SOUTH AFRICAN CITIES GREEN TRANSPORT PROGRAMME

ACCELERATING THE TRANSITION TO GREEN TRANSPORT

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RESEARCH AND POLICY DEVELOPMENT TO ADVANCE A GREEN ECONOMY IN SOUTH AFRICA

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ACCELERATING THE TRANSITION TO GREEN TRANSPORT: SOUTH AFRICAN CITIES GREEN TRANSPORT PROGRAMME

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RESEARCH AND POLICY DEVELOPMENT TO ADVANCE A GREEN ECONOMY IN SOUTH AFRICA

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The Government of South Africa, through the Department of Environmental Affairs, has set up the Green Fund to support the transition to a low-carbon, resource-efficient and pro-employment development path. The Green Fund supports green economy initiatives, including research, which could advance South Africa's green economy transition. In February 2013, the Green Fund released a request for proposals (RFP), ' Research and Policy Development to Advance a Green Economy in South Africa', inviting interested parties with relevant green economy research projects to apply for research funding support. The RFP sought to strengthen the science-policy interface on the green economy by providing an opportunity for researchers in the public and private sectors to conduct research which would support green economy policy and practice in South Africa. Sixteen research and policy development grants were awarded in 2013. This peer-reviewed research report series presents the findings and policy messages emerging from the research projects.

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EXECUTIVE SUMMARY

Greening transport infrastructure and services in cities is a complex enterprise. It requires strategic vision, multi-disciplinary skills and experience in integrated transport planning. A key imperative for South African cities is to move away from privately owned cars towards mass public transport, cycling and walking. This will reduce traffic congestion and road maintenance costs, improve accessibility, increase spatial efficiency and achieve better public health outcomes through improved air quality. At the same time, this modal shift will reduce GHG emissions associated with transport.

Given the need for these modal shifts, an investigation was carried out into the options for further 'greening' the transport sector by switching to green vehicle technologies and alternate fuels such as compressed natural gas (CNG). The options were considered in terms of costs, environmental performance, policy and regulatory environment, with particular reference to municipal bus fleets and the minibus taxi (MBT) industry.

The research suggests that the lifecycle costs for procuring and operating green bus fleets using either biofuels, CNG, biogas or electric batteries have largely converged with those of EuroV diesel buses. While all options comply with EuroV tailpipe emissions standards, the wells-to-wheels[1] GHG emissions for 'green' buses are lower than those of diesel buses, with biogas providing the best environmental performance.

Cities seem to be willing to commit to greening their municipal fleets and, in principle, the projected demand for new buses from municipalities is sufficient to support the local manufacturing of green buses. However, cities currently have concerns regarding a centralised procurement mechanism that could provide bus manufacturers with the guarantees needed to justify such an investment. Amongst these concerns is the need to accommodate differing technical requirements between cities as well as local political accountability.

In Gauteng, there is already some momentum around CNG as a vehicle fuel for buses and MBTs. Analysis of a gas retailer's business model found that an additional charge on the gas prices could cover the costs of converting MBTs to dual-fuel (i.e. these vehicles can switch between CNG and petrol), while at the same time reducing fuel costs to the operator. However, gas is not currently subject to a transport fuel levy similar to that placed on petrol and diesel. The addition of such a levy could increase the price, reducing CNG's price advantage, and subsequent investment necessary for its infrastructure development. Furthermore, although widely adopting CNG could potentially reduce South Africa's emissions, this would only be a first phase towards becoming truly sustainable. Compressed biogas and alternate power such as electric power and biofuels also need to be adopted for significant impact on pollution in cities.

Greening municipal fleets makes sense in all respects – reduced air pollution, reduced respiratory illnesses and savings on fuel costs. Cities can assist in expanding the scale of taxi conversions by facilitating awareness and dialogue

[1] Historically, evaluation of vehicle/fuel systems from wells to wheels was called fuel-cycle analysis. It takes into account the production and distribution of the fuel, thereby allowing comparison of emissions over the entire life cycle of a vehicle —from the energy and materials used to power a vehicle, to the direct tailpipe emissions (http://www.electricridecolorado.com/are_you_ready/wells_to_wheels/what-does-it-mean/what-does-wells-to-wheels-mean).

between gas retailers and taxi associations, providing refuelling infrastructure and financing the conversions in partnership with the private sector and/or finance institutions. Furthermore, cities own and operate thousands of vehicles that account for more than 20% of the direct municipal energy consumption (SACN, 2014) which could contribute to greening the transport sector.

CNG is of growing importance to South Africa, as a consequence of regional discoveries of natural gas reservoirs and the potential for shale gas extraction in the Karoo. At the same time, biogas has a far better environmental profile, and potential sources of biogas such as municipal waste and wastewater treatment plants are underutilised. CNG and biogas have a potentially important role to play as a transport fuel, particularly while technologies such as battery-electric and hydrogen fuel cell vehicles become more accessible and appropriate for adoption at scale in South Africa.

RESEARCH TEAM

The research team was led by the South African Cities Network which provided coordination, oversight and liaison with cities and other stakeholders. The South African National Energy Development Institute provided the additional technical support, access to previous relevant research and implementation of demonstration projects, while Linkd Environmental Services played the role of project management and technical research. Sandiswa Tshaka, Carel Snyman, Crispian Olver, Matthew Gaylard, Muhammed Suleman and John Less were all members of the research team from the respective organisations.

The research team would like to thank the Green Fund for funding the project. Furthermore, the team is indebted to the many stakeholders in national government and government agencies, the Industrial Development Corporation (IDC), the taxi associations, the bus manufacturers, gas companies, and the municipalities themselves who gave their time and information so generously.

ABBREVIATIONS

APDP	Automotive Production Development Programme
BEV	Battery-electric vehicle
BRT	Bus rapid transport
CCI	Clinton Climate Initiative
CDM	Clean Development Mechanism
CNG	Compressed natural gas
CO_2	Carbon dioxide
CSDP	Competitive Supplier Development Programme
DBSA	Development Bank of Southern Africa
DEA	Department of Environmental Affairs
DME	Department of Minerals and Energy
DoE	Department of Energy
DoT	Department of Transport
DTI	Department of Trade and Industry
EV	Electric vehicle
GHG	Greenhouse gas
GREET	Greenhouse Gases, Regulated Emissions, and Energy use in Transportation
GUMP	Gas Utilisation Master Plan
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
IDC	Industrial Development Corporation
IEA	International Energy Agency
IEP	Integrated Energy Plan
IPAP	Industrial Policy Action Plan
IPP	Independent Power Producer
IRP	Integrated Resources Plan
MBT	Minibus taxis
NIPP	National Industrial Participation Programme

NMT	Non-motorised transport
NOx	Nitrogen oxides
NPC	National Planning Commission
NREL	National Renewable Energy Lab
OECD	Organisation for Economic Cooperation and Development
REIPPP	Renewable Energy Independent Power Producer Procurement Programme
RFP	Request for Proposals
SACN	South African Cities Network
SANEDI	South African National Energy Development Institute
SOx	Sulphur oxides
TIA	Technology Innovation Agency
WWTP	Wastewater treatment plant

1. INTRODUCTION

This research report consolidates an extensive research process into a coherent overview. It provides conclusions and recommendations that support the continued development of a green transport programme by South African cities under the umbrella of the South African Cities Network (SACN).

From the outset, the scope of the research was somewhat loosely defined, as the project steering committee felt that the principal beneficiaries of the project i.e. the member cities of the SACN, had a critical role to play in validating the research agenda. In practice, this approach had both benefits and pitfalls. For example, the initial focus was on researching a transversal[2] or centralised procurement mechanism for green municipal buses and low carbon fuels that cities could sign up to. This would allow an aggregation of demand, which would drive down prices and create sufficient scale to support local manufacture. However, after consulting with cities, this focus was found not to be a realistic short-term objective around which to build a green transport programme. With guidance from the cities, the research team refocused their efforts on investigating how cities could support the conversion of taxis to compressed natural gas (CNG).

The reports produced at each phase of this project reflect this shift in focus. Providing a blueprint for a centralised procurement mechanism might have appeared to be a useful outcome but is unlikely to have had any traction in practice. Nevertheless, the research and modelling of the costs and emissions performance of various technologies as well as the economies of scale required to support efficient procurement and local manufacture of green bus fleets, should serve as a useful resource for municipalities that are contemplating alternatives to diesel buses for the first time.

2. BACKGROUND TO RESEARCH

The SACN encourages the 'exchange of information, experience and best practices on urban development and city management' and 'identifies, assembles and disseminates information that enhances the ability of decision-makers to learn from the experience of others and efficiently use their resources to build sustainable cities'. Accordingly, one of the SACN's goals is to analyse strategic and sustainability challenges facing South African cities. Transport and urban mobility is one of the most pressing of these challenges. The transport sector is the largest contributor to greenhouse gas (GHG) emissions in South African cities, in part because of the legacy of apartheid-related spatial planning. Cities are embarking on the daunting task of creating a paradigm shift, away from 'one person, one car economic development' towards eco-mobility, non-motorised/low-carbon transit and urban mass transit systems. Achieving this paradigm shift will require new thinking about spatial planning and form, and about commuting/transportation at a societal level. It also involves understanding the long-term public health impacts of the diesel/petrol combustion economy, and motivating for budgets to support a radical change in transportation infrastructure planning and implementation.

