of the development of a CBG downstream infrastructure to that of CNG a reasonable assumption, it is also important to consider that, due to the limited range of a CNG vehicle, a higher density of CNG refuelling stations would be required than would be the case for diesel or petrol refuelling stations.

In essence, CBG does not differ from CNG when it comes to downstream storage, treatment and transport use. Hence, the volumetric energy density, similar to CNG, is only 25% of that of diesel (for details see the inception report section on the customer base), making the required tank in a vehicle for CBG larger and costlier than a conventional fuel tank. This smaller range/larger tank rationale needs to be taken into account when assessing the uptake of CBG (and CNG for that matter) as it develops over time.

Initially, a limited number of refuelling stations will be available to customers. This implies that the conversion from petrol or diesel to CNG or CBG is only practical in situations where the refuelling station is located along a route that is frequently used by the customer base. Although this kind of routing pattern exists in a domestic environment where, for example, a member of the household commutes back and forth to work along the same route on a daily basis, it is the standard pattern within public transport where buses and minibus taxis travel the same route on an ongoing basis.

An additional advantage of initially focusing on the public transport sector is that public transport in a certain region is often collectively owned or controlled by one or a limited number of entities. These 'fleet owners' can convert a number of taxis and/or busses in one go, thereby kickstarting the development of a refuelling station's customer base. In contrast to converting from passenger cars, minibus taxis and city busses can accommodate an additional fuel tank without materially reducing the loading capacity of the vehicle. The table below provides an overview of the number of minibus taxis and city busses in South Africa (eNATIS, 2012).

Table 4.2.2: Number of minibusses and busses per province

Province	Minibusses	Busses, bus-train, midi-busses
Gauteng	110 765	16 779
KwaZulu-Natal	46 320	6 753
Western Cape	33 887	5 329
Eastern Cape	20 688	3 700
Free State	11 933	2 267
Mpumalanga	20 732	5 320
North West	16 618	3 260
Limpopo	19 280	4 533
Northern Cape	3 966	1 313
Total	284 189	49 254

As can be expected, the majority of both minibus taxis and city busses operate within South Africa's main metropolitan areas. When looking at the geographic distribution of potential sources of biogas as outlined in Section 3.3 of this report, it becomes apparent that the majority of these sources are also located in and around the country's urbanised areas.

As indicated, there is a limited CNG infrastructure within South Africa, of which only a very small portion is dedicated to transport applications. As part of this study, a site visit was conducted to one of the front-runners within the CNG for the transport sector in South Africa, CNG Holdings. With assistance from the IDC, CNG Holdings has developed two CNG refuelling stations in Johannesburg with the intention of developing additional refuelling stations in other parts of the country. The table below provides an indication of identified current and proposed refuelling stations across the country at present.

Table 4.2.3: Current and proposed CNG refuelling stations

Area	Address
Johannesburg	72 Main Reef Toad, Langlaagte
Johannesburg	1162 Steve Kgane Street, Dobsonville
City of Tshwane	N/A
Vereeniging	N/A
Cape Town	N/A

In summary, this section shows that, as a result of the downstream similarities between both CNG and CBG for transport applications, by developing the CNG downstream infrastructure, the potential for developing CBG for transport increases substantially.

4.3 High-level macro-economic and environmental impact

As part of the analysis, the study also asked for a high-level assessment of the macro-economic and GHG mitigation impact of the large-scale uptake of biogas for transport. The biogas potential identified in this study will have a number of important consequences on an economy-wide level. In additional to this, there are significant environmental benefits (i.e. GHG emission reduction and reduced air pollution) associated with the uptake of biogas. In order to gauge these effects, the study provides an analysis of a number of key areas that have been identified, where the impact is expected to be the largest. To structure things logically, the analysis below first focuses on the macro-economic impact, and then provides a detailed analysis of the GHG mitigation impact.

4.3.1 Macro-economic impact

The project team, together with the Project Steering Committee, has identified three key areas where the socioeconomic impact of biogas for transport is likely to be largest, and which therefore require further analysis. These include the following:

- Job creation in the renewable energy sector, which will result from the production of biogas
- The substitution of biogas for foreign crude oil imports, and hence a reduction in the dependence on foreign energy, an improvement in the country's trade balance and a decrease in foreign-currency expenditure

These two factors, in conjunction with the estimated production potential of roughly three million Nm^3 of raw biogas per day in South Africa (see Section 3.3), could imply significant socioeconomic benefits from the uptake in transport. As such, it has the potential to unlock significant private-sector investment and create a completely new green industry in the country. This would spur economic growth and sustainable development, in addition to creating significant environmental benefits.

Job creation

Stakeholders who were consulted during this study indicated significant potential for biogas to create permanent jobs throughout the South African economy. These findings are confirmed by international experiences. For obvious reasons, forecasting (macro-economic) variables like the number of jobs added that result from private-sector investment are surrounded by significant uncertainties. There are several cross-sectoral dynamics at work. Jobs added can be compared to job creation through investments in alternative sources of renewable energy, such as solar and wind energy (some sources indicate a job creation potential of biogas over solar and wind of 10 to

one). However, when it comes to biogas for transport, one would also have to take into account employment loss, for example, in crude oil refining. Investments are typically also long-term, adding further uncertainty/risk.

The below assessment of the large-scale uptake of biogas in transport is based on stakeholder consultations and inputs. The numbers have been confirmed by international experiences and research. The latter is, of course, not strictly comparable to the South African situation, but can be used to check whether domestically generated numbers are approximately in line.

There are several stages at which biogas production adds to job creation potential as a result of investment in biogas production capacity. For example, employment is generated in the production phase of biogas, and, when used for transport, in the upgrading and compression phase, as well as in the distribution phase.

What is more, for job creation to be 'true' job creation in an economic sense, a necessary condition has to be that the biogas can be produced and sold at prices that are roughly competitive with its alternatives in the form of petrol and diesel on an equivalent litre basis (see next section for an elaboration of the 'gasoline litre equivalent' concept). The subsidies required to jumpstart the biogas industry in South Africa cannot be considered excessively high compared to international experiences, and can be seen as necessary precisely for that reason. This, moreover, comes at a time of relatively low international oil and gas prices[14].

In line with the purpose of the study, Table 4.3.1 provides an indication of the job creation potential associated with the large-scale uptake of biogas for transport. The numbers are based on an assumed raw biogas production potential of about three million Nm^3 per day, the total potential as indicated in the Biogas for Transport Sources Inventory. This indicates a job creation potential with a lower range of 2 324 and an upper range of 14 248 jobs created on a full-time equivalent (FTE) basis. The job potential has been subdivided into three categories of skills, according to the definition provided by Statistics South Africa: low-skilled (elementary and domestic workers), semi-skilled (clerks, sales and services staff, skilled agriculture, craft and machine operators) and skilled (managers, professionals and technicians)[15].

Table 4.3.1: Biogas-for-transport job creation potential by skills category

	Lower range (full-time jobs added)	Upper range (full-time jobs added, FTE)
Low-skilled	697	4 274
Semi-skilled	1,395	8 549
Skilled	232	1 425

Source: Stakeholder meetings, IDC and EcoMetrix team analysis

It can be seen that the resulting range is rather wide. The lower range is based on a per project basis as obtained from various stakeholder inputs. The upper range is based on work by the IDC (Industrial Development Corporation, 2013). In the first case, it concerns only direct jobs created by the production of biogas. However, depending on whether one chooses to include indirect jobs as well, this number increases. An example is jobs at refuelling stations, for which one needs to be mindful of double counting (whether the consumption of CBG creates an extra job at the service station, or does it simply displace labour that would otherwise have been used to refuel petrol- or diesel-powered vehicles). Moreover, a certain amount of expertise will always be required for the production of CBG, but this may not be significantly more than, for example, is the case with the production of solar or wind energy.

Reduction of crude oil imports

Aside from the economic benefits related to job creation, the question has been raised whether the uptake of biogas can have a significant impact on fuel imports and thus on the trade balance (as part of the current account) of the country. Currently, South Africa relies substantially on oil/fuel imports to meet its energy demand for transport. Among other things, this has a

14. www.macrotrends.net/1369/crude-oil-price-history-chart

15. http://www.statssa.gov.za/presentation/Stats%20SA%20presentation%20on%20skills%20and%20unemployment_16%20September.pdf

considerable impact on the balance of trade, which is already significantly negative (last year the current account deficit stood at 5.4% of gross domestic profit (GDP) according to the International Monetary Fund (IMF)). It also implies a substantial reliance on foreign crude oil imports, with implications for energy security and exposure to international crude oil price fluctuations. As part of this macro-economic impact assessment, this section therefore includes a high-level analysis of the potential of biogas to reduce the country's import of fuels.

The import of transport fuels comes in a number of forms, but most notably as crude oil, which is processed at various petroleum refineries in the country. Among other places, oil is produced in Angola, the Middle East and Nigeria, and then transported to Durban by ship. Here, the oil is transformed into end-products such as naphtha, liquified petroleum gas (LPG), kerosene, bitumen and heavy oil, as well as petrol and diesel. Locally, fuels are also produced through coal- and gas-liquifaction processes. The assessment assumes the latter output to hold constant. To keep things strictly comparable, and to be able to put a more exact monetary number to it, the study focuses on the direct substitution of biogas for petrol and diesel, the main fuels used in transport, and not on oil as the imported product, which – as indicated – has several other end-products associated with it, making such an analysis unnecessarily complex.

In calculating the potential of biogas to replace petrol and diesel 'imports', a number of factors are taken into account. Firstly, alternative fuels each have a different energy content, so in order to make a valid comparison, an adjustment needs to be made. Secondly, the fuel economies of vehicles using various fuels differ. Generally speaking, a diesel engine is more efficient than a petrol engine in converting energy to kilometres travelled. This factor also influences the outcome, since less-economical fuel engine types require more of the substitute fuel to get the same result. Finally, we need to put a price on this to estimate the overall impact on the trade balance in rand.

Due to different chemical compositions, the fuels under consideration vary in energy content. In an effort to compare 'apples with apples', a correction has to been made. In practice, the energy content of various fuels is compared using a gasoline litre equivalent (GLE) or diesel litre equivalent (DLE)[16]. For example, diesel fuel has a higher energy content than petrol. Its GLE is about 0.88. In other words, one litre of diesel contains about 113% of the energy contained in one litre of petrol. The table below provides the GLE of a number of alternative fuels. The original table is from the US Department of Energy and provides the values in gasoline gallon equivalent (GGE).

Table 4.3.2: The gasoline litre equivalent per fuel type

Fuel type	Chemical structure	Gasoline litre equivalent
Gasoline/E10	C_4 to C_{12} and ethanol ≤10%	97 to 100%.
Low-sulphur diesel	C_8 to C_{25}	One litre of diesel has 113% of the energy content of one litre of gasoline.
Biodiesel	Methyl esters of C_{12} to C_{22} fatty acids	B100 has 103% of the energy of one litre of gasoline or 93% of the energy of one litre of diesel. B20 has 109% of the energy of one litre of gasoline or 99% of the energy of one litre of diesel.
Propane (LPG)	C_3H_8 (majority) and C_4H_{10} (minority)	One litre of propane has 73% of the energy of one litre of gasoline.