This shift is based on massive spending on infrastructure to densify cities, without which the practical and financial business case for walking, riding and public transit is more difficult. Lastly, and perhaps most challenging, is the cultural element of change: how can sustainable transportation compete with the prestige, convenience and freedom of

[2] A transversal term contract is a contract with one or more suppliers for the supply of goods or services over a period required by more than one department or public entity.

owning a car? And what can cities do to redirect public perceptions of the private car as a primary mode of transport, which has clearly large and unsustainable societal and personal negative externalities.

In 2014, the SACN in partnership with the South African National Energy Development Institute (SANEDI) and Linkd Environmental Services (Linkd), received grant funding from the DBSA Green Fund to undertake research into establishing a South African cities green transport programme. The focus was initially on municipal fleets and later shifted to the conversion of minibus taxis (MBT). The project timeline was April 2014 up to September 2015. The primary beneficiaries of the project are the SACN member cities (Buffalo City, Nelson Mandela Bay, eThekwini, Msunduzi, Tshwane, Ekurhuleni, Johannesburg, and Mangaung), although other municipalities may also apply these findings to their own processes.

3. AIMS AND OBJECTIVES

The project's overarching aim was to support the establishment of a cities' green transport programme. The research encompassed a review of international best practices and local experiences, as well as the evaluation of lifecycle costs and emission profiles of various green transport technologies. The primary objective is to make a convincing and pragmatic business case for cities to adopt green transport initiatives.

4. LITERATURE REVIEW

A status quo report was produced based on a review of relevant literature in order to define green transport concepts and solutions. For the last century and a half, petroleum has been a driver of global growth, particularly global transportation. However, burning fossil fuels has unavoidable and negative effects: petroleum is a non-renewable resource (it will run out one day) and produces carbon dioxide (CO_2) and other noxious gases when burned, which means that the more petroleum we burn, the more uninhabitable we make our planet.

Serious consequences result from the use of petroleum-based fuels. The high concentration of CO_2 in the atmosphere is already causing climate change and concomitant increased incidences of extreme weather, which is detrimental to the human population (DEA, 2013). Despite short-term market fluctuations, the long-term trajectory of petroleum-derived fuel prices is inexorably upward (Gue, 2006; Parker, 2006).

4.1 Green Transport in South Africa

South African transport is highly dependent on petroleum and its derivatives. Petroleum is the single largest import item, representing about 80% of the country's primary energy imports and using the majority of the earnings from mineral exports (Vanderschuren et al., 2008). As South Africa is acutely vulnerable to scarcity of this non-renewable resource, 'identifying alternative sources of energy is a matter of urgency' (Greben et al., 2009:1). As BalticBiogas Bus (2012:4) points out, 'dependency on fossil fuels makes public intervention to support energy innovation both necessary and justified'.

South Africa is committed to participating in the mitigation of global climate change and also has a direct interest in addressing the ill-effects of transport. These ill-effects include noise pollution, poor air quality (particularly from

particulates[3]) and congestion. South African cities are becoming highly congested with traffic. For example, with over 700 vehicles per kilometre, Gauteng has the highest road density in South Africa and the smallest road network (National Treasury, 2009). Congestion increases emissions, decreases the liveability of cities and represents a major economic cost. Poor air quality also plagues South Africa, and urban air quality is a major risk factor for death (Norman et al., 2007). Green transport will improve both congestion and air quality, and reduce the noise pollution associated with streets congested with polluting motorised modes of transportation.

The concept of green transport extends beyond the technical specifications of vehicles, as 'ultimately, the number of vehicles on the road needs to be reduced. Relying on new technology is not the answer in itself' (Chapman, 2007). Green transport must encourage sustainable choices in vehicle design and purchasing, and the policy must encourage sustainability in the transport system as a whole. This means investing in public transport, incentivising modal shifts (and dis-incentivising driving private cars) and green urban planning. Cities currently support an economy and development that is oriented around the private car. This focus needs to change in order to encourage more people to walk, cycle and make use of (and share) smaller and lighter low emission vehicles as feeder systems for public transport.

Key Concepts in measuring emissions from the transport sector

Well to Wheels – This includes all emissions associated with the production, distribution and consumption of transport fuels and electricity used to power transport.

Pump to Wheels – This includes only emissions associated with the operation of the vehicle – these are also sometimes referred to as Tank to Wheels emissions. Electric vehicles that are powered with renewable energy, for instance, have zero emissions in terms of this metric.

4.2 Electric Vehicle Technologies

Batteries were once the most common means of powering automobiles (Chapman, 2007) and today are enjoying something of a comeback, as an alternative energy source in both private cars and in limited trials for public transport. Electric motors are much more efficient than internal combustion engines, which lose up to 75% of the fuel's energy to heat, vibration and noise, whereas electric motors lose only 5–10% (Khare and Sharam, 2003). Furthermore, modern electric vehicles (EVs) make use of 'regenerative braking', which transforms the vehicle's kinetic energy into chemical energy in the battery when braking the vehicle. This increases the energy efficiency of electric vehicles in urban traffic. The electric motor may still be on when the car is at rest ('idling') or coasting, but does not turn (or do any work), which again is beneficial in stop-start driving conditions because it is not consuming any energy (Khare and Sharam, 2003). Battery-electric vehicles (BEVs) have no tank-to-wheels emissions at point of use - they 'run clean'. They also run nearly silently, which reduces noise pollution but is perceived to be a potential safety hazard for pedestrians. As a result, many BEVs are designed to produce artificial 'engine' noises.

Battery technology has long been (and remains) the limiting factor for the mass acceptance of electric vehicles. Batteries are expensive, bulky and heavy (Lave et al., 2000), which limits the number of batteries that one vehicle can

[3] Particulates are extremely small particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. They are the air pollutant that most commonly affects people's health.

reasonably carry, constraining vehicle designs. This is the reason why BEVs typically have much shorter ranges than internal combustion engine (ICE) vehicles (Tzeng et al., 2005). Recharging time is also a problem, as depleted batteries need to be charged for several hours. This is not a problem for commuting distances but is for long-distance driving or all-day driving (as buses are required to do). However, innovative battery development is busy addressing these problems, and higher energy densities and lower costs are expected soon. A vehicle with a flat battery can visit a swopping station to have its battery removed entirely in exchange for a fresh one. The spent battery can then be charged at the depot for as long as necessary before being swopped back in; allowing for all-day driving. New technologies allow batteries to fast-charge in around 20 minutes, or to wireless charge by induction while driving thereby serving as a range extender.

BEVs are up to 80% more expensive to purchase than ICE vehicles (Mathiesen et al., 2008), although this cost can be partly recouped through lower fuel costs. A notable example of BEVs contributing to green power can be seen in Adelaide, Australia, which has a fleet of Tindo BEV buses that are 'fast-charged' between trips from solar panels on the roof of the central bus depot. Pairing BEVs with renewable electricity generation is about as green as transport gets, and is an attractive long-term goal in South Africa, which has double the solar radiance of Germany and triple the radiance of England.

Hybrid-Electric Vehicles (HEVs) share many of the components of BEVs, with the addition of a petrol or diesel engine. A vehicle that pairs an electric motor and batteries with an ICE benefits from both the fuel economy of electric propulsion and the energy density of conventional fuel, which batteries cannot compete with. Broadly, two possible configurations of HEVs are:

i. The electric motor is always used to propel the vehicle, and the ICE is only used to charge the batteries as necessary. In a parallel process, either the electric motor or the ICE can propel the vehicle depending on driving conditions. The former is more efficient for urban 'stop-start' driving, while the latter is more efficient on the open road (Richardson, 2013).
ii. An HEV can be designed either to charge its batteries by 'plugging in' or directly from the ICE when necessary or possible. Like BEVs, HEVs also use regenerative braking to recuperate some energy that would have been lost during braking.

As HEVs use an ICE, they may be thought to be an efficiency upgrade rather than a new power source. In public buses the most common configuration is hybrid diesel-electric, but hybrid CNG-electric or biogas-electric is also possible and potentially much more attractive. The efficiency gains can be substantial: diesel-electric buses are between 10–50% more fuel-efficient than diesel alone (Richardson, 2013), with corresponding reductions in emissions. According to some studies, hybrid-diesel buses produce fewer total well-to-wheel emissions than any non-BEV alternative (Beer et al., 2004). However, HEVs also require fuelling and battery-maintenance infrastructure and staff trained to maintain the buses. They are typically more expensive to purchase than conventional diesel buses or buses that run on CNG. Several cities worldwide have begun hybridising their bus fleets, including Rotterdam and Barcelona (OECD/IEA, 2012). More detailed study is required to establish the economics of hybridising buses in South Africa, but hybrid buses are potentially a very effective transitional solution and should be considered carefully.

4.3 CNG and Biogas Technologies

CNG has been used as a vehicle fuel since at least the 1930s, although it has only recently become cost-effective on a large scale, and today is in widespread use. A mixture of gases (mostly methane) is extracted, either from dedicated

gas wells or alongside petroleum, and is then processed, compressed and combusted in a specially-designed engine. In March 2014, the first public CNG filling station in South Africa was opened in Langlaagte Johannesburg, and more filling stations are planned for the near future. The filling station provides fuel mostly to MBT converted to use CNG. Like other alternative fuels, CNG requires substantial infrastructure: depots need to be converted, and staff must be retrained to fill and maintain CNG buses.