16. Since this is an international concept, the term 'gasoline' is used instead of the term 'petrol' common in South Africa.

Fuel type	Chemical structure	Gasoline litre equivalent
CNG	CH_4 (majority) C_2H_6 and inert gasses	0.68 kg or 0.95 m³ of CNG has 100% of the energy of one litre of gasoline; 0.76 kg or 1.04 m³ of CNG has 100% of the energy of one litre of diesel.
LNG	CH_4 – same as CNG with inert gasses <0.5%	0.64 kg of LNG has 100% of the energy of one litre of gasoline and 0.73 kg of LNG has 100% of the energy of one litre of diesel.
Ethanol/E100	CH_3CH_2OH	One litre of E85 has 73 to 83% of the energy of one litre of gasoline (variation due to ethanol content in E85). One litre of E10 has 96.7% of the energy of one litre of gasoline.
Methanol	CH_3OH	One litre of methanol has 49% of the energy of one litre of gasoline.

Source: US Department of Energy – Alternative Fuels Data Center[17]. EcoMetrix team analysis.

It is well known that different engines have different efficiencies in transforming energy. In general, diesel engines are able to get relatively more 'work' out of an equivalent litre of fuel input (i.e. a certain amount of energy content) than petrol engines are. In other words, diesel engines are better at transforming a given amount of energy into kilometres on the road. This gives rise to an effect over and above the one that can theoretically be expected from the varying energy contents of various fuels (as discussed above). As a rule of thumb, modern petrol engines, in practice, have a maximum average thermal efficiency of 35 to 40%, while this may be up to 40 to 45% for diesel-powered engines[18].

To capture the differences in fuel economy, an average has been applied, which is assumed to hold constant over time. Numerous international studies and sources are available on fuel economies. For the purpose of this assessment, we rely on the result of a study for South Africa specifically, conducted by the Energy Research Centre of the University of Cape Town in cooperation with SANEDI (Energy Research Centre, 2012). Table 4.3.3 summarises the most important categories. While this table does not contain CNG-powered vehicles as a category, international sources indicate that, on average, the fuel economy of CNG-powered vehicles is approximately equal to that of a conventional petrol vehicle on a GLE basis[19].

Table 4.3.3: Vehicle fuel economy

Type of vehicle	Vehicle fuel economy (ℓ/100 km)
Diesel car	7.5
Gasoline car	8.3
Diesel suburban utility vehicle (SUV)	11.5
Gasoline SUV	13.0
Diesel light commercial vehicle (LCV)	11.5
Gasoline LCV	13.0
Diesel medium commercial vehicle (MCV)	28.1
Gasoline MCV	33.3
Diesel heavy commercial vehicle (HCV)	37.5
Diesel main battle tank (MBT)	11.4
Gasoline MBT	13.5
Diesel bus	31.2

Source: Energy Research Centre (2012)

17. http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf

18. http://large.stanford.edu/courses/2011/ph240/goldenstein2/

19. http://www.afdc.energy.gov/fuels/natural_gas_basics.html

In practice, LFG has significantly lower CH_4 content than biogas produced through AD. International research on this topic shows that 65% CH_4 content is a reasonable assumption with regard to biogas from AD, while this is on average 45% for LFG. From a theoretical perspective, it is possible to produce biogas from MSW using both methods (AD or LFG). For the purpose of the GHG mitigation impact assessment, the study distinguishes between two scenarios. These scenarios function as so-called ‘boundaries’, or cases between which an infinite number of possibilities can occur.

In the first scenario, all MSW is treated as being processed entirely through AD, so that, in effect, all waste types are assumed to produce the same constant CH_4 content of 65%. In the second scenario, the biogas production attributed to the MSW part of the inventory is produced entirely as LFG, which has an average CH_4 content of 45%, while the remainder is assumed to come from AD/LFG.

Moreover, with regard to the use of the Biogas for Transport Sources Inventory’s to determine the potential of biogas as a transport fuel, biogas can be substituted for either the consumption of petrol or the consumption of diesel fuel. As indicated, the two fuels have different energy contents and fuel economies. This provides a further two scenarios that can function as ‘boundaries’ with regard to the overall import reduction potential.

This gives a range of possibilities to consider. The matrix below provides the results of the potential of the large-scale uptake of biogas for transport as a substitute for fuels that are currently imported for the different scenarios. Depending on the specific scenario, biogas production in South Africa has the potential to replace between approximately 500 million litres of diesel fuel and 700 million litres of petrol on an annual basis. The results are based on an estimated biogas production potential in South Africa of around three million Nm^3 per day, as currently projected by the Biogas for Transport Sources Inventory. Merven et al. (2012) indicate a fuel demand for the South African economy of approximately eight and 12 billion litres of petrol and diesel fuel, respectively. This implies a substitution potential in the fuel mix of between 4 and 9%, depending on the fuel type. To put this into perspective, in Germany, the share of biofuels in primary fuel consumption is currently 5.8%[20].

Table 4.3.4: Biogas-for-transport substitution potential

	Substitution potential for diesel fuel (ℓ per annum)	Substitution potential for petrol (ℓ per annum)
AD/LFG	496 708 335	643 685 574
AD	546 546 691	708 271 224

Source: EcoMetrix team analysis

Earlier in the study, a breakdown was also provided of the retail price of petrol and diesel fuel. This price is subject to monthly or even weekly fluctuations. To calculate the overall impact of biogas production in South Africa on the trade balance, prices reported for May 2005 (excluding levies) have been assumed and applied. This yields the following import substitution potential with regard to petrol and diesel fuels in rand (see table below). The lower range of the calculation indicates a potential of around R3 billion. A maximum potential exists at R4.4 billion.

Table 4.3.5: Biogas-for-transport-related reduction in fuel imports

	Reduction in fuel Imports (rand per annum)	Reduction in fuel imports (rand per annum)
AD/LFG	2 960 530 691	3 962 850 234
AD	3 257 582 224	4 360 471 788

Source: EcoMetrix team analysis

20. http://www.biodeutschland.org/tl_files/content/dokumente/biothek/Bioenergy_in-Germany_2012_fnr.pdf

4.3.2 Environmental impact

An important contribution of biogas in creating sustainable transport lies in its GHG mitigation potential. The GHG mitigation impact of the large-scale uptake of biogas for transport entails several aspects. There are a number of effects, both direct and indirect, that work towards this end. For the reasons discussed below, the study will provide the direct GHG mitigation effects related to the uptake of biogas for transport by providing a detailed impact analysis, but will briefly highlight the indirect effects as well.

The direct impact on GHG emissions comes from the substitution of fossil fuels with biomethane as a transport fuel and the associated reduction in emissions. While the combustion of biogas produces CO_2, just like the combustion of other fuels, including natural gas, the carbon content in biogas comes from organic matter that has previously absorbed this carbon from atmospheric CO_2. For this reason, the burning of biogas is considered carbon-neutral and does not add to the overall GHG emissions of a country or region.

Thus, net carbon emissions are zero, or close to zero (as the production of biogas itself would lead to some emissions, which are not accounted for at this point – in the same way that upstream emissions associated with the production of fossil-based fuels are not accounted for at this point). This is in line with common international approaches, which explicitly exclude CO_2 emissions resulting from the combustion of biomass or biofuels from national GHG emission inventories (World Biogas Association, 2012). Therefore, when biogas is used as a substitute for fossil fuels, overall GHG emissions and the national carbon footprint will be reduced.

The indirect GHG mitigation impact of a large-scale uptake of biogas comes from reduced GHG emissions (mainly CH_4 and CO_2) occurring naturally from biomass sources, or from reduced emissions resulting from the production of fossil fuels for transport that are now avoided (as noted above, such indirect emissions also occur with the production of biogas, especially for transport, for example emissions resulting from electricity used for upgrading and compressing biogas and related CH_4 losses). These emissions are not part of the assessment, as the scope of this study is specifically geared towards transport. Moreover, international practice in GHG inventories accounts for these emissions at source as opposed to a cradle-to-grave approach.

DEA's GHG MPA for South Africa considers several sector-specific marginal abatement cost curves (MACCs) with mitigation options for three years: 2020, 2030 and 2050. These MACCs effectively summarise the technical mitigation potential of measures to reduce GHG emissions and the associated costs across the South African economy over the different time horizons.

The report includes estimates of the GHG emission abatement potential of measures in five sectors relevant to this study on the large-scale uptake of biogas for transport:

- MSW for electricity generation through LFG (Appendix F)
- AD of (food) wastes (Appendix F)
- Municipal wastewater (MWW) (Appendix F)
- The treatment of livestock waste (Appendix G)
- The pulp and paper industry (Appendix D)

Anyone wishing to gain more elaborate insights into the extent of GHG emissions avoided in these sectors as a result of mitigation measures related to biogas production can consult the MPA Report (Department of Environmental Affairs, 2014). The report of the Kreditanstalt für Wiederaufbau (KfW) (2012) also contains information on this topic.

CBG versus petrol and diesel, and the contribution towards reducing the national carbon footprint

The Biogas for Transport Sources Inventory currently indicates a total biogas production potential of around three million Nm^3 of raw biogas per day from large-scale sources in South Africa. After upgrading and compression, CBG can be used as a substitute for petrol and diesel fuel consumption in transport. It can also be used as a substitute for CNG in those cases where this is already used as a transport fuel. As previously noted, net GHG emissions associated with the combustion of biogas are zero or close to zero, so substitution should lead to an overall improvement of the country's carbon footprint. Below, the report first sets out the theoretical framework for estimating the direct GHG mitigation effect and then goes into the specific calculation.

The relative merits of CBG-powered vehicles need to be compared to alternatives in terms of the overall

GHG mitigation potential. In practice, CBG serves as an alternative fuel to a number of fuels used in transport. The most important ones are petrol, diesel and CNG. For this reason, when calculating the overall GHG mitigation impact from switching to CBG, it is necessary to know the direct carbon emission levels (on a CO_2 equivalent basis) associated with the consumption of these fuels. The 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines provide a standard emission factor for each of these respective fuels, which is used for the purposes of making the calculations in this study. They are captured in the table below.

Table 4.3.6: Fuel emission factors

Direct emission factors	Kg CO_2e/GJ
Gasoline	74
Diesel	69
CNG	56

Source: As reported in Appendix E of South Africa's GHG Mitigation Potential Analysis.

While direct GHG emissions per unit of fuel consumed will differ even within the relevant fuel-type categories, these are internationally accepted averages. They are commonly used in these types of assessments and, as such, are deemed appropriate for the purpose of this high-level assessment as well. Because CNG as a transport fuel is currently only scarcely used in South Africa, there is very limited potential for substituting CBG for CNG. Consequently, this fuel type is omitted from the overall GHG mitigation calculation.

A second factor affecting the direct GHG emission mitigation impact from switching to biogas in transport is the amount of energy contained in each of the alternative fuels (also referred to as the calorific value). The energy contents of different fuels can be compared by calculating the amount of the alternative fuel needed to equal the calorific value of one litre of petrol or diesel fuel. This latter measure is referred to as GLE or DLE, respectively. Generally, diesel will have a higher energy content than petrol on a GLE basis. Because of this, a given amount of energy from biogas production will be able to substitute fewer litres of diesel than petrol.

This effect is amplified by a varying engine fuel efficiency. As discussed above, which repeated the results from a study by the Energy Research Centre at the University of Cape Town on fuel economy for different types of vehicles in South Africa, diesel engines are able to get 15% more 'work' out of a litre of fuel on average than petrol engines are. In other words, the fuel economy of diesel engines is higher. The assessment of the GHG emission mitigation potential when switching to biogas as a transport fuel makes an additional correction for this fact.

Taking these factors into account, what does this imply for the GHG mitigation potential of switching to biogas as a transport fuel? About three million Nm^3 of raw biogas per day could potentially be produced from large-scale sources in South Africa. This amounts to a potential of over one billion Nm^3 of raw biogas per annum. Of this production potential, a little over 300 million Nm^3 is produced from MSW. Biogas from MSW can be produced as LFG by drilling wells into landfills, or through AD of the waste. The study therefore distinguishes between a number of scenarios, which are represented in the matrix below.

Table 4.3.7: Biogas-for-transport GHG emission mitigation

	GHG emission mitigation potential when used to substitute for diesel (tCO_2e per annum)	GHG emissions mitigation potential when used to substitute for gasoline (tCO_2e per annum)
AD/LFG	1 226 969	1 543 301
AD	1 350 080	1 698 151

Source: EcoMetrix team analysis

Depending on how biogas is produced and whether it substitutes petrol or diesel, the GHG mitigation impact of the uptake of biogas for transport ranges between 1.2 and 1.7 million tonnes of CO_2e emissions avoided per year. Hence, the highest mitigation potential is achieved through AD, using the biogas produced to substitute fully for petrol. The latter is due to two separate effects. Firstly, as we have seen, petrol has a higher CO_2 emission factor per MJ burnt than diesel, so replacing it contributes more to mitigating climate change. Secondly, petrol has a lower calorific value and fuel economy. This also means that replacing it contributes relatively more to reducing emissions than replacing diesel. From a GHG mitigation perspective, therefore, there is a double effect at work in favour of substituting biogas for petrol.

CBG as a vehicle fuel and urban air pollution

While there is limited local experience in South Africa

with the use of CNG or CBG in transport, there is substantial international experience when it comes to a decrease in urban pollution by switching to CNG- or CBG-powered vehicles. Countries like Argentina, Brazil, China, India, Iran and Pakistan have sizable CNG-powered vehicle fleets[21]. Experiences in these places show that CNG is very efficient as a vehicle fuel and can contribute significantly to a reduction in local urban air pollution, especially when used as a substitute for diesel fuel, which is used by most city busses and other heavy commercial vehicles (see Narain and Krupnick, 2007).

Table 4.3.8: Non-GHG emission reductions (%) of new CNG compared to in-use petrol/diesel vehicles

	LDV (car)		LDV (truck)		School bus		Heavy duty truck	
	CNG vs gasoline				CNG vs diesel		CNG vs diesel	
	2002	**2007**	**2002**	**2007**	**2002**	**2007**	**2002**	**2007**
NO_X	91	34	97	91	92	76	95	88
PM_{10}	50	0	98	12	98	21	98	22

Source: Argonne National Labs complete full fuel cycle analysis using the latest US Environmental Protection Agency figures[22]

As illustrated in the table above, CNG (or CBG for that matter) emits far fewer pollutants than conventional fossil fuels, including significantly less particulate matter (PM), i.e. up to 50 to 98% reduction in PM versus older light petrol to heavy diesel vehicles. The latter is a considerable source of air pollution in major urban areas like Johannesburg, Durban and Cape Town (CNG also has relatively less carbon emissions associated with it compared to petrol and diesel per 100 km driven). The general findings in countries like India and Pakistan are that switching to CHG- or CBG-powered vehicles can improve urban air quality significantly. CNG- or CBG-powered vehicles generally also have lower maintenance costs than petrol- or diesel-powered vehicles.

4.4 Findings on the viability of CBG for use as transport fuel

The major findings regarding to the viability of CBG as a transport fuel are summarised. Based on these findings, the options for policy interventions are further defined in Chapter 5.

4.4.1 Competitiveness of CBG as a fuel

At the moment, biogas is mainly used to generate electricity, even though the monetary benefits, as analysed in Section 4.1.3, are better when processing biogas further to CBG as a transport fuel. With current market prices of petrol and diesel around R11 to R14 per litre, there has not been a strong momentum in the emergence of a biogas-for-transport or CNG-for-transport market. Hence, it is evident that, under current conditions, the market barriers identified further on in this study prevail. Nevertheless, there are biogas-for-transport projects near financial closure, and CNG Holdings and NOVO Energy have opened up a limited number of CNG fuel stations in Gauteng, focused on the taxi industry.

The implicit subsidy on CBG as a transport fuel (or CNG as a transport fuel for that matter), where there is a lack of any fuel levies or taxes, therefore seems to be essential. In addition, the current incentive provided by the IDC seems to be the final push required to get new CNG fuel stations off the ground. If petrol and diesel prices increase in the future, the case for CBG and CNG will strengthen further and become more attractive.

21. http://www.iangv.org/current-ngv-stats/

22. See: http://www.ngvamerica.org/natural-gas/environmental-benefits/

When comparing CNG with CBG from an economic perspective, CNG will probably remain more competitive, as the Gas Users' Group estimates gas from Mozambique to be imported by Sasol at only R20/GJ, but to be sold at around R42/GJ on average. Nevertheless, as petrol and diesel prices are largely governed by international markets, which are only influenced in a minor way by local alternatives, this will not be of importance. As long as petrol and diesel prices do not decrease further[23], CBG may only be viable in combination with current informal subsidies, and further incentives to counter market-entry barriers may be viable.

Acknowledging the foregoing, the attractiveness for government to potentially stimulate biogas for transport would need to lie in the appreciation of the macro-economic, as well as the environmental impact biogas for transport can make.

4.4.2 CNG for transport is a prerequisite for CBG as a transport fuel

A main barrier experienced by biogas project developers is securing demand for CBG for the longer term (10 to 15 years is essential to finance biogas projects). Therefore, most project developers still opt for biogas-to-electricity as electricity for own use, wheeling agreements and delivery to third parties, as well as the delivery of electricity to the municipal grid, seem to provide better opportunities, regardless of certain difficulties encountered in realising this.

The parallel emergence of a transport market for CNG and CBG therefore seems essential. While CBG can bring in the desired green content, if managed well, CNG – as a low-carbon fuel – can provide the longer-term security and continuity of supply that this market needs to take off. On a critical note, one has to acknowledge that the City of Johannesburg is choosing dual-fuel buses (CNG/diesel) to manage the risk of a security of supply of CBG/CNG[24].

23. http://www.macrotrends.net/1369/crude-oil-price-history-chart

24. Metrobus set to go green, April 2014: http://joburg.org.za/index.php?option=com_content&view=article&id=9049:metrobus-set-to-go-green&catid=88:news-update&Itemid=266

Considering the latter, it seems essential that government, in its overall policy framework, acknowledges the importance of a combination of CNG and CBG for transport, and facilitates the introduction of policies that should guarantee security of supply.

4.4.3 Importance of high-volume recurring transport patterns

CNG/CBG as an alternative to diesel and petrol can only work if sufficient fuel stations are provided. At the moment, only a handful of CNG fuel stations are operational, and a small number are under development in Gauteng. Considering the limited range of CNG vehicles versus diesel- or petrol-powered vehicles, it is essential to focus on recurring transport patterns so as not to get mixed up in a 'chicken and egg'-type dilemma. The following options therefore seem to be most attractive:

- The map of biogas for transport sources in Section 3.3 of this report shows that sources mainly lie within urban areas. Minibus taxis in many of South Africa's major cities form a substantial part of urban transport and, with a preference for petrol, are relatively easy to convert to biogas or bi-fuel operation. Following examples in Johannesburg and Tshwane, these localised transport operations can be serviced by a minimum of well-located CNG/CBG service stations.
- Long-haul cargo transport using CNG/CBG can potentially be economically attractive due to a lower overall fuel cost. Currently, the most frequent long-haul routes lie between Gauteng (Tshwane/Johannesburg) and eThekwini, as well as Gauteng and Cape Town. However, trucks driving on CNG/CBG will have a maximum radius of around 300 to 400 km, and since the Gauteng-to-Cape Town route is approximately 1 400 km and the Gauteng-to-eThekwini or Richards Bay route is approximately 570 to 650 km. This lies beyond the distance that a CNG/CBG truck could cover without refuelling. This interesting alternative should therefore be investigated in conjunction with developing CNG/CBG fuel stations along these routes, supplied, for example, by a virtual CNG and/or CBG pipeline.
- Public city transport includes programmed recurring transport patterns related to city bus routes and schedules. The Biogas for Transport Sources Inventory makes it clear that municipalities own and operate several large biogas sources, such as landfill sites and wastewater treatment plants. These

could potentially be used to provide the fuel for city bus transport systems that are owned and operated by the same municipalities.
The next section of this report looks at this potential in more depth.

4.4.4 The exclusive position of municipalities

Municipalities are in the unique position of being most dominant in the top four owners of biogas-for-transport sources in terms of municipal solid waste and wastewater plants. They also have interesting markets of general public transport and minibus taxis. Despite this extraordinary position, they tend to opt for biogas-to-electricity, while larger monetary and environmental benefits (including urban air quality) could be achieved when using these resources for public transport.

In practice, the use of CBG/CNG for busses is being questioned in the case of dual-fuel engines (diesel/CNG). Several stakeholders indicate that stop-start operations, as with the Johannesburg Bus Rapid Transit System (BRT) – called Rea Vaya, do not perform well using the dual-fuel option. In case of dual-fuel (diesel/CNG), one apparently still runs on diesel about 20 to 30% of the time due to the type of start-stop operation. Moreover, a city bus supposedly drives only 100 to 200 km a day, whereas a minibus taxi drives a multiple of this distance. The latter therefore seems to be the first option of choice.
Given the extraordinary position of the largest municipalities, in particular, there seems to be an opportunity for Johannesburg and eThekwini to develop CNG-/CBG-fuelled minibus taxi and long-haul cargo freight industries, fuelled by CNG/CBG between Johannesburg and Tshwane, and between Johannesburg and eThekwini. For the latter, at least two intermediate CNG/CBG fuel stations would be required. If this were to be realised, a business case for commercial cargo could be created. This specific route might be strengthened by the fact that CNG in the pipeline between Johannesburg and eThekwini would have a side branch going to Piet Retief, which could be extended to facilitate a CNG/CBG fuel station.

4.4.5 Comparative summary of biogas for transport

The previous sections of Chapter 4 discussed the cost benefits, as well as other elements determining the feasibility of converting to CBG as a transport fuel. All these are relevant to government to consider when formulating any policy aimed at supporting biogas for transport. The main findings are summarised in the following table, which makes a comparison between biogas-to-fuel and biogas-to-electricity, as this is the main alternative against which biogas for transport is competing.