Natural gas is much cleaner when burned than diesel and other petroleum derivatives, with emissions reduced by up to 30% (Lave et al., 2000). According to some studies, CNG has higher tank-to-wheel emissions than diesel, which may be because of the relative immaturity of CNG engines – emissions might reasonably be expected to decrease (Beer et al., 2004). Natural gas is also a non-renewable fossil fuel that produces both carbon dioxide and the more potent GHG methane. Therefore, adopting CNG could potentially reduce South Africa's emissions but would not put the country on the path towards a truly sustainable, minimal-emissions green transport system.

Biogas is chemically comparable to CNG. Both are a mixture of combustible gases, predominantly methane, and can be used interchangeably or even mixed to fuel the same gas-driven vehicles. However, biogas and CNG have very different origins and net environmental impacts.

South Africa landfills enormous quantities of waste. Landfills are overstressed, and as a result some are under pressure to close (Jewaskiewitz, 2008). Up to 40% of household waste is organic material, which slowly decomposes into various organic gases including methane. Methane contributes 23 times more to global warming than CO_2 and is naturally released into the atmosphere at waste dumps, whereas combusting biogas in an engine produces only CO_2. Controlling waste decomposition, capturing the resulting methane and burning it into CO_2, reduces the net effective emissions of the system. Therefore, theoretically, a biogas bus fleet could have negative net emissions. In practice, emissions contributing to the carbon intensity of biogas can originate from fossil fuel-based energy used in different parts of the well-to-tank biogas chain including the cleaning, compression and transport of biogas.

To produce biogas, organic waste is placed in an anaerobic digester (instead of a landfill) containing a particular mixture of bacteria. Over a period of about two weeks and with minimum additional input, these bacteria break down the waste into methane and CO_2 in a process similar to what happens in a landfill. However, in an anaerobic digester, the process is controlled, quicker and allows the gas to be captured, purified, compressed and used. The same process can be used to process both agricultural waste and sewerage. This process used to be standard in many South African sewerage plants, but many of the digesters used have fallen into disrepair and disuse. A recent study suggests that South Africa could produce about three million normal cubic metres of raw biogas per day in close proximity to urban centres, with municipal solid waste being the largest contributor (EcoMetrix, 2015).

Several municipal wastewater treatment plants (WWTPs) already have anaerobic digesters onsite. These treatment plants are designed for sewerage but could also digest organic waste from households, restaurants or farms (co-digestion[4]). Co-digestion increases the biogas yield of the digester and 'can also be applied at existing WWTP without excessive investment costs, thereby combining the treatment of the two largest municipal waste streams' (Greben et al., 2009:6). This would reduce the waste burden on municipalities and produce low-cost biogas from a resource that is currently going to waste.

[4] Formally, 'anaerobic treatment of a mixture of at least two different organic waste types'. (Greben et al., 2009:6).

Biogas is a complete renewable fuel that both reduces transport emissions and removes emissions from another sector i.e. waste management. It has the potential to reduce short-term emissions at relatively low cost. An Industrial Development Corporation (IDC) pilot programme in Gauteng showed that the savings from converting buses to use a diesel-biogas mixture enabled the capital cost to recovered within about 3.5 years (IDC 2013). The technology is proven and already being used in South Africa.[5] Municipalities and the private banking sector have also shown interested in the potential for biogas as a vehicle fuel, with Johannesburg being one city to show commitment:

The city has already completed a pre-feasibility study on the potential of the Johannesburg Market waste stream, and it was found there is potentially sufficient biomethane to supply approximately 700,000 litres of diesel equivalent fuel every year. The mayor said biogas would be upgraded through a process of cleaning and compression before it is either used at a site of production or injected into the existing CNG pipeline to be used wherever it is required.[6]

The eThekwini municipality has several Clean Development Mechanisms (CDM) projects[7] underway to produce biogas from landfill, wastewater and agricultural effluent. Even more important than short-term gains is long-term sustainability and biogas infrastructure will remain important for waste treatment and energy production. Unlike any other energy source, biogas increases with population, which is important as 'not only will the population and the economic growth cause a demand on the energy supply, it will also contribute to the generation of waste and add pressure to the amount of sewage needed to be treated' (Greben et al. 2009:1).

South Africa has both international and national support for biogas. Finland, Austria and the United Kingdom have been key donors of biogas projects in South Africa, while the World Bank and the Development Bank of Southern Africa (DBSA) have demonstrated a strong commitment to biogas initiatives. The DBSA is keen to provide financial support for relevant biogas proposals that will take Independent Power Producers (IPPs) in South Africa to a bankable stage. The Department of Energy (DoE) has the necessary information around the potential of biogas, the legislative landscape and the intentions of the policymakers. The Department of Energy (DoE), through SANEDI, have undertaken research that suggests that there are sufficient potential sources of biomass for biogas production at the scale required for use as a transport fuel and there is policy support for expanding the role of gas in South Africa's energy mix.

4.4 Biofuels

Apart from biogas, other biologically produced combustible fuels include bioethanol and biodiesel. These can be produced from waste but preferably are produced from high-carbohydrate crops such as sugar cane, sugar beets, or starches in an industrial process. Petrol or diesel can be mixed with up to 5% bioethanol or biodiesel and still be used in normal unmodified vehicles. As the dilution can happen before the fuel gets to the filling station, it has little effect on

[5] 'Metrobus unveils eco-friendly bus fleet' http://www.reavaya.org.za/news-archive/july-2015/1200-metrobus-new-green-bus-fleet-unveiled, 24 July 2015.

[6] 'Johannesburg Mayor commits to NGV use to improve city air'. http://www.ngvjournal.com/johannesburg-mayor-commits-to-using-gas-for-vehicles-to-improve-city-air/, 2 October 2014.

[7] Defined in Article 12 of the Kyoto Protocol, CDMs allow emission-reduction projects to be implemented in developing countries. These projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO2, which count towards meeting Kyoto targets. http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

consumers. Modified vehicles can run on mixtures with greater proportions of biofuels, as in Brazil where all petrol is at least 22% sugar cane-derived bioethanol, while more extensively modified vehicles can run on pure bioethanol or biodiesel.

Both bioethanol and biodiesel are renewable resources that burn cleaner than conventional fuels. However, producing biofuel from crops requires an industrial process and energy input, and biofuel is more expensive than conventional fuels (Chapman, 2007). More worryingly, dedicating agricultural land to biofuel production reduces food production and opens questions of food security and sovereignty. Nonetheless biofuels are widely used globally for both private cars and buses, representing around 2% globally within the transportation sector (Schill, 2013), although in many cases their production requires large subsidies. Currently South Africa has a Biofuels Industrial Strategy in place that seeks to mitigate potential impacts on food security by excluding certain crops from being used for biofuels. It aims to achieve 2% penetration of biofuels in the national liquid fuel supply in the near term. This can be accomplished using an estimated 1.4% of South Africa's arable land, around 14% of which is currently underutilised – mainly in the former homelands (DME, 2007). In practice, this target has proved difficult to achieve. Due to the existence of policy in relation to biofuels, biofuels have not formed part of the focus of this research project.

4.5 Driver training and vehicle maintenance

Elements of green transport do not depend on alternative fuels and could be implemented at relatively low-cost regardless of how buses are powered. Fuel consumption, and therefore emissions, can be dramatically reduced through modifying driver behaviour, regardless of the fuel being used. Training drivers to anticipate traffic flow, drive smoothly without unnecessarily aggressive acceleration or braking, use higher gears, and minimise unnecessary air conditioning can result in fuel and emission savings of up to 10% without decreased performance or speed (Zarkadoula et al., 2007).

Similarly, correctly maintaining a vehicle can dramatically reduce fuel consumption and emissions, regardless of fuel type. In a petrol vehicle this includes tuning the engine correctly (4% efficiency gains), frequently replacing air filters (10% gains), having the correct tyre pressure (3% gains) and using the correct motor oil (1-2% gains) (Vanderschuren et al., 2008).

5. METHODOLOGY

The research was conducted in four phases, with each phase consolidated into a written report. These reports are available for download from the Technical Reports section on the Green Fund website www.sagreenfund.org.za/research. The first report was a *Status Quo and Programme Concept Note*, which defined the research problem, provided an overview of green transport in South Africa and gave insight into green transport technologies across the fuel and propulsion system spectrum.

Based on this, and following a preliminary engagement with stakeholders from the cities and central government, a more detailed scoping was done of opportunities for greening of municipal bus fleets, resulting in the second report: *Accelerating the Transition to Green Fleets*. This report looked at the regulatory and policy environment as well as the lessons learned globally from introducing green fleets into municipal operations. It presented a lifecycle analysis (financial, GHG, and tailpipe emissions) of ethanol, CNG, biogas, and battery electric buses based on South African

pilot projects, using locally produced fuels and biofuels at current fuel, repair and maintenance and capital expenditure (capex) prices offered by local manufacturers or global suppliers operating in South Africa.

Stakeholder engagement was a critical aspect of the research, since local authorities have considerable leeway in procurement decisions. Therefore, their buy-in to a green transport programme is critical. As such, the principles of participatory research in which stakeholder priorities, processes and perspectives are taken into account (Cornwall and Jewkes, 1995) were central to the project.

The stakeholder engagement process took place over nine months, between October 2014 and June 2015. Stakeholders were from national government, member cities and private stakeholders in the gas sector, as well as research-based organisations. During the development of the second report, consultations were held with stakeholders involved in various technologies, including ethanol and electric vehicles.