The comparative analysis has been subdivided into the following categories:

- Economic/financial
- Environmental
- Socioeconomic
- Infrastructural

Table 4.4.1: Summary of findings of biogas for transport analysis – fuel versus electricity

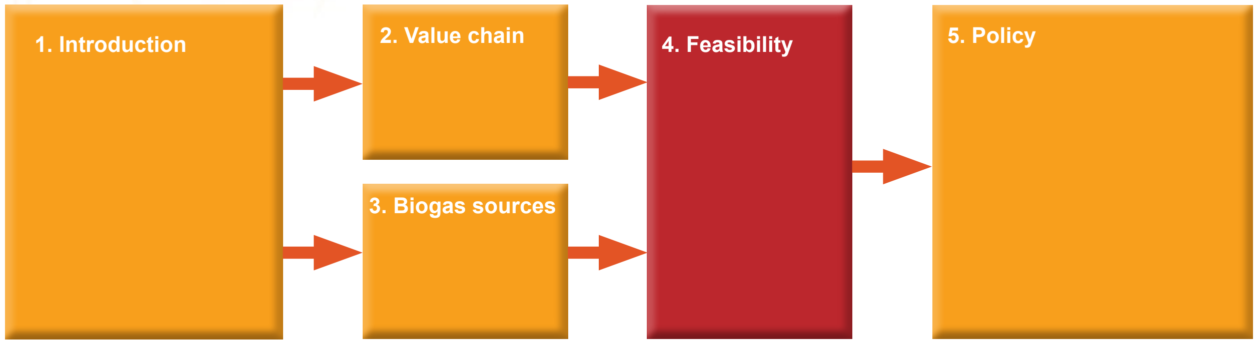
	Biogas to fuel	Biogas to electricity
Economic/financial		
Tax revenue (14% VAT)	A two- to three-times higher monetary value, meaning more VAT income for government	Lower value per GJ of energy, resulting in lower VAT income for government
	R675 to R743 million per annum	R225 to R248 million per annum
Forex[1]	R3.0 to 4.4 billion per annum	Mainly domestic market
Security of supply	No issue, as supply is largely satisfied by world markets	Potential of 240 to 320 MWe generated by biogas sources above transport threshold of 750 Nm^3 per hour[2]
Environmental		
GHG mitigation potential	1.2 to 1.7 Mt per annum[3]	About 10 to 47% for a CHP generator efficiency of 30 to 40%
Air quality	Potentially concentrated in urban areas, where air quality has a direct effect on human health	Generally concentrated in more remote areas where large-scale electricity plants are located
Value of mitigation measure in portfolio of measures	Use of biogas as biofuel would be one of the few GHG mitigation measures implemented in the sector	The electricity sector has several options for mitigation and several active policies; biogas-to-electricity is just one of them
Socioeconomic		
Job creation	The steps to upgrade or compress raw biogas could create one or two extra jobs per sizable facility; indirect job creation is envisaged through investments in new gas infrastructure	Raw biogas is directly used in CHP and electricity if fed to the grid or local network
Infrastructural		
Distribution	The gas grid is limited, with no examples of access for biogas; there is only a handful of fuel stations with CNG/CBG dispensers	Grid is available; access is achieved by some projects; regulatory hurdles can be substantive
Skills	No projects operational in South Africa; the service industry developing	Several projects are operational; the service industry is developing

[1] See Section 4.3.1 and Table 4.4.52.

[2] Based on an approximate potential of three million Nm^3 per day of biogas (65% CH_4) and an efficiency of 30 to 40% for conversion to electricity (CHP generator).

[3] See Section 4.3.2.

Chapter 5: Policy intervention rationales and options



Previous chapters of this report demonstrate that without government intervention, a positive business case for biogas in the national transport sector currently does not exist. This chapter looks at the potential policy interventions that government could consider if it decides that the additional benefits for the country as a whole would justify such an intervention.

Without being prescriptive as to what the policy interventions towards the large-scale uptake for biogas in the transport sector should be, this chapter provides a summary overview of the following:

- The potential benefits of implementing supporting policy interventions
- The financial quantum of such interventions within existing government interventions
- Based on international experiences, where such interventions within the biogas-for-transport value chain would be more and less effective and efficient

5.1 Overview of biogas-for-transport benefits and barriers

Before investigating the potential quantum of government intervention and the effectiveness and efficiency of the different types of interventions, it is important to obtain a coherent overview of the potential benefits for the government and country as a whole, as well as the barriers – both financial and non-financial – that government could alleviate if it feels that the envisaged benefits justify doing so.

5.1.1 Benefits for implementation

From the analysis in Chapter 4, it is clear that, at the moment, the economics of biogas-for-transport is such that no commercial business case for the implementation of biogas solutions within the South African transport sector exists. On the other hand, Chapter 4 also indicates that there are substantial benefits for the country to develop a biogas-for-transport infrastructure, even when compared to the benefits for the country from a biogas-for-electricity perspective. Table 4.4.1 (Biogas-for-transport analysis – fuel versus electricity) provides an overview of the co-benefits in comparison to the benefits of use for electricity, but also gives insight into a number of practical co-benefits that could be realised as a result of the development of a biogas-for-transport sector, as well as infrastructural requirements.

However, when looking at the potential benefits from a more strategic level, some additional co-benefits can be identified that might apply to the use of biogas in the transport and/or electricity sector. These include the following:

- *Reduction of energy dependency:* With a constantly increasing globalisation of the energy sector, the control of energy resources becomes more and more relevant from a geopolitical perspective. By developing domestic energy resources, such as biogas, a country can increase its national energy security by reducing its dependency on foreign imports of fossil fuels.
- *Diversification of the energy mix:* By upscaling the generation and utilisation of biogas as an energy source, the country's fuel mix further diversifies. In practical terms for South Africa, this means that its vast reserves of coal become a smaller component of the fuel mix, and as a result thereof, will last longer, even though – by definition – such a resource is finite.
- *Early-mover advantage:* Although – globally – biogas is used in transport applications in only a few isolated cases, it is potentially a material component of the transport fuel mix. By developing such a sector in the realisation of the large-scale application of biogas in transport, the country could occupy a unique position as a hub for biogas-for-transport technologies, funding models and policies in a similar way as Kenya has done in the area of geothermal energy, and Denmark has done in the development of wind energy.

When the South African government decides whether or not it is in the best interest of the country to develop policy interventions towards the large-scale uptake of biogas within the transport sector, it should do so against the backdrop of these more strategic benefits, and the more practical benefits outlined in Section 4.4.5, taking into consideration the financial and non-financial barriers as outlined in the next section of this report.

5.1.2 Barriers for implementation

During engagements with both individual stakeholders and stakeholder groups, several barriers were pointed out that could hamper the promotion of biogas for transport. Many of these barriers are not unique to South Africa, and resemble experiences in other countries. The sections below detail the different barriers that were identified, making a distinction between financial, regulatory and other barriers.

Financial barriers

Several parties have indicated that in-principle financing is available, but that accessing such financing in a reasonable period of time can be difficult. Some experiences show that this is not only related to the rigorous financial process, which in principle is good financial practice. The current complexity of developing projects in a new and emerging market can prolong the journey of reaching a bankable project extensively.

What seems to play a role is the fact that, because of the large variety of waste streams and types of facilities generating those waste streams, projects tend to be very different in nature, requiring parties to (partially) embark on a new learning curve for each project, and dealing with related uncertainties that affect the business case. This complexity materialises both on the side of project developers in realising bankable feasibility studies, as well as financiers having to assess these feasibility studies.

Current financial and funding instruments are not biogas-specific or – for that matter – biogas-for-transport-specific. Therefore, one needs to target various potential funding and financing sources, and meet a variety of financiers and funders, who are less familiar with the specific biogas subject at hand. In addition to this, project developers indicate that funding and financing options for feasibility studies that can assist project developers overcome the relatively long lead time are scarce.

In summary, the following barriers have been identified with regard to financing:

- Complexity and duration of the funding/financing process
- Lack of knowledge and low risk appetite of financiers/funders
- No dedicated funding for biogas or biogas-for-transport projects
- Lack of funding/financing for feasibility studies

It is interesting to note that the French Development Agency (AFD) is supporting an initiative to establish a database of funding options for biogas projects both locally and internationally.

Non-financial barriers

Regulations and related licences are often mentioned as barriers for the implementation of biogas projects. Depending on the type of waste and size of the project, this can vary. In the case of abattoir waste, regulations are most strict, as one is dealing with potentially hazardous waste, and the destruction of pathogens, for example, needs to be ensured. Related licences need to be obtained on a national level. Moreover, the digestate is not always acknowledged as being safe (prion-free) and can still be considered as waste, limiting the opportunities to use and sell it.

At the National Biogas Platform held in April 2015, SABIA estimated that only around 400 biodigesters are currently installed in South Africa. The unfamiliarity with biodigestion results in several benefits not being fully acknowledged. These benefits include energy security, job creation, fertilizer production and diversion from landfilling related to biogas production. Moreover, biogas-to-transport is not fully acknowledged. This plays an important role in delaying the uptake of biogas. Current operational projects do not provide sufficient confidence in the technical and economic viability of biogas projects. SABIA has an information hub/web portal under development with the aim to partially address this.

Various project developers experience access to municipal waste streams as being extremely difficult. Some developers have targeted these waste streams for several years, and at a certain point decided to give up. An important stumbling block for municipalities is the Municipal Finance Management Act (Act No. 56 of 2003) (MFMA) and its amendments in 2005, which include a limitation to contracting periods (maximum of three years). It is geared towards prudent procurement and not sales. The solutions that municipalities have applied in dealing with the MFMA in respect of waste-to-energy projects vary from alternative project structures, requesting an exemption on the MFMA, or focusing on being compliant with the objective(s) of the MFMA rather than on the detailed procedures and requirements (EcoMetrix/SACN, 2014). Nevertheless, this often results in long delays.

A biogas-for-transport-specific barrier is that municipalities (when they succeed in developing waste-to-energy projects) seem to dedicate their waste sources to waste-to-electricity in particular. Part of this preference for electricity stems from the fact that some initiatives were launched years before the biogas-for-transport option came on the agenda. Three larger biogas-to-electricity initiatives can be mentioned in particular:

- City of Cape Town: Plans are underway to develop several landfill gas-to-electricity projects (including two to three sites) under a carbon credit programme of the City
- City of Johannesburg:
  - The Johannesburg Landfill Gas-to-electricity Programme, incorporating up to five landfills
  - Johannesburg Water is implementing CHP facilities at Northern Water Works, Bushkoppie, Goudkoppie, Olifantsvlei and Driefontein
- eThekwini: An LFG-to-electricity programme has been initiated, which encompasses the extraction of CH_4 from three Council-owned landfill sites (Mariannhill, La Mercy and Bisasar Road) for electricity generation and sale. The Bisasar Road landfill is the largest on the African continent.

Gas in South Africa only plays a marginal role in the energy mix and – as such – there is very limited transport and retail infrastructure in place. As detailed in Section 4.2, it will be important that natural gas and biogas-for-transport go hand in hand to circumvent issues around risk of supply and forcing a breakthrough in a ‘chicken-and-egg’, supply-and-demand situation, thereby unlocking demand. In this regard, it could be of importance to request NERSA to arrange access to the gas grid and develop standards and legislation to also make this practically possible.