At city level, officials from both the corporate fleet management and transport departments were involved. The purpose was to discuss and agree on a common way forward for transitioning to greener transport. A series of informal meetings with the cities were held, together with two workshops on the 25th February and 25th March 2015. The workshops provided an opportunity to share the results of the research, discuss the practical implications and identify areas of potential collaboration to jump-start green transport in their cities. Initially the project focused on gas as an alternative low emissions fuel, with research done on procuring gas and converting buses and/or MBTs to run on gas. In addition, the project team identified existing green transport plans within cities, received feedback about the direction cities wanted to pursue with respect to green transport, and engaged on possible options for accelerating the transition to greener transport.

On a national level, the team engaged with the Department of Transport (DoT), the Department of Trade and Industry (DTI), the Department of Environmental Affairs (DEA), National Treasury and the DBSA. This engagement was done through a workshop on the 2nd February 2015 (details of the workshop can be found in Annexure 2). Outside of the workshop, the team engaged individually with the various departments on several occasions to ensure that the project aligned with national objectives and policies.

The team further engaged with other entities, both private and public, to gain a deeper understanding of the gas market, and to better understand the challenges facing the gas sector and the potential role of cities in helping to overcome these challenges. These included SCANIA South Africa, Build Your Dreams, Electric Bus Business Development, Sustainable Energy Africa, CNG Holdings, NovoEnergy, and the South African Gas Association.

A model developed by the Clinton Climate Initiative (CCI) was used to analyse the lifecycle costs, tailpipe emissions and well-to-wheel GHG emissions performance of different green transport options. This global transport fleet model developed for the C40 Cities Climate Leadership Group (C40) was customised to local South African conditions. The model was first customised and run between 2010 and 2012 to help the City of Johannesburg's Transport Department make strategic green fleet and BRT decisions. This original work was conducted in partnership with the Institute for Transportation and Development Policy and the International Council on Clean Transportation. The project team re-run the model in September 2014 with updated fuel and capital expenditure prices. Limitations of this model include:

- The use of operating data for Johannesburg Metrobus from 2012.
- The use of Stockholm Public Transit's diesel, biogas, and ethanol bus operating costs (cents per kilometre) during 2010–2012. No other transit system in the world had as many buses of all three technologies in operation for

several years. The operational expenditure would naturally be different for these bus technologies and fuels in South Africa. Therefore, while it should provide reliable comparative data, there may be local South African differences, particularly with respect to sources and quality of fuel that could affect the relative outcomes.

- The use of inputs provided by local bioethanol (agricultural and waste-derived), biogas (agricultural and waste-derived) and CNG providers, based on receiving an order for 100 buses worth of fuel at least one year from the first delivery of fuel. This highlights the quantum of demand required by the bus manufacturers to tool up.
- Assumptions about the future regulated price of gas and diesel, as well as the tax regime applied to ethanol and biogas based on the current regulatory and pricing mechanisms in the country. Some of these are in the process of being changed or are open to interpretation, while uncertainty exists around taxes on biofuels.
- The total effective cost of electricity to charge a bus from midnight to 3am daily was based on September 2014 estimates from SANEDI and assumed to be R0.79 per kWh. This is an all-in cost inclusive of demand, network, and administrative charges.
- Capex cost differentials were based on an average of global cost differentials in markets such Brazil, Europe, and the United States as well as data received confidentially from major manufacturers in 2010–2012. The major manufacturers of green buses competing in South Africa appear to be offering to sell buses, fuel, and maintenance at current lifecycle diesel prices. New disaggregated data for capex has not been received from manufacturers selling locally.

To calculate the lifecycle wells-to-wheels emissions (long cycle CO_2 equivalent lbs/ton of diesel equivalent fuel) of the different fuel options, the Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET 1 Simulation Software, version 1.8a) model was used.

6. CHALLENGES AND CONSTRAINTS

The initial engagement with national stakeholders, including National Treasury, indicated a strong interest in investigating the potential for using a transversal public procurement mechanism in order to achieve benefits of scale in the procurement of municipal buses. However, it became evident from engagements with the cities that although it seems likely that the requisite scale of demand for new buses does exist within cities to support such a mechanism in theory, there is very little appetite for centralized procurement in practice. Cities cited both political and practical obstacles that act as constraints on the business case for aggregating demand for green municipal buses in the absence of concrete financial incentives and support for centralized procurement from national government.

At the same time, there was an interest from cities in the potential impact of gas-powered minibus taxis in terms of reducing carbon emissions, NOx and SOx emissions and the potential role of cities in supporting the development of biogas production as a transport fuel. However, it should be noted that this direction was predominately supported by Tshwane and Johannesburg, based on initiatives and advanced plans that these two cities have already begun in Gauteng, as well as the fact that they were more consistently represented during stakeholder engagements than other cities due to the location of such engagement meetings.

Initially, the team had envisaged undertaking small scale pilots and spent some time and effort exploring the potential of using waste biomass at the Johannesburg Zoo as a transport fuel for the zoo's vehicles. This concept took longer than anticipated due to institutional challenges. A number of small scale pilots have already been conducted locally that

have produced useful data. Unfortunately, the pilots conducted in South Africa to date have not involved more than one bus at a time and have not been run on consistent drive cycles against multiple vehicles of similar age and body using other propulsion and fuel systems. This makes it difficult to draw direct fleet comparisons for the purpose of recommending specific public transit technologies with a high degree of confidence.

6.1 Demonstration projects

There is an interest from cities in demonstration projects as a means of building awareness of green transport technologies. The concept of demonstration projects was built around using a small budget allocation from the research project to leverage private sector funds to implement such demonstration projects. After long over-drawn negotiations with partners, the SA Cities Green Transport Programme through SANEDI, have managed to implement three demonstration projects:

6.1.1 Conversion of a golf cart to run on solar energy

City Parks and the Zoo make use of battery electric golf carts for a variety of services. This includes garden services, removal of garden waste and transporting of people and tools. In the Zoo people rent the golf carts to move between the cages viewing the animals in captivity. Resorts, hotels and hospitals use these golf carts or extended versions (14 seats) for transporting people from the parking areas to the buildings. On golf courses a mixture of petrol and electric powered golf carts is found.

Typically, the batteries of these vehicles can store enough energy for 6-7 hour operation, decreasing as the batteries age. This may cause the batteries to run out of power before the work has been done – leading to failure and frustration. The batteries are recharged using normal 15A plug points (at the normal electricity price). During load shedding and black-outs batteries cannot be charged causing additional failures and frustrations.

The high solar radiation makes it possible to use photo-voltaics (PV) produced electricity to recharge the batteries of the electric golf carts. The surface area on the roof of the golf cart could produce about 1kWh of electricity in one day.

If the operation of the cart is mainly in the sun and the cart is parked in the sun, then it may not be needed to even charge the battery using grid power. This means that electricity costs will be saved and load shedding or black-outs would not have any negative effect.

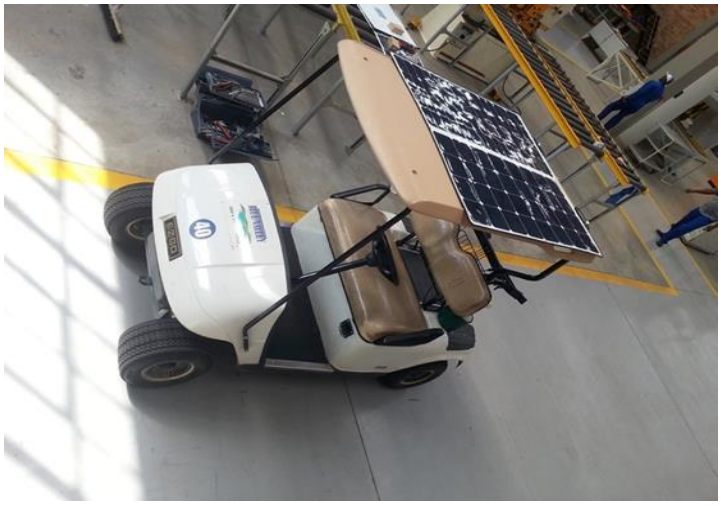
Flexible PV solar panels, as shown in figure 1; can be placed on the roof of a golf cart in order to charge the battery that stores electricity to power the motor of the cart. In this way, if the PV panels are exposed to the sun, the battery energy is being replenished during the operating cycle of the cart and they remain in an almost full state of charge.

Figure 1: Bendable PV module (source: SANEDI)

At first, the Joburg Zoo was targeted for a demonstration, however these negotiations were not successful hence the selection of the botanical gardens later on in the process.

A golf cart used in garden services at the Joburg Botanical Gardens is fitted with a PV roof to demonstrate the concept as explained. Two 100W PV panels are fitted to the roof of the golf cart. A trickle battery charger to charge the battery during operation in the sun and a monitoring system were also added. Due to challenges mentioned above this retrofit was done in September 2015 and observations will be made in order to measure performance going forward.

Figure 2: Demonstration of solar golf kart for the Joburg Botanical Gardens (source: SANEDI)



6.1.2 Conversion of a municipal truck to a biogas-diesel fuel system

City Parks is in the process of turning its garden and other suitable waste into bio-methane or biogas. This is done during controlled decomposition of the waste into biogas. In turn, the biogas can be purified to 95% methane by removal of non-methane gases. This gas is then compressed (compressed biogas or CBG) and used like compressed natural gas (CNG) as a fuel. This fuel can then be used to power internal combustion engines to produce electricity or propel a vehicle.

Diesel trucks can be converted to use either CBG or CNG as fuel. Typically, the vehicle having a compression ignition combustion engine will start using diesel and then supplement the diesel mixture with methane. This is called dual-fuel operation. Up to 60% of the diesel can be substituted with methane gas. This leads to more efficient and cleaner combustion – releasing less pollution to the atmosphere.

Due to the combustion of a renewable energy, carbon released to the atmosphere as a result of bio-methane combustion, does not count towards global warming. In fact, if the waste would have bio-degraded naturally, methane would have been released to the atmosphere with a 23 times higher contribution to global warming than the CO_2 - the result of the combustion process in the truck.

Planning is at its advanced stages for a demonstration in partnership with Cape Advanced Engineering (CAE) company that has won a contract with Joburg City Parks to build a biogas digester within the premises. The purpose is to convert waste into biogas that can be stored and used as a fuel for the trucks and other heavy duty vehicles when needed.

6.1.3 Installation of a mobile solar charging station

Electric vehicles (EV) are becoming more popular in the market and on the roads. Eskom, DEA, the CSIR and Tshwane Municipality lease or have purchased electric vehicles from Nissan and BMW in order to demonstrate technologies that

would lead to low carbon economic development. Using electric rather than petroleum powered vehicles will lead to reduced oil imports, improve energy efficiency in transport and reduce harmful environmental emissions.

These cars typically have a trip range of about 100km to 130km, depending on the driving conditions (acceleration and speed). The battery of the car needs to be recharged at every still standing (parked) opportunity (typically at home-base and end destinations) to enable daily commuting. Therefore, recharging points need to be installed at various destinations that these vehicles may visit for purposes of meetings and other business. These charging points do not require fast charging because vehicles will remain for more than an hour in these parking bays – on average.

BMW and Nissan have installed fast charging points at selected dealers in order to support EV users. These points provide a fast charge of 20min for 60% charge for users needing a quick top-up on the way to a destination, much like a fuel filling station.

In South Africa the bulk of electricity supply comes from coal as primary energy source. Most charging will thus come from a source of energy that releases CO_2 to the atmosphere – not a wanted scenario if the objective is to reduce carbon emissions[8]. This situation can be turned around completely through using solar power to charge the EVs thus decreasing the entire well to wheels to near zero.

[8] Should off-peak electricity (21:00-05:00) be used it could be argued that this electricity is produced anyway - even though there is no takers or buyers for this electricity. If this otherwise "wasted" or "not-used" electricity is used to charge batteries, then the emissions should not be allocated to the end user - the electric vehicle in this case.

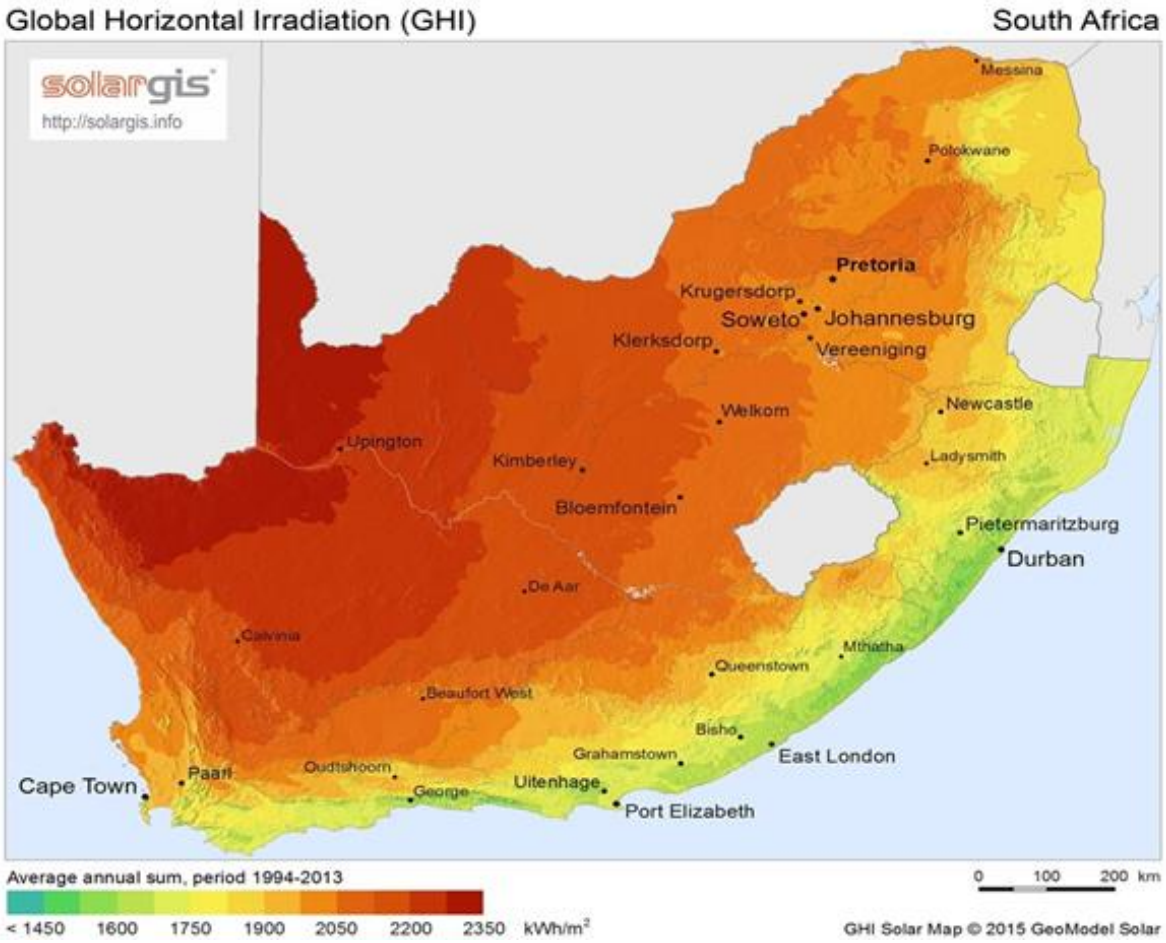


Figure 3: Global Horizontal Irradiation map illustrating solar energy (source: SANEDI)

The high solar radiation of the country as reflected by Figure 3 makes it possible to use PV produced electricity to recharge the batteries of EVs. The surface area of 2 carports could produce enough electricity in one year to provide 80'000 EV kilometres for a conventional sized electric car (on average a person travels 15'000 km per year).

There are at least two options involved in energy storage, namely the electricity grid and the battery bank. These are briefly described below -

a. The electricity grid

The solar installation can be used to charge the battery of an EV and to feed back into the grid thus supplementing the building electricity consumption where the vehicle is kept. This will reduce the building's energy use and lower the cost of electricity for the building. At the same time the vehicle can charge its battery when the sun is not supplying the energy. This way the grid becomes the "energy bank".

b. The battery bank

In this case, the energy to charge the EV battery will come from a bank of batteries that is recharged by the sun. It would also be possible to charge them when load shedding or black-outs happen or when the sun is not shining. In this case the battery pack is sized to do a number of complete charges of the EV battery.

c. A combination of the above

It is also possible to have the grid connection as well as a battery pack and have all the benefits of the above examples. In this case the battery pack is sized to at least provide an emergency charge.

The City of Johannesburg and ICLEI International hosted the "EcoMobility 2015 World Festival" in Sandton during the transport month of October. SANEDI was tasked with the exhibition of EcoMobility vehicles (skateboards, bicycles and light electric mobility options). This presented an opportunity to merge the two assignments coordinated by SANEDI i.e. the EcoMobility exhibition and the SA Cities Green Transport demonstration for solar charging of EVs. The roof of the old taxi rank was used for an installation of PV cells to service the vehicles.

Figure 4: Solar charging demonstration during the Exhibition at the EcoMobility Festival (source: SANEDI)

In order to re-use the installation after the EcoMobility Festival, it was designed as three installations working in tandem. So there are three sets of 20 PV panels and three hybrid inverters - each to become an independent PV charging station. This was then used to power the exhibition and to charge the batteries of the electric vehicles (electric bikes, sedge-ways, scooters, etc.) used during the exhibition.

SANEDI will continue to collect data on all these demonstrations beyond the Green Fund project in order to understand reliability, efficiencies etc. for the benefit of the broader green transport evolution in the country.

7. RESULTS

The research results from the project are structured in the following way:

- **Regulatory and policy environment.** A summary of the regulatory and policy environment for green transport, based on a review of the relevant documents and engagement with stakeholders.
- **Analysis of green transport options for municipal bus fleets:** A summary of the outcomes of a modelling of costs and emissions for different fuel technology options and engagement with bus manufacturers on costs
- **Green taxi conversions:** A summary of the business case and emissions performance of MBTs converted to run on gas.
- **Green transport targets for cities:** A summary of the outcomes from engagement with each city on willingness to set green transport targets.

Greater detail with respect to each of these areas can be found in the individual research reports for each phase of the project. These reports are available for download from the Technical Reports section of the Green Fund website.

7.1 Regulatory and Policy Environment

The regulatory requirements relating to alternative low carbon fuels such as gas and biofuels were reviewed. The Gas Act (No. 48 of 2001) stipulates certain licensing requirements that apply to commercial transmission, storage, distribution, liquefaction or re-gasification facilities or to trade in gas, but these do not represent an unnecessary burden to stakeholders. Similarly, stakeholders do not regard the more extensive regulations covering biodiesel and ethanol under the Petroleum Products Act (No. 120 of 1977) and subsequent amendments,[9] to be obstacles to the take-up of these transport fuels.