Last, but not least, the current regulatory uncertainty around the continuation of CNG as a transport fuel not being classified as a fuel levy good (in other words, being implicitly exempt from fuel-related levies and taxes) limits possibilities to fully bank on the related financial advantages over conventional fuels.

In summary, the following non-financial barriers have been identified:

- Licensing and regulations are complex and onerous
- Unfamiliarity with biogas and its advantages
- Access to municipal waste and the MFMA hampering longer-term commitments
- The current preference of municipalities for waste-to-electricity projects

- Lack of gas infrastructure, skills and market
- Lack of regulatory certainty regarding fuel-related levies and taxes

5.2 Strategic framework for policy development

The high-level framework set out in this section on policy development deals with the perspective of South Africa as a society, and how South Africa – considering its strengths, weaknesses and its needs as a country – could benefit from the development of biogas as a transport fuel. Setting the stage, using a strengths, weaknesses, opportunities and threats (SWOT) assessment, policy options, effectiveness and international experiences are covered, concluding with specific recommendations for South Africa.

5.2.1 SWOT on a national level

Although the most common use of a SWOT analysis is in corporate strategy development, the use of SWOT analyses in the context of national policy (or climate change policy for that matter) is certainly not unique. An interesting example is the Scottish Government using a SWOT analysis to develop policies aimed at reducing GHG emissions resulting from energy consumption (see box below).

Box 5.2.1: Scottish Energy Study – SWOT on CO_2 Reduction Strategy for the Transport Sector

As part of the Scottish Energy Study (Scottish Government, 2009), a thorough SWOT analysis has been applied to the different sectors in the context of the objective of reducing energy consumption and related CO_2 emissions. This included the transport sector being close to the subject at hand in this study.

The definition of the four factors in the SWOT analysis are:

- Strengths: attributes of the organisation, which are helpful to achieving the objective
- Weaknesses: attributes of the organisation, which are harmful to achieving the objective
- Opportunities: external conditions, which are helpful to achieving the objective
- Threats: external conditions, which could do damage to the business's performance

Central to the use of a SWOT analysis is the definition of the objective to be accomplished. Without this, it is hard to judge if a specific factor of influence is helpful or harmful.

Objective - Scottish Strategy to reduce energy and CO_2 emissions from transport		
	Helpful to meeting the objective	**Harmful to meeting the objective**
Internal factors	**Strengths** • ESSAC Network to influence travel choices for households • Existing programmes support mode shift • Climate Change Act targets require change • Carbon budgeting will inform future transport project decisions • Planning can influence the need for and mode of future travel	**Weaknesses** • Limits to funding available • Limited devolved powers (e.g. planning devolved, but not vehicle and fuel duty) • Pressure to provide key road infrastructure projects
External factors	**Opportunities** • ESSAC Network to influence travel choices for households. • Existing progammes support mode shift • Climate Change Act targets required change. • Carbon budgeting will inform future transport project decisions • Planning can influence the need for and mode of future travel	**Threats** • Car ownership and use continue to grow • Air travel is predicted to double by 2020 • Difficulty/cost influencing two million drivers • Driving embedded as most practical/convenient • Congestion creates new road demand • Public transport in rural areas is expensive • Access to competitive transport options is essential for business

Central to using the SWOT analysis is the definition of a clear objective to be accomplished. The strengths and opportunities are attributes or conditions in the internal and external environment, which are helpful in achieving the objective. In contrast, the weaknesses and threats are attributes or conditions in the internal and external environment that are harmful to meeting the objective.

Although the SWOT analysis, as a tool, in principle provides a simple method of analysis, one needs to adhere to the framework set in order to get useful results. Besides a clear objective, it is important to clearly distinguish between co-benefits and strengths. While a strength is an attribute that is helpful to meeting the objective, a co-benefit can be part of what one aims to achieve, while in essence it does not contribute to realising the objective.

For example, in the case of the Scottish Transport Strategy, with a focus on public transport, a co-benefit is easing congestion in the region. Nevertheless, this co-benefit is not mentioned as a strength (see Box 5.2.1), as it does not assist in the process of householders making the modal shift from car to bus or train. Rather, the European Science, Support and Advisory Committee (ESSAC) Network is mentioned as a strength. Th is network delivers energy advice to and can influence the decision-making of householders, communities and businesses in terms of how to save money, reduce energy usage and make an impact on the environment.

The following section of this report applies the SWOT framework to the case at hand in the way described above.

5.2.2 Analysis of the case for South Africa

The SWOT analysis in the context of this study is applied on a national level dealing with public- and private-sector organisations and how these can work together to achieve the objective of 'transforming to CBG as a transport fuel'. External factors in this sense are factors outside the control of public- and private-sector organisations, while internal factors deal with the strengths and weaknesses of the public and private sector.

In line with the SWOT framework as set out in the previous paragraph, the co-benefits are considered part of the wider objective and, as such, are not repeated as strengths. The barriers summarised under weaknesses have already been identified and discussed under Section 5.1.3 and, as such, are not further detailed.

An overall summary based on an analysis of the internal and external environment, as well as the engagement with stakeholders, is presented in the figure below. Subsequently, the results of the SWOT analysis are discussed in more detail. In order to make the link with the SWOT results summarised in Figure 5.2.1 clearer, the main key words are highlighted in the text.

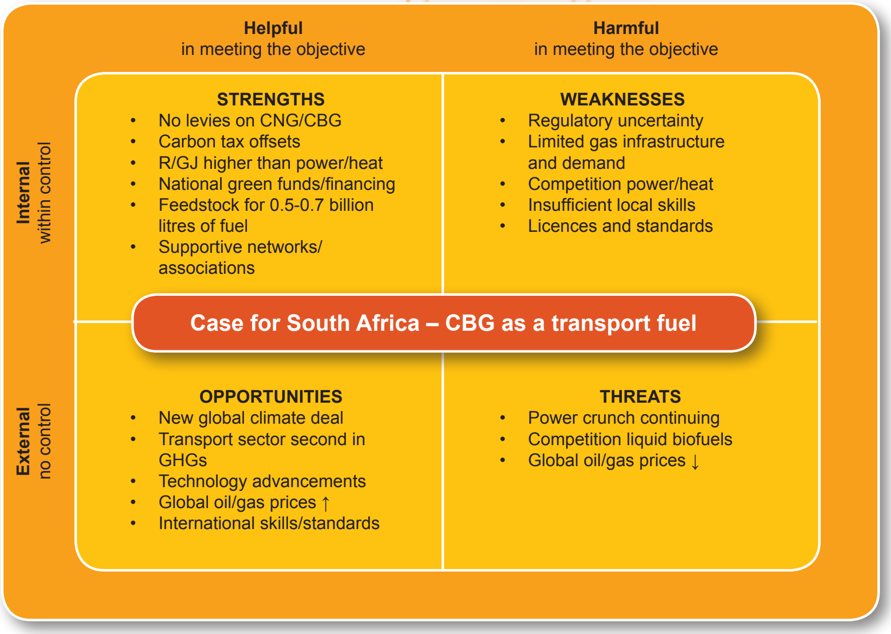


Figure 5.2.1: A SWOT analysis of the case for CBG as a transport fuel in South Africa

Strengths and weaknesses – financial perspective
A current key strength, which has assisted in the emergence of the first CNG/CBG for transport initiatives in the country, is the fact that *no fuel-related taxes and levies are charged on CNG/CBG*, which provides a competitive advantage over regular diesel and petrol. Then again, this advantage is required in order to compensate for the fact that, generally speaking, CBG is more costly to produce than CNG. The regulatory uncertainty around whether the exemption from the various fuel-related taxes and levies will be continued is, however, hampering CBG business cases to become bankable and take the full benefit of this exemption. Longer-term certainty on the contribution of fuel-related taxes and levies to profitability is required (say 10 to 15 years) in order to take this exemption fully into account, and thereby strengthen the business case and enhance capability to pay back a commercial loan.

The *carbon tax* that is envisaged to be implemented in 2016 and its carbon offset component could also provide a financial stimulus. Although exposed indirectly through refineries within the borders of South Africa that are being taxed, the transport sector is not directly included in the tax net (National Treasury, 2013; 2014) and, as such, can provide offsets on a project basis when developing and implementing initiatives under one of the carbon standards eligible for carbon tax. Any remaining uncertainty about this instrument will largely disappear upon implementation of the tax and its offset components.

Although biogas-for-transport is *in competition with the conversion to biogas-for-electricity and heat*, there is currently a strong financial upside when converting and selling it as a fuel, as has been illustrated in Section 4.1 of this report.

Opportunities and threats – financial perspective
How fuel and electricity prices will develop in the future remains uncertain. *Continuation of the electricity crunch* may drive electricity prices up and, accordingly, drive businesses to generate their own electricity using biogas to avoid further electricity price increases, and to make themselves more self-sufficient. How long the electricity crunch will continue and how the price of electricity will develop remains uncertain and hard to bank on. The same uncertainty comes into play regarding the development of *international oil/gas prices* in combination with *rand-dollar exchange rates*, which in the end will determine the cost of fuel.

Technological advancements may lower the cost of producing biogas for transport. However, one needs to take into account that the AD of biomass is a relatively mature technology and has been around for a long

time. Generally speaking, breakthroughs changing the game are not likely in that case. However, if there are breakthroughs with a substantial positive impact on production cost, the question is what the time to market of these technologies will be. For these reasons, technological advancements have been left out of the scope of this study. As global biogas markets develop, optimisations may be expected. However, it remains to be seen to what extent this will happen.

What we do know is that the biogas industry in South Africa, although small, is at the start of its development, with environmental, as well as co-benefits mobilising both local and international support, whether in terms of *funding/financing* or technical assistance. A *new climate deal* during the next United Nations Climate Change Conference of the Parties (COP) in Paris on 21 December 2015 could provide further stimulus. As the *transport sector is the second-largest source of emissions* in the GHG Inventory for South Africa 2000–2010, it is certainly a sector that will receive further attention when implementing plans to reduce the national carbon footprint, as defined in the National Climate Change Response White Paper and its transport flagship programme (Republic of South Africa, 2011).

Strengths and weaknesses – non-financial perspective

Several organisations and projects have emerged in support of the development of the biogas sector in general. Although not specifically supporting biogas for transport, they are beneficial in supporting the biogas industry overall. Gaining more momentum with the development of biogas for transport projects, it is likely that it will also be possible to obtain support from these organisations in the case for transport.

Current main initiatives supporting biogas are the following:

- *National Biogas Platform*[25]: Established in 2013, the National Biogas Platform comprises representatives from donor agencies, industry, local/national government, academia and research institutions. The German Gesellschaft für Internationale Zusammenarbeit (GIZ) is the facilitator of the platform on behalf of DoE and SABIA. The platform focuses on *regulatory requirements, information gathering and financing options* for biogas projects.
- *The South African Biogas Association*[26]: This association was formed in 2013/14 by a core group of interested and affected parties out of a common need for active representation of the biogas industry in South Africa. SABIA is focused on industrial parties, and included around 35 official members in 2014. The association supports the biogas industry overall, irrespective of the final application in the form of heat, electricity and/or fuel.
- *The United Nations Industrial Development Organisation (UNIDO)-Global Environment Facility (GEF) Project – Promoting organic waste-to-energy in small, medium and micro enterprises (SMMEs): Accelerating biogas market development (UNIDO-GEF, 2015):* This is a four-year US$36 million project running until 2018, which is focused on promoting the market-based adoption of integrated biogas technology in SMMEs in South Africa. It includes the components of *capacity building, regulatory framework and demonstration*. The latter component involves co-funding and support to five to nine selected biogas projects. Currently, only five biogas-to-electricity projects have been selected.

These initiatives show that a lot of attention is already going towards addressing implementation hurdles related to regulations. GIZ is currently supporting a study regarding regulations and licenses when developing biogas projects. It has also been suggested within the National Biogas Platform that a list of licences should be defined against which funders and financiers can assess the regulatory compliance of biogas projects that are seeking funding/financing. The regulatory framework is also part of the UNIDO-GEF project, which addresses this issue in a practical manner as part of selected demonstration projects.

The aforementioned initiatives also address capacity building, supporting the development of local skills through demonstration projects, educational curricula, information sharing and working groups on certain topics. In that sense, the weaknesses identified

25. http://www.energy.gov.za/files/biogas/nationalBiogasPlatform.html

26. http://biogasassociation.co.za/

regarding licences/standards and local skills already seem to be well mitigated.

Opportunities and threats – non-financial perspective

Apart from an envisaged increase in funding and financing opportunities as a result of positive developments in the global climate change negotiations in the context of the United Nations Framework Convention on Climate Change (UNFCCC), a stronger influx of international skills and technical assistance can also be expected. Several countries in Europe have extensive experience in relation to AD, processing different types of feedstock and using biogas in different ways (for example, electricity, heat and transport fuel). Upon a new global climate deal, including envisaged commitments from industrialised countries to assist developing countries in term of technical assistance and funding/financing, current support could increase if this goes together with good programming and planning within the South African public and private sector.

5.2.3 Types of policy instruments

The previous section provided insights into the strengths, weaknesses, opportunities and threats of the case for the large-scale uptake of biogas in South Africa. A SWOT analysis, as such, is a useful tool for strategy development towards the future. Having analysed the biogas-for-transport value chain, identified significant sources in the country and examined the feasibility of biogas for transport in the previous chapters, the next step involves designing a conceptual policy framework in support of the large-scale uptake of biogas for transport.

We have seen that a certain level of support is likely to be necessary at least in the near future. In this regard, an important question becomes how best to implement such support through an appropriate government policy.

Generally speaking, the main economic functions of modern government are threefold:

- *Allocation function* of providing public goods and preventing harm, for example in the case of environmental degradation when certain costs have not been internalised (a so-called externality).
- *Distribution function* to affect income and wealth distribution, and ensure a more desirable and fair outcome.
- *Stabilisation function* of reducing business-cycle fluctuations through appropriate monetary and fiscal policies.

Designing a suitable environmental and/or energy policy lies well within the confines of the first of the three objectives of government as defined above. To affect outcomes in this regard, the (international) public finance literature identifies a number of policy options at the disposal of government. These can be categorised into three primary types of measures:

- Subsidies
- Taxation
- Regulation

In the environmental realm, this gives rise to a wide range of possible policy alternatives. Some of these are market-based instruments in that they use markets, prices and other economic variables to affect behaviour through incentives. Moreover, some of these are transparent, like a direct subsidy in the form of a cash transfer. Others are indirect, like a tax incentive. A second set of policy measures can be categorised as so-called command-and-control strategies, which aim to steer behaviour through direct regulation and mandatory standards that dictate certain rules. The following table provides an indicative overview of potential policy measures.

Table 5.2.1: Taxonomy of different types of policy instruments

Subsidies	Taxation	Regulation
Cash transfers to producers or consumers	Preferential tax rates (income tax or VAT)	Price controls (price floors/ceilings or feed-in tariffs)
Low-interest, preferential loans or government guarantees	Tax-base exemptions or deductions for certain activities or transactions (accelerated depreciation, carry back/forward, or exemption from income tax or VAT)	Demand guarantees
Government services provided at less than full market-based costs (e.g. public investment in infrastructure or research and development)	Tax credits (percentage reduction of income tax payable)	Mandated deployment rates (blending requirements)
	Pigovian taxes (a carbon or fuel tax)	Limits on market access
	Trade restrictions (in the form of tariffs at the border)	Controls over access to resources/ planning consent
	Gate fees	Trade restrictions (quota and technical restrictions)

As one can see, the list of potential policy options is extensive and wide-ranging. It includes both positive and negative financial incentives through subsidies and taxes, as well as regulatory measures. For obvious reasons, there is unlikely to be a 'one-size-fits-all' policy instrument that is best used in all situations. Different circumstances and scenarios will require different solutions. However, a number of things can be said in favour of market-based financial incentives in general.

In contrast to a market-based incentive like a tax or subsidy, a command-and-control strategy simply mandates a rule or standard. There is an entire range of economic literature that compares both types of policies. The general consensus among economists is that market-based financial instruments are more efficient (partly because private parties generally have more detailed information than regulatory bodies and are better able to make decisions provided the incentives are set right) and carry less risk of regulatory capture (where the regulator colludes with the regulated and the public interest is disregarded).

As to the first point, for example, because different production plants have different marginal abatement costs, a command-and-control type of rule mandating every plant to reduce carbon emissions equally would be inefficient. On the other hand, a uniform carbon tax or cap-and-trade system would incentivise modern plants with low abatement costs to cut relatively more while older plants with higher abatement costs would continue to pollute and pay the tax. Overall, the same amount of emission reductions would be achieved, but at a relatively lower cost, in the latter case, than in the former.

The same goes for rules and regulations versus market-based financial incentives in the transport sector. Rules that apply equally to everyone, like a fuel economy standard for cars, are likely to yield a less efficient outcome, while letting the market do its work through a system of (fuel) taxes or subsidies should, in theory, generate an efficient result.

Furthermore, all other things being equal, on-budget policy instruments like a direct subsidy should (theoretically) have preference over indirect, off-budget measures like a tax benefit. Off-budget incentives do not appear on national accounts as government expenditure. Typically, this means that transparency and accountability suffer. Although some countries have so-called tax expenditure budgets to reign in finance ministers and keep budgets under control, this is not common practice.

On the other hand, political realities often prompt governments to favour off-budget instruments exactly for this reason. The practicability of granting an indirect tax benefit is generally higher than accounting for an explicit direct subsidy. Moreover, subsidy allocation often costs a lot of time and resources. Even if people are well intended, the allocation may not go as desired.

A tax incentive is easier to implement. In addition to this, it is important to take consideration of the level of institutional capacity. Hence, whether to choose a subsidy or tax is ultimately a political choice. The next section will therefore focus on both on- and off-budget financial incentives.

5.2.4 Position of interventions across the value chain

The theoretical framework provided above gives rise to a number of policy intervention options within the biogas-for-transport value chain to incentivise production. Not all policy instruments (subsidies, taxes or regulation) will be equally applicable at each stage in the value chain. This will, among other things, depend on the specific activities at that stage in the value chain, and factors such as whether the activity is capital-intensive or labour-intensive, or whether the stage is already subject to an existing regulatory framework.

In the analysis below, we will apply the theoretical framework of policy intervention options to the biogas-for-transport value chain, as depicted in Figure 5.2.2. For each stage, the main options for policy intervention are highlighted with the aim of stimulating biogas-for-transport production.

Figure 5.2.2: Various options for policy intervention within the biogas-for-transport value chain

1. The first stage involves the collection or production of biomass (since we are not considering crop-to-fuel here, the latter is not relevant at this point). The main policy instrument one could consider at this stage comes in the form of higher gate fees that should, all things being equal, provide an incentive to find alternative uses for waste, for example, in the form of biogas production. Regulation can also come into play, for instance, in the case of abattoirs or chicken farms where there is strict government oversight of on-site waste handling. Biogas in these sectors can be promoted by adapting the regulatory environment in a way that still adequately guarantees public health and safety, but is nevertheless more conducive to the production of biogas from wastes.
2. Upstream logistics deals with getting the biomass from the source to the biogas production plant. The latter can be on-site or off-site. This stage is rather capital-intensive and costs of on-site and off-site collection and transport (so-called first transport and processing, and transport to destination) are important factors. Various tax incentives, like accelerated depreciation for trucks and machinery used at this stage, can reduce costs. Lower fuel taxes for operating vehicles is another example.
3. The biogas production stage is mostly about capital expenditure (capex) and operational expenditure (opex) for operating the digester and related equipment to process the biomass. Low-interest loans or guarantees for building the capital equipment can be used, as well as various capital tax incentives. In the latter case, one should keep in mind that, especially in the start-up phase, there might not yet be (sufficient) taxable income against which to offset the tax incentive, although there are ways to work around this, for example by granting a refundable tax credit. In such a case, the tax treatment should allow for sufficiently lenient rules for carry back and carry forward. Theoretically, lower labour taxes for workers employed in this sector could reduce costs and stimulate hiring. Since labour costs and taxes are relatively low in South Africa, it is not clear whether the effect from the latter measure would be significant.
4. The raw biogas production stage is followed by the highly capital-intensive upgrading stage. Again, low-interest loans or guarantees, and capital tax incentives could play an important role in stimulating biogas production. Since the upgrading phase is the crucial step in the supply chain when it comes to using biogas for transport (and thus not generating heat and electricity through CHP), measures at this stage might be especially effective in promoting biogas for transport. Other than that, not much labour is used at this stage, making measures targeting the workforce likely to be less effective at providing an overall incentive for the production of biogas.

5. Downstream logistics is about compression, storage and transport to the envisaged off-taker (e.g. through the actual or virtual pipeline). Again, this phase is highly capital-intensive, making all the factors mentioned in the above point applicable. In addition, government-provided services and public investment could provide a significant boost at this stage. As we have seen, the present network of natural gas pipelines in South Africa is relatively under-developed. Direct infrastructure investment would make natural gas more widely available throughout the country, and would encourage the uptake of biogas for transport significantly (provided biogas producers can tap into the network).
6. The last stage of the supply chain is where the off-take of the biomethane actually takes place. That is, where the CBG is consumed by fleet owners or retail users. Here, several measures can be contemplated. First off all, this stage is where the actual tax burden of fuel-related levies and taxes, as well as VAT, falls. Exemption from one or more of these consumption taxes is a realistic option. Guaranteed off-take agreements in the form of demand guarantees is a second category of measures that are worth looking at. In that case, fleet owners and/or government guarantees a certain off-take and thereby reduces risk for the producer of biogas. Thirdly, government is in the position to grant licences to build service stations that are equipped to distribute biomethane at strategic locations throughout the country. Lastly, mandatory-blending requirements/regulations can be used to stimulate the off-take of biomethane at the pump.

From a theoretical perspective, this gives a wide-ranging mix of policy instruments that can be considered when promoting biogas for transport. Furthermore, several of these options can be applied at multiple stages throughout the value chain. That being said, some instruments are likely to be more effective or practical to implement than others. To get a general idea of what is and what is not practicable, the next section looks at some of the main international experiences in this regard.