However, the above-mentioned legislative framework is currently in a state of flux, as various legislative amendments affecting the downstream petroleum industry have been proposed:

- The draft Gas Amendment Bill, 2013 (Gas Bill) was published for public comment under Notice 443 in the Government Gazette 36425 on 2 May 2013. The public comment process has closed and, having undergone internal review processes at the DoE, the Gas Bill has been forwarded to the state law advisor for final pre-certification, after which the relevant parliamentary processes will commence. The Gas Bill primarily seeks to:
    - Review and strengthen compliance monitoring and enforcement.
    - Address new technological advancements in both conventional and unconventional gas, including transportation mediums for liquid natural gas and CNG.
    - Facilitate gas infrastructure development and investment.
    - Ensure cooperation between the public and private sectors.
- Proposed amendments to the regulations under the Petroleum Products Act have also been published for public comment. These provide further requirements for the obtaining of licences and quality assurance standards.

[9] Petroleum Products Amendment Act (No. 58 of 2003) and Petroleum Products Amendment Act (No. 2 of 2005).

Private sector stakeholders from the gas industry identified concerns about the uncertainty over the status of gas as a transport fuel and the possible imposition of fuel taxes (like those currently levied on petroleum fuels). Unlike petroleum retailers, gas retailers who supply to the emerging gas-powered MBT industry collect VAT. Therefore, any taxation and/or price regulation should ensure that gas remains competitive relative to petrol as a transport fuel. This is because the current model depends on recovering the costs of MB conversions through the gas price charged to MBT operators. Keeping the gas competitive is justified from the perspectives of policy (aligned with South Africa's commitments to lowering GHG emissions), health (reduced NOx and SOx emissions from public transport benefits public health), economic (potential for job creation) and energy security (reduced reliance on petroleum imports).

For cities, their concerns were not primarily the standards or licensing of particular fuels and technologies, but rather the generic complexity of public sector procurement frameworks. In particular, cities were reluctant to sign up to a transversal procurement mechanism in order to aggregate demand. This is because an external public sector entity would lead the process, but city administrators and politicians would carry the procurement and management risks associated with the municipal bus fleets.

The energy policy framework comprises various key development-based policies and integrated plans, which together indicate that the government considers natural gas and biogas as central to South Africa's energy mix (Table 1).

Table 1: Policy summary

Policy	Contents
Competitive Supplier Development Programme (CSDP)	The CSDP aims to improve the capacity and competitiveness of the local supply base and contribution to growth, employment creation, poverty reduction, skills development, and B-BBEE imperatives. These aims are to be achieved primarily through the requirement for local manufacturing.
National Industrial Participation Programme (NIPP) and Industrial Policy Action Plan 2012–2015 (IPAP)	The NIPP and IPAP consider transportation to be a key multiplier for economic development. An important development sector identified is fleet programmes and products, albeit in the context of supply chains and local manufacturing, rather than the provision of a municipal service. IPAP also considers biofuels development to have significant economic development potential because of its strong linkages to agriculture, manufacturing and distribution, and its ability to create substantial numbers of labour-intensive jobs in the agriculture sector. Government has committed to a 2% blend target for including biofuels in the national fuel supply but is looking to increase this to 10%, which would create approximately 125 000 direct jobs.

Renewable Energy Independent Power Producer (IPP) Procurement Programme (REIPPPP)	REIPPPP has generated 64 new renewable energy IPPs, of different sizes at different sites. A total of US$14-billion has been committed for the construction of 3922 MW of capacity in technologies such as grid-connected wind, PV and concentrated solar power, as well as smaller amounts of hydro, landfill gas, biogas and biomass energy (in round 3110 MW of biomass, biogas and landfill gas).
Integrated Energy Plan (IEP)	Having published a draft IEP for public consultation in June 2013, the DoE is compiling a new draft IEP that will be subject to a further round of public consultations. The current IEP includes the following: Gas presently constitutes 3% of the total energy mix. Between 2010 and 2050, the demand for petroleum products is projected to increase more significantly than for other energy carriers. Imported natural gas plays an increasing role in all test cases throughout the planning period. Natural gas has a significant potential for both power generation and direct thermal uses.
Integrated Resources Plan (IRP) 2010–30	The IRP 2010–30 was promulgated in March 2011 and is described as a 'living plan' that the DoE would revise every two years (i.e. in 2013). The DoE completed and published an updated IRP 2010 with the closing date for public comment being 7 February 2014. The current IRP indicates that regional and domestic gas options must be pursued and shale exploration stepped up. A natural gas energy option is likely to feature more prominently in the updated IRP. The South African government is undertaking a Strategic Environmental Assessment and Risk Analysis of gas extraction through hydraulic fracturing (fracking) in the Karoo. Careful investigation is needed because of South Africa's limited water resources, the water requirements and the possible impacts on groundwater of this process.

In consultation with various industry stakeholders, the National Planning Commission (NPC), departments of energy and trade and industry, and National Treasury are in the process of drafting the Gas Utilisation Master Plan (GUMP), which will take a 30-year view of the industry from a regulatory, economic and social perspective. Initially commissioned to

diversify South Africa's energy production mix with conventional and unconventional gas, GUMP has developed to include industry and infrastructure planning models and acknowledges that it should also inform the gas IPPs. The latter development directly affects the downstream petroleum sector. The NPC recognises that, in order for gas exploration and production to remain viable, suitable downstream entities will need to provide the demand. Gas IPPs are expected to provide the initial demand but, for sustainability purposes, other downstream players will also need to contribute to demand. This offers scope for downstream petroleum sector players, such as municipalities intending to switch municipal bus fleets to gas, to benefit immensely from the GUMP process.

South Africa's success in the automotive industry has been the driver behind efforts to develop an electric vehicle industry. The DTI's second Industrial Policy Action Plan (IPAP2) includes the commercialisation of electric vehicles, and appropriate support to encourage local manufacture of EVs and related components, installation of infrastructure for such EVs, creation of testing facilities, provision of demand-stimulation mechanisms, and public education on the use and benefits of alternative-energy vehicles. Led by the DTI, the plan was supported by the DoT, the Department of Science and Technology, provincial governments, as well as certain metros.

From 1 January 2013, the Automotive Production Development Programme (APDP) replaced the Motor Industry Development Programme. The APDP does not include a programme for developing the EV industry, which is instead outlined in the EV Industry Roadmap that the DTI launched in April 2013. Among other measures, the EV Roadmap:

- Provides tax and VAT incentives and rebates to reduce price and vehicle registration costs.
- Supports investment, including an amendment of the Automotive Investment Scheme of the APDP to provide 35% cash back for EVs (compared to the 30% cash back incentive for ICEVs). The Roadmap calls for the reduction in qualifying annual units per plant producing EVs from 50 000 to 5 000.
- Promotes research and development, especially activities that will lead to reduced component costs (in particular of the battery).
- Makes provision for a regulatory framework to ensure the safe manufacture and operation of EVs in South Africa.
- Investigates the introduction of preferential tariff schemes and intelligent charging methods to encourage off-peak charging of EVs. Eskom has undertaken to look at reduced tariffs and intelligent-charging systems.
- Provide urban infrastructure to prepare metropolitan municipalities for the introduction of EVs across the country, by increasing the level of integrated planning in the areas of urbanisation and transportation.

In March 2013, the Technology Innovation Agency (TIA) launched the National Electric Vehicle Technology Innovation Programme. The programme provides a collaborative environment for entrepreneurs, equipment manufacturers, technology companies, higher education institutions and science councils to accelerate the development and commercialisation of new technologies, processes and services. The aim is to address the current charging infrastructure and energy storage technology challenges that are critical to the support of a viable EV industry in South Africa. The TIA focuses on the EV value chain, specifically the infrastructure requirements and energy storage. The programme is intended to support the local market for EVs and, ultimately (and if viable), to support the export of EV value chain products (other than the vehicle itself) to international markets. The key drivers of this approach are cost reduction, job creation, and adaption of technologies to meet local specifications and standards.

In certain instances (such as with certain charging components), the cost of imported products is considerably higher

than if the products were produced locally. Significant cost savings could be achieved in cases where the technology is relatively simple and the country has the capacity to produce to the appropriate standards. Local production would support local job creation and, should local component producers be able to sell into international markets, achieve substantial job creation in the longer term. Local innovation is also seen as important for ensuring that South Africa is not left behind and forced to adopt expensive technologies that may not be suited to the local context (and therefore not meet local specifications). The approach acknowledges the need for a living lab where innovation happens on the ground. A living lab provides the space to test what will work in the local context and the flexibility to adapt to market developments. The risk and uncertainty in the international EV market may necessitate such a flexible approach to developing the local industry.

The TIA is working closely with international governments, particularly Finland, India and the UK, to learn from their experiences and to adapt them for local context. The TIA model is to invest in proposals that are innovative, promote socioeconomic development, and are commercially viable. Funding is provided from idea to commercialisation, with the intellectual property and the production being done 'in-house'. To support this, the TIA intends to develop world-class infrastructure for testing e-mobility value chain technology. Efforts are also underway to partner with infrastructure component and battery technology companies.

7.2 Analysis of Green Transport Options for Municipal Bus Fleets

The key finding from this research was the convergence of electric, gas, ethanol bus technologies and fuels, in terms of costs, emission profiles and security of fuel supply/availability.

- Electric bus manufacturers are leasing their batteries at the same running costs as diesel fuel. The potential for operators to use PV to charge buses would reduce the GHG emissions associated with reliance on the national grid.
- Gas and ethanol bus manufacturers are willing to provide their vehicles at the same price as diesel buses through lease arrangement that cover full lifecycle costs by offsetting higher bus costs against the lower fuel prices. The major obstacle is the cities' lack of familiarity (and therefore confidence).
- Second generation (locally produced waste-derived) biogas and bioethanol have an almost identical GHG footprint, varying only slightly depending on waste by-product displacement analysis.
- Plenty of local first generation agricultural biogas or bioethanol options could be available as backup to second generation waste-derived biofuel. A third layer of security of supply is provided by importing CNG or ethanol, with the potential to lean on larger ethanol blending plants when mandated blending legislation kicks in.
- Municipalities are able to transfer technology, infrastructure and fuel risks onto the manufacturer through leasing buses, allowing a municipality to change technology and fuel every 5–7 years with no penalty above the current lifecycle cost of buying more diesel buses. This reduces the risk of 'white elephant' decisions, prevents contractor/supplier lock in, and gives municipalities' maximum flexibility to negotiate better deals every 5–7 years.

The research compared the costs and environmental performance of municipal buses powered by diesel, ethanol, CNG, compressed biogas, and battery electric. Through subsequent engagement with bus manufacturers, the project team determined that manufacturers of electric, gas, and ethanol buses are essentially prepared to provide all these

technologies at the same full lifecycle cost as the EuroV diesel buses. Nevertheless, modelling the five-year lifecycle costs (Table 2) provides insight into the trade-offs that manufacturers and cities are making across technologies, and identifies the risks for municipal service level agreements. For instance, based on Stockholm's experience in 2008–2010, the actual maintenance cost is 71% higher for gas than for diesel buses. However, fuel costs are 28% lower, which more than makes up for higher maintenance costs. Compared to gas buses, ethanol buses are 23% cheaper, but their five-year fuel bill is twice as high. Electric buses cost double the capital of diesel buses but save 79% in fuel and 32% in maintenance costs. A worthwhile way of looking at the technology trade-offs may be to consider which risks are easiest to manage by a municipality, i.e. maintenance, fuel costs, fuel availability or financing costs.

Table 2: Modelled costs for alternative bus technologies

Rands (000s), including VAT	Diesel Baseline	Ethanol	Compressed Natural Gas	Compressed Biogas	Battery Electric
Local Vehicle Price (Cap Ex)	2,372	2,609	2,965	2,965	4,744
Lifecycle Financed Vehicle Cost	2,970	3,267	4,010	4,010	5,941
Lifecycle Fuel Cost	1,612	2,601	1,149	1,011	345
Fuel Price (R/DLE)	12.59	13.10	7.52	6.62	N/A
Unit Price (R/liter, /m^3, /kWh) + 1 rand of taxes	12.59	8.00	7.76	6.83	0.79
Lifecycle Maintenance Cost[2]	296	403	507	507	202
Total (Nominal Lifecycle Cost)	4,878	6,272	5,666	5,529	6,488
Total (Discounted Cash Flow)	3,489	4,481	4,066	3,968	4,669

As Table 2 shows, biogas is the clear lifecycle cost winner, 13% higher than EuroV diesel, versus 16% for natural gas, 28% for ethanol, and 34% for battery electric. Nevertheless, if a municipality is unable to lock in both the long-term costs and the long-term supply of biogas, it could end up with natural gas prices dependent upon the imported price of CNG and no truly green transport option to pursue.

Table 3: Percentage comparison of lifecycle costs to EuroV diesel baseline

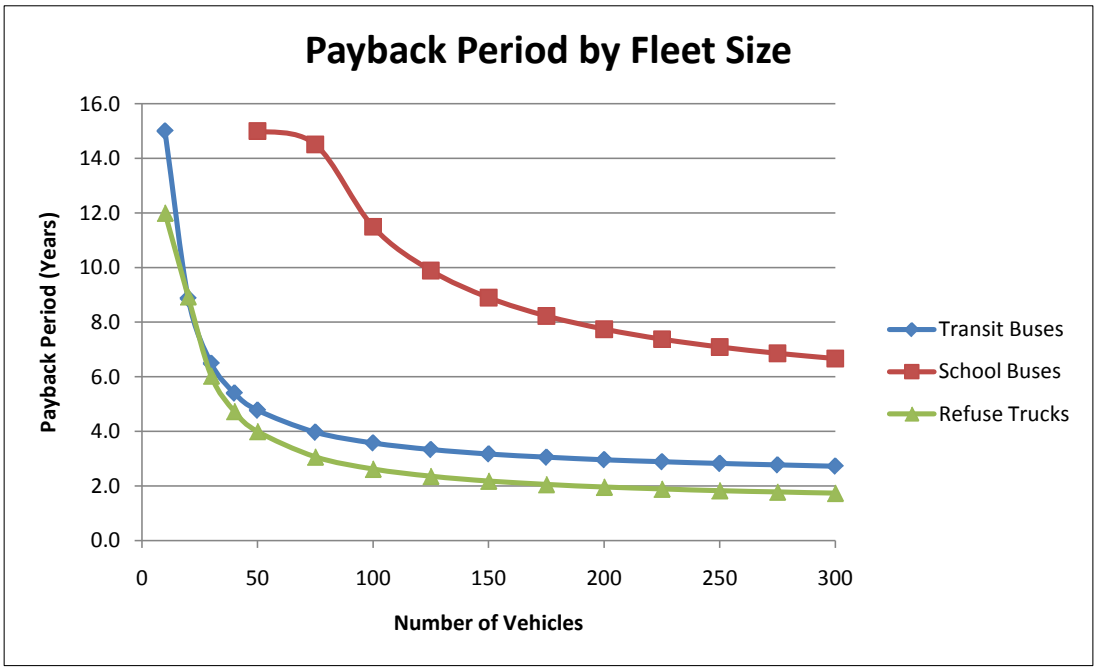
	Ethanol	CNG	Biogas	Battery Electric
Lifecycle Financing Costs	+10%	+35%	+35%	+100%
Lifecycle Fuel Costs	+61%	-28%	-37%	-79%
Lifecycle O&M Costs	+36%	+71%	+71%	-32%
Total Lifecycle Costs	+28%	+16%	+13%	+33%
Meet Euro 5 emissions	☺	☺	☺	Zero tailpipe emissions
GHG Footprint	-71%	-14%	-78%	-2%

According to the GREET model analysis, biogas has similar GHG emissions reductions to CNG on a pump-to-wheels basis, as well as significant credits as a result of reduced GHG emissions from landfill and waste that would otherwise be unrecovered. The well-to-wheels impact biogas depends greatly on the source of biogas: energy derived from waste is regarded as a GHG credit, with absolute values dependent on the regional livestock, climate, and overall waste management system applicable to the source of biogas.

There are four good alternatives to diesel. Each technology can deliver diesel lifecycle costs, as proven by firm fixed manufacturing proposals submitted to at least two major metros. The above model provides insight into the inherent cost and GHG advantages and disadvantages of each technology. However, every disadvantage can be overcome. Solar power and the availability of Chinese financing can eliminate the capex and GHG disadvantages of electric buses. Bioethanol can make up for its fuel efficiency limitations through manufacturers committing to deliver fuel at prices on par or below diesel fuel costs per km travelled.

In further investigating the business case, the research team looked at existing work done by the National Renewable Energy Lab (NREL) of the US Department of Energy using the CNG Vehicle and Infrastructure Cash Flow Evaluation model to demonstrate the relationship between project profitability (the purchase of gas buses, gas refuelling infrastructure, and gas fuel) and fleet operating and fleet size parameters (Mitchell, 2015).

Figure 4: Payback period by fleet size (source: NREL, 2010)



Based on NREL's modelling, the return on a CNG bus investment by municipalities shows a distinct advantage (based primarily on refuelling station costs) of purchasing a fleet of at least 25 buses, and ideally over 50: the payback period curve is extremely steep up to 50 buses, when it flattens out. Although these figures relate to US conditions they are believed to provide some indication of likely payback periods in South Africa.

During engagements in the scoping phase of the project, most bus manufacturers are willing to set up new manufacturing plants for either CNG/biogas, ethanol or electric buses in South Africa, if committed orders (across municipalities) are received of approximately 300 buses over three years ramping up to at least 300 buses per year for a negotiated period of time. Table 4 shows the cities' projections for planned orders of new CNG/biogas buses over the next 5–7 years:

Table 4: Indicative targets for planned CNG/biogas bus procurement (source: cities' consultation)

Municipality	Total 5–7 year Planned Order
Johannesburg BRT / Metrobus	402
Cape Town BRT	320
Tshwane BRT	130
Ekurhuleni BRT	50
eThekwini BRT	60
Rustenburg BRT	25
Total	**977**

The planned orders in Table 4 relate only to direct purchases by some of the cities and do not include the fleet replenishment plans of private bus companies, many of which have contracts with the cities. There is a clear potential for local manufacturing of green buses that will contribute towards job creation and skills development.

The research investigated the potential of a transversal procurement mechanism to which cities could sign up to, thereby aggregating demand to achieve benefits of scale and drive down costs. In-principle support was reached for such a mechanism from National Treasury, DoT and DEA. However, the cities resisted the idea, citing concerns around governance, potential implications for municipal procurement accountability, and divergent technical requirements and perspectives on appropriate technology.

While there is little co-operation between cities in terms of aggregating demand, Tshwane and Johannesburg are introducing CNG into their bus fleets, albeit using different technologies.

7.3 Green Minibus Taxi Conversions

The cities asked the team to investigate the business case for converting MBTs to dual-fuel systems capable of running on CNG and how cities could support such a process.