5.3 International policy experience

This section of the report highlights a number of international experiences with regard to government intervention, with the aim of stimulating the uptake of biogas and its effectiveness, as a precursor to conclusions and recommendations regarding potential South African support measures.

5.3.1 International policy overview

While there is a lot of international experience when it comes to policies promoting biofuels like bioethanol and biodiesel, policy interventions with regard to biogas are less common. The main countries that provide useful lessons are Austria, Denmark, Germany, Sweden, The Netherlands and the United Kingdom. Of these countries, Germany, Sweden and The Netherlands feature in the top three of the European Biogas Association, in terms of the total number of biomethane plants[27]. The governments of all countries mentioned above have a relatively long history of promoting biogas production. Moreover, and partly because of this, they have relatively large and developed biogas markets.

In practice, it is often the case that policy measures aimed at promoting biogas go hand in hand with policies or legislation promoting biofuels or renewable energy more generally. The analysis is therefore necessarily broad. However, it is easy to imagine that measures aimed at biofuels or renewable energy in general could also be applied more specifically to the case of biogas. The following table provides an overview of the legislation aimed at the uptake of biofuels for transport in the relevant countries.

27. http://european-biogas.eu/wp-content/uploads/2014/12/Biomethane-graph-20131.png

Table 5.3.1: Measures aimed at promoting the uptake of biogas for transport in selected countries

Country	Measure	Measure
Austria	Tax-incentive mechanism	Fuels from a minimum content of 4.6 to 6.6% (depending on the type) of biogenic material are subject to a lower fuel tax. Mineral oil solely from biogenic material is fully exempt.
	Biofuel quota/blending requirement	Biofuels have to make up a defined percentage of producers'/importers' total annual fuel sales.
Denmark	Tax-incentive mechanism	Energy products are taxed a certain amount. This amount is reduced for fuels blended with biofuels.
	Biofuel quota/blending requirement	Biofuels have to make up a defined percentage of producers'/importers' total annual fuel sales.
	Promotion of Renewable Energy Act	Detailed feed-in tariffs for biomass/biogas and other renewable energy sources.
Germany	Biofuel quota/GHG reduction quota	Biofuels have to make up a defined percentage of producers'/importers' total annual fuel sales.
	Tax-incentive mechanism	The Energy Tax Act obliges producers/ importers of energy products to pay a defined amount of tax. Tax relief for biofuels exists depending on the type of biofuel.
	KfW Renewable Energies Programme	Programme that, among other things, comprises reduced-interest loans for up to 100% of the investment costs.
The Netherlands	Tax-incentive mechanism (Environmental Investment Rebate (MIA)/and Arbitrary Depreciation of Environmental Investments (Vamil) schemes)	Extra deduction of investment cost from the taxable profit for investments in biofuels.
	Tax-incentive mechanism (Energy Investment Allowance (EIA) scheme)	Tax benefit enables companies to write off investments aimed at the effective use of energy.
	Biofuel quota	Biofuels have to make up a defined percentage of producers'/importers' total annual fuel sales.
Sweden	Tax-incentive mechanism	Fossil fuels are taxed with energy and carbon levies. Biofuels are exempt from these taxes.
The United Kingdom	Renewable Transport Fuels Obligation	Long-term mechanism requiring transport fuel suppliers to ensure that a set percentage of their sales are from a renewable source.

Source: RES Legal and EcoMetrix Africa team analysis

The table above shows that most countries typically rely on a tax incentive scheme, whereby biofuels are taxed at a lower rate than fossil fuels, or are completely exempted from regular consumption/fuel taxes. The UK is the only exception, in that it does not use the tax system to promote biogas. A mandatory blending requirement/quota system is the second-most relied on measure. In addition, Germany has a policy in place that provides low-cost loans for biogas investments through the KfW Renewable Energies Programme. Of the six countries, The Netherlands is the only one that does something with an investment tax benefit in its income tax system.

5.3.2 Policy effectiveness experiences

To evaluate whether these measures have been effective in stimulating the uptake of biogas for transport, one would not only need to look at the specific policy measure to see whether there has been an increase in the production and consumption of CBG. One would also have to establish a causal relationship between the two variables. While this is interesting, it is very hard to do, and only a few dedicated studies have been identified that have done this successfully.

There are many dynamics at work. It would require substantial data to establish valid and robust results. This is especially true in the case of biogas, where, in practice, many different feedstocks are used, with various yields under different circumstances. Baseline emission factors differ per waste-related feedstock, as well as the specific energy source displaced and the type of biomass and upgrading technology applied. It is generally acknowledged that, even for countries where lots of data is collected and transparency is high on the agenda, such as in case of Germany, The Netherlands and the United Kingdom, it is hard to come by the necessary information.

However, international studies are available on the effects of support measures for renewable energies, including, for example, reductions and exemptions in energy taxes and levies (see Beaton and Moerenhout, 2012; Rosenberg et al., 2011; Varadarajan et al., 2012). Generally, these studies find positive results with regard to the use of government policy to promote renewable energy and the potential to mobilise private investment and substantially expand the renewable energy industry. For example, an interesting study assesses the cost-effectiveness of renewable energy deployment subsidies for biomass power in the United Kingdom and Germany. Another study looks more generally at the effect of policy on renewables in relevant European Union countries and the USA. A third study on the impact of tax exemptions and levy reductions on the production of energy from biomass finds that the effect is significant.

Overall, these results are supportive of using financial incentives in combination with other policy measures to promote biogas for transport. There does not seem to be any compelling reason why this should be different in the case of South Africa. As a result, it seems safe to conclude that government incentives can play a pivotal role in promoting the uptake of biogas for transport in South Africa as well.

5.4 South African policy conclusions and recommendations

From Section 5.1.1 and earlier chapters in this report, it becomes clear that the direct economic benefits do not outweigh the direct economic costs in the case of biogas for transport. However, if the South African government feels that the co-benefits, as summarised in Section 5.2 and elaborated on in previous chapters, justify supporting the development of the South African biogas-for-transport sector, then it should first support the economic viability of the case. Secondly, it can do so by structurally alleviating the barriers for implementation as outlined in Section 5.1.3.

5.4.1 CBG policy rationale

When looking purely at the economic case for biogas, it becomes clear that one or several incentive policies should be implemented to make it successful, building on international experiences as to (the effectiveness of) different types of incentives. Before identifying the optimal incentive model, it is useful to identify the size of the financial incentive that could be applied. One rationale to determine the 'level' of financial support is by looking at domestic and international examples and existing levels of support in relation to the different co-benefits.

Figure 5.4.1 provides a graphic representation of how the different levels of support compare, if converted to rand per GJ of biogas at the pump. This figure is followed by an elaboration of the different support levels.

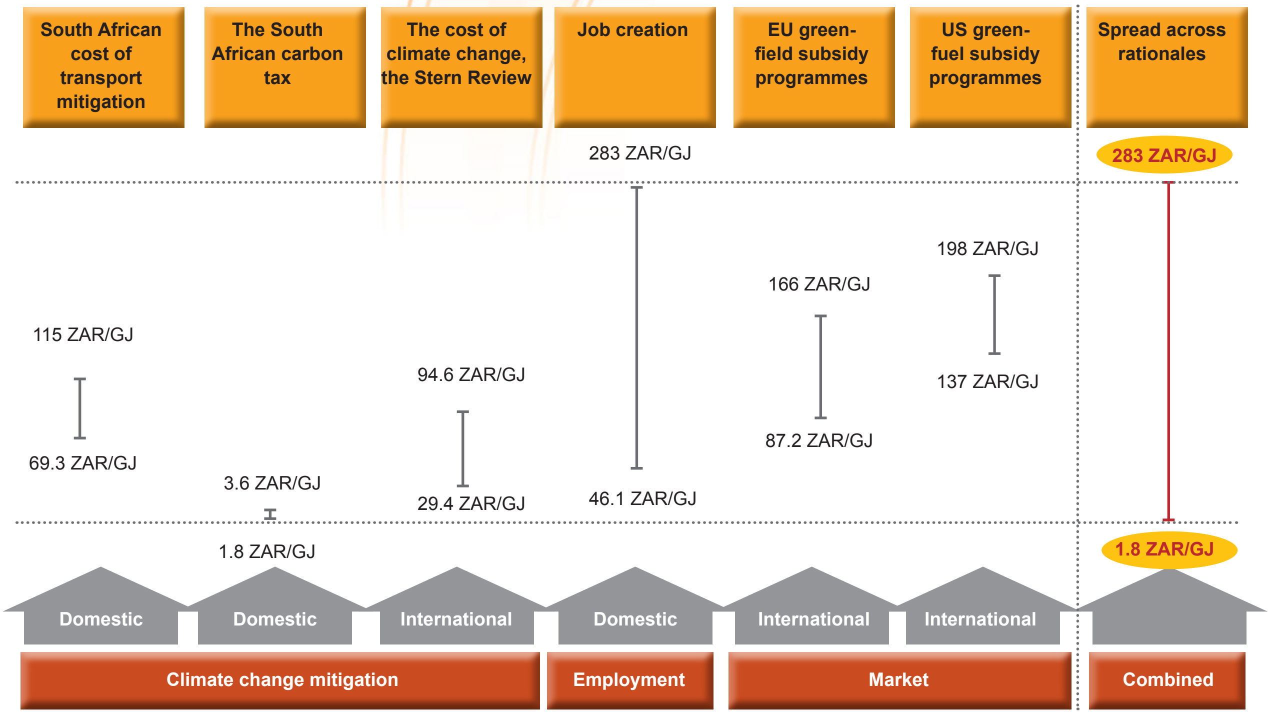


Figure 5.4.1: Biogas-for-transport incentive rationale range

As is apparent from the above figure, the different domestic and international rationales are either driven by climate change mitigation, employment or market-based factors. The following six rationales were applied:

- *South African cost of transport mitigation (climate change mitigation):* The GHG MPA (Department of Environmental Affairs, 2014) estimates that the mitigation costs for second-generation (organic waste-based) biofuels within the country's transport sector lies in the range of R936 to R1 554/tCO_2e between 2020 and 2050. At a carbon intensity of petrol at 74 kg CO_2e/GJ, this would equate to R69,30 to R115,00/GJ.
- *The South African carbon tax (climate change mitigation):* In May 2013, National Treasury released the Carbon Tax Policy Paper (National Treasury, 2013) for public comment. At the time of writing this report, the draft carbon tax legislation based on the policy paper was being reviewed by Cabinet. In essence, the proposed carbon tax applies a R120/tCO_2e on a number of carbon-intensive sectors. The tax is proposed to be implemented in 2016 and applies a number of discounts depending on, among other things, the profile of the taxed entity. As such, it results in an effective 'cost of emission' that lies in the range of R24/tCO_2e to R48/tCO_2e. Although the transport sector is currently excluded from carbon tax and the tax constitutes a cost and not an incentive, it could provide a rationale for the potential biogas-for-transport subsidy. Converted into rand per GJ, this subsidy would lie in the range of R1,80 to R3,60/GJ.
- *Job creation (employment):* Under the Gro-E Scheme (the IDC's fund aimed at driving job creation[28]), a benchmark of around R500 000 invested should result in one job created as a result of the investment. As detailed in Section 4.3.1, along the biogas-for-transport value chain, the realisation of the full biogas potential within the country could result in between a lower range of 2 324 and an upper range of 14 248 additional full-time jobs. At an energy content of 23 MJ/Nm^3, this relates to an incentive in the range of R46,10 to R282,90/GJ.
- *The cost of climate change, the Stern Review (climate change mitigation):* In 2006, the British government published the Stern Review on the Economics of Climate Change (Stern, 2006). The report, states that the costs of stabilising the climate are significant, but manageable, and that

28. http://www.capricornfm.co.za/ads_html/idc/Creating%20jobs%20through%20efficiency.html

delay would be dangerous and much costlier. Via a number of iterations, the report indicates that the cost of mitigation for meaningful action should lie somewhere in the range of US$32/t$CO_2$e to US$103/tCO_2e. Applying a rand-dollar exchange rate of 12.41 and a carbon intensity of petrol of 74 kg CO_2e/GJ, a range of R29,40 to R94,60/GJ is calculated.

- *EU Green Fuel subsidy programmes (market):* Across the European Union, there is a wide range of subsidies for different types of 'green fuels,' such as bioethanol and biodiesel. According to the 2010 update of a study on biofuel subsidies in the European Union for the Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD) (Jung, 2010), government support from the EU and its member states equated to approximately €0,24 and €0,22 per litre consumed in 2008. Converted to a rand-per-GJ equivalent, this would indicate support in the range of R137/GJ to R189/GJ.
- *US Green Fuel subsidy programmes (market)*: At a state and/or federal level, the USA has implemented a range of Green Fuel subsidy programmes, predominately for ethanol and biodiesel. One of the studies, part of a series of reports addressing subsidies for biofuels in selected Organisation for Economic Cooperation and Development (OECD) countries (Koplow, 2007), indicates that the subsidies per unit of energy for the different types of green fuels fluctuate between US$11/GJ and US$14.50/GJ, depending on what benchmark year between 2006 and 2012 is reviewed. At a rand-dollar exchange rate of 12.41, this would equate to a set of subsidies in the range of R136,50/GJ to R198,40/GJ.

When looking at the above, the level of support that the South African government could provide towards the development of biogas for the transport sector could lie in the range of R1,80/GJ to R282,90/GJ when 'pegged' within the range of domestic or international rationales that exist. If this rand per unit of energy basis were to be translated into a rand per GHG emission range, this would equate to between R24/tCO_2e and R3 800/tCO_2e. However, in understanding these figures, it is important to consider that they include several non-GHG mitigation co-benefits, now expressed as GHG mitigation benefits.

5.4.2 CBG stimulus scenario

As indicated, the direct economic benefits do not outweigh the direct economic costs in the case of biogas for transport. If, considering the co-benefits as described in Section 5.1.2, the South African government decides that there is sufficient cause to incentivise and support the development of the biogas-for-transport sector, then CBG should be made competitive at the pump in comparison to petrol and CNG. This can be realised by applying the same incentives that are currently in place for CNG, in which CNG is made competitive in comparison to petrol. These incentives can be extended with one or several incentives that purely target the development of the biogas-for-transport sector. The following figure provides a schematic overview of these staggered incentives.

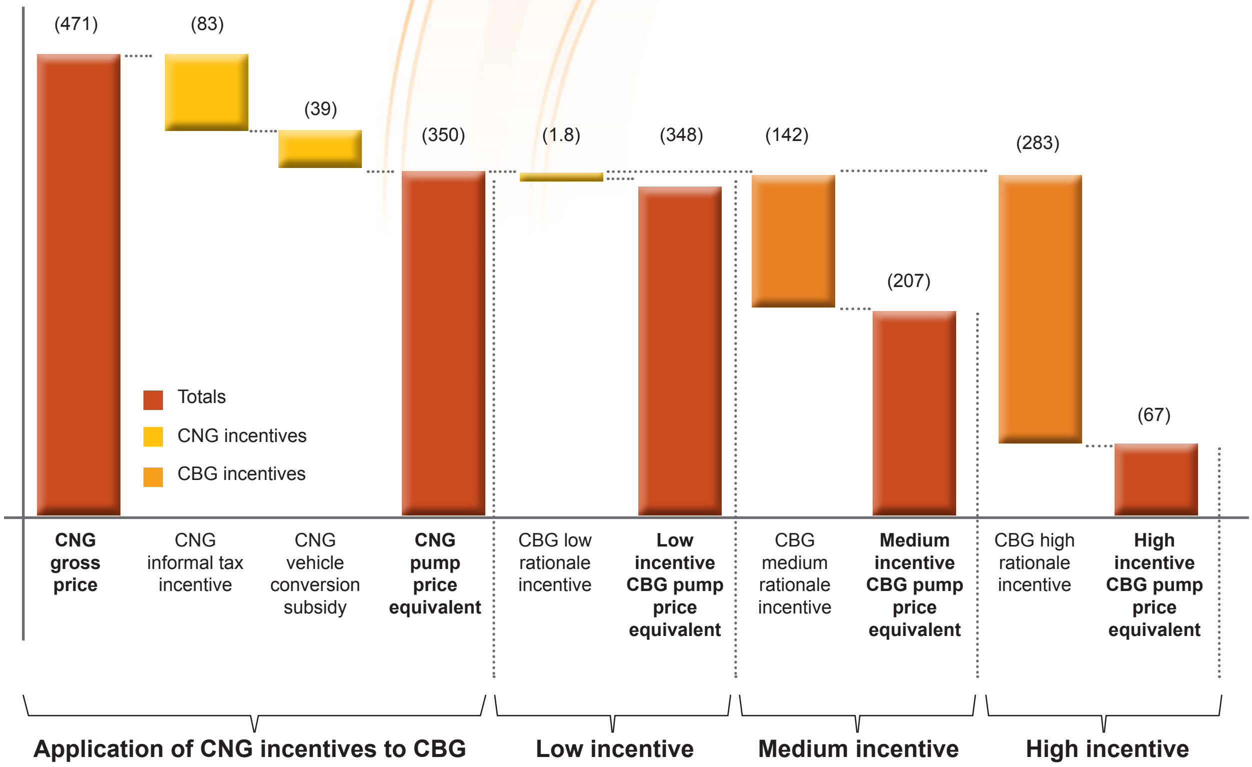


Figure 5.4.2: Biogas-for-transport incentive rationale range

It is outside the mandate of this study to describe the magnitude of the potential stimulus measures that are specific for biomass-for-transport utilisation. However, the figure above applies the range as taken from Section 5.4.1 to provide an indication of what the minimum and maximum levels of stimulus could be if the South African government decides to apply an incentive that lies with the domestic and international rationale.

5.4.3 Envisaged policy interventions

Given all of the above, a compelling case can be made for government intervention to promote the uptake of biogas for transport and develop a sustainable and thriving biogas industry in South Africa. There are a number of elements to this. First of all, the economic and social upside of a policy to this end needs to be sufficiently large to justify any policy intervention. As we have seen, there are substantial co-benefits to the South African economy regarding the uptake of biogas for transport. These need not only relate to the overall mitigation potential, additional jobs created and fuel imports substituted, and hence reliance on forex reduced. They can also include enhanced energy security, diversification of the energy mix and a clear first-mover advantage. Moreover, at a local level, considerable improvements in urban air quality could be achieved.

A second aspect involves the type of policy instrument used. Here, one can build forward on the high-level theoretical framework for policy instruments developed in this study. It is important to take into account the relevant international experience in this regard. Governments rely on direct subsidies, tax measures and/or regulation to affect (market) outcomes. The above analysis indicates that fuel/consumption tax reductions or exemptions are the most commonly used measures internationally. They are also effective in terms of the ultimate result. Moreover, an important feature of positive tax incentives is perhaps that these are more practical to implement. International experience demonstrates that it is often politically easier to get positive tax incentives through Parliament than direct subsidies, the latter being on budget with a higher visibility vis-à-vis other government expenditures. These instruments are also market-based and therefore, in many cases, preferred to regulation in terms of the overall economic efficiency of the policy.

The third consideration revolves around the size of the stimulus provided. Here the analysis shows what is necessary to place CBG on a competitive footing compared to petrol and diesel at the pump. An exemption for CBG from road tax and other fuel levies, but including VAT, as is currently the case for CNG, and a 10% subsidy for vehicle conversion, as currently provided by the IDC, could be sufficient to achieve that goal. In addition to this, the analysis indicates that (further) incentivisation of up to R283/GJ would be in line with domestic and international outlays for sustainable development in the transport sector (see Figure 5.4.1).

Important to note in this regard is that exemption from fuel-related taxes and levies will not be sufficient in the absence of regulatory uncertainty around its continuation. Because it concerns long-term investments, both the size of the incentive, as well as for how long the incentive will be in place, must be clear from the onset. This is another reason why a tax incentive is preferable over a subsidy. The latter is more frequently subject to change when budgets change, for example when a new government comes to power. Hence, while both policy instruments should be able to provide the same kind of stimulus, a tax incentive will generally do so with less regulatory uncertainty for the investor.

All things considered, the case for biogas for transport a priori could be viewed as a strong one. The international evidence is supportive of measures promoting biogas and its effectiveness. The benefits to the South African economy and its society, as analysed, are substantial. This leaves us with a final point, which concerns the broader environment and conditions surrounding the creation of a successful biogas industry and market in South Africa.

To seize the opportunity and fully reap the benefits, a hands-on approach is called for from all stakeholders involved. The biogas market is likely to take off and evolve quickly with the completion of a few successful projects. For this, interaction and constructive collaboration between the private and public sector is essential. Forums like SABIA are ideally suited to provide the necessary inputs and consultations to come to a sensible and workable approach. The technology is there. Various stakeholder engagements show that the will is also there. This should all but guarantee unlocking the full potential of biogas for transport in South Africa.

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Appendix – List of stakeholders

During the course of this study, several stakeholders were contacted from both the private and public sector, including the following:

- Bronkhorstspruit Biogas Plant
- Biogas Platform
- Biogas Power
- Biogas SA
- Cape Advanced Engineering
- City of Cape Town
- City of eThekwini
- City of Johannesburg
- City of Tshwane
- Clarke Energy South Africa
- CNG Holdings
- Department of Energy
- Department of Environmental Affairs
- Department of Transport
- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
- EBF Group of Companies
- Elgin Fruit Juices
- Ener-G Systems
- Gas2Power
- Industrial Development Cooperation
- Johannesburg Water
- Mondi
- National Biogas Platform
- NOVO Energy
- Oceana Group
- Paper Manufacturers Association of South Africa
- Pikitup
- Provincial Veterinary Services
- Re-energise Africa
- SAPPI
- SASOL
- Selectra
- South African Biogas Industry Association
- South African Cane Growers Association
- South African Cities Network (SACN)
- South African Fruit Juice Association (SAFJA)
- South African Local Government Association
- South African National Energy Development Institute
- South African Sugar Association
- Trade plus Aid
- Uhuru Energy
- UNIDO/GEF Waste-to-Energy Biogas Project
- Xergi

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