Table 5 describes the gas pricing model used by a gas retailer, which incorporates incentives (commissions) to MBT owners and associations and the cost of gas with and without a margin to recover the costs of CNG conversion. The pricing is for a volume of gas equivalent to one litre of petrol. In order to stimulate the market for CNG as a vehicle fuel, the company funds the conversion of MBT and recovers the cost from gas sales, at a rate of R1.26 per litre equivalent (L/eq) sold. Even with cost recovery built in, a significantly lower fuel price for MBT operators is still achieved. Converting a MBT with two gas storage tanks will cost around R20,000 including VAT, while a private vehicle with one tank would cost around R16,500.

Table 5: Financial model for CNG fuel (source: private sector consultation)

	Gas price kit funded (Rand per L/eq)	Gas price kit owned Rand per L/eq)
Retail selling price including VAT	8.99	7.56
VAT	1.10	0.93
Retail selling price excluding VAT	7.89	6.63
CNG kit recovery cost	1.26	0.00
Selling price excluding VAT & kit recovery cost	6.63	6.63
Commissions MBT owner	0.07	0.07
Commission MB association	0.07	0.07
Total commissions	0.14	0.14

Note: L/eq – litre/equivalent

Table 6 shows the results of the tests that were conducted on a 2005 Toyota Hilux pick-up vehicle converted to dual-fuel (the vehicle used in the trials was a carburettor-fed four-cylinder engine). The findings are based on the SANERI 2011 test, as reported by Schmidt et.al (2012).

Table 6: Fuel consumption and CO_2 emissions of the CNG pickup Toyota Hilux (source: private sector consultation)

Operation	Cycle	Fuel consumption			CO_2
		Nm^3/(100 km)	l/(100 km)	kWh/km	g/km
CNG	Vehicle operation/ SANERI	11.19	-	1.11	220
Petrol	Vehicle operation/ SANERI	-	12.65	1.13	301
Petrol	Manufacturer data	-	12.0	1.07	287
Petrol	Vehicle operation/ Australia	-	12.34	1.10	294

This specific engine model resulted in about 20% fuel saving compared to a gasoline fuelled variant. As the price of converting fleet vehicles to CNG is R16,500,[10] the payback period is about 13 months, the same as a MBT. Pilot projects have also shown that converting vehicles to natural gas reduces maintenance cost and service intervals, as no lead or benzene content fouls the spark plugs.

7.4 Green Transport Targets for Cities

Collective targets for accelerating the transition to green transport were collected using a crib sheet that the cities (Johannesburg, Tshwane, eThekwini, Buffalo City, Nelson Mandela Bay, Mangaung, Cape Town, Ekurhuleni and Msunduzi) completed. The crib sheet described green transport initiatives based on local and international best practices. The aim was to obtain a level of commitment from cities on green transport targets, i.e. a percentage conversion of municipal fleets to alternate fuel and a percentage reduction in GHG emissions by 2020.

[10] Costing provided by CNG Holdings at the Green Transport Workshop.

Table 7: Green transport targets per city (source: cities' consultation)

Options	Green transport targets	Joburg	Tshwane	eThekwini	Msunduzi	Buffalo City	Nelson Mandela Bay	Cape Town	Mangaung	Ekurhuleni	Total	Weighting
Choice A	No commitment to targets: city not ready for green transport initiatives	0	0	3	0	1	0	0	0	0	4	7%
Choice B	Commit to 15% reduction in GHG emissions by 2020	3	3	0	2	2	1	1	2	2	16	29%
Choice C	Commit to convert 50% of the municipal fleet to alternate fuel by 2020	3	3	0	2	0	1	0	2	1	12	21%
Choice D	Commit to 35% reduction in GHG emissions by 2020	2	2	0	0	0	2	1	0	0	7	13%
Choice E	Choice B + Choice C	3	3	0	1	0	1	0	2	2	12	21%
Choice F	Choice C + Choice D	2	2	0	0	0	1	0	0	0	5	9%

Scoring	
0	Strongly disagree / unrealistic / unachievable
1	Uncertain, it is conceivable, but would require major shifts in the current direction.
2	Agree that it is realistic if certain structures where put in place to make sure this happens
3	Strongly agree / very realistic and achievable in the context of where we are currently headed

The overall outcome was a broad commitment from cities to a 15% reduction in GHG emissions and a 50% conversion of municipal fleets to alternate fuel by 2020. Although green transport forms a part of the cities' current programmes, these initiatives are not always evaluated in terms of GHG emission reductions. An issue for cities is the absence of structures and systems for measuring GHG emissions within the transport network, making it difficult to demonstrate progress towards targets. Cities need to prioritise this critical issue for the future, although some municipalities already have such systems in place, i.e. Johannesburg, Cape Town and Tshwane.

Cities are currently involved in programmes that include improving public transport through bus rapid transport (BRT), alternate fuel vehicles (both gas and electric), non-motorised transport (NMT) upgrades such as cycle and walking lanes, and low emission zones (such as restricted NMT and public transport routes). Given the existing investment in these programmes, another major issue for cities is the need to find funding for further green transport projects. The project

team's engagement with development finance institutions suggested a willingness on their part to finance properly scoped projects, suggesting that at least part of the obstacle lies in a lack of capacity and financial support for project preparation.

8. CONCLUSION

The research team spent a relatively small amount of time on the modelling of costs and environmental performance of different fuel technology options for municipal bus fleets. Far greater effort was spent in engaging with stakeholders, attempting to forge consensus among cities and other stakeholders on the most productive strategy for greening the transport sector, with municipal fleets being the low-hanging fruit and a starting point for cities.

The costs of green transport options were examined through several local pilot projects and extensive international literature and research. The establishment of a Cities Green Transport Programme, which in time could be expanded to other municipalities, is aligned to the Gauteng 2012 Integrated Transport Master Plan (Department: Roads and Transport, 2012). This Master Plan refers to a Green Re-fleeting Strategy, which looks to shift the energy source for transportation from current non-renewable oil resources to sustainable or 'clean' fuels. The Strategy aims to reduce transport's contribution to GHG emissions by 35% by 2020 and 50% by 2040. It also focuses on improving vehicles and fuels in order to reduce urban air pollution and GHG emissions, as well as contribute to the green economy and employment and income generation opportunities.

What emerged strongly from the engagements was the need for better and more regular communication between stakeholders (government, civil society and private sector) who are interested in reducing emissions in the transport sector. In particular, horizontal learning across cities needs to be strengthened with respect to greening municipal fleets and bus services.

8.1 General Conclusions

Municipalities are still considering a range of different technology options for lower emissions and moving away from petrol and diesel fleets. No single technology has emerged as a strongly preferred option, although there is some momentum behind the use of natural gas (methane) as an alternative technology for buses and MBTs in Gauteng.

The challenge is one of scaling-up, as all the value chain elements (fuel supply, distribution infrastructure, vehicle technologies, maintenance, support and training) are already in place in South Africa for the use of natural gas as a vehicle fuel, and the policy environment is generally supportive. The public sector, in particular cities, can play a crucial role in driving the market for CNG as a vehicle fuel. The private sector has already demonstrated its capacity to finance fuel distribution infrastructure and vehicle conversions of MBTs to CNG, and cities can contribute to achieving greater scale in various ways.

Municipal demand can potentially drive local manufacturing capacity for green vehicles, through greening their fleets in the cases where cities procure and operate municipal bus fleets. The research found that the full lifecycle costs for gas/ethanol/electric vehicles are converging with those of conventional diesel vehicles, to the extent that bus manufacturers are willing to offer the same price terms under lease arrangements. Johannesburg and Tshwane are already greening their fleets, and therefore lessons learned need to be effectively disseminated to other municipalities. Despite the reluctance of cities to commit to a formal transversal (centralised) procurement mechanism, the potential

for municipal demand to drive local manufacturing capacity (which could contribute to green jobs) should not be ignored.

Municipalities are also starting to procure electric or hybrid electric vehicles for their corporate municipal fleets. Like for the municipal bus fleets, cities can support local production through better coordination and aggregation of demand for EVs. At the same time, converting municipal corporate fleets to gas should also be considered as a viable option for reducing GHG emissions and other air pollutants.

The Gauteng Integrated Transport Master Plan supports the greening of transport and reducing traffic congestion through popularising cycling and short distance walking trips to destinations; using NMT modes (walking and cycling) as feeder systems to public transport; applying travel demand management and transport system management; and using 'sustainable power sources' for transport facilities, amenities and equipment. Cities generally understand the value of these initiatives, despite slow progress and uneven capacity.

8.2 Key Policy Messages

The following key policy messages emerged from this research:

a) National government can facilitate the development of an enabling regulatory environment and a stable environment for long-term investment. It needs to endorse gas as a vehicle fuel and ensure that regulation does not make gas uncompetitive as an alternative to petrol. Currently, CNG sold to MBT operators incurs VAT but not a transport fuel levy.
b) Cities have little appetite for aggregating demand in the absence of a clear vision and financial incentives from national government for cities to commit to transversal procurement of green transport technologies.
c) There is potential for securing institutional support for the development of an industrial cluster around CNG-powered taxis through the DTI's Manufacturing Competitiveness Enhancement Programme.
d) The DEA can ensure that city transport departments are actively involved in developing the emissions monitoring framework linked to the national GHG inventory and, where necessary, provide capacity-building support.
e) Cities are willing to make commitments to aspirational targets for the greening of municipal transport, but these commitments will remain relatively conservative in the absence of financial and technical support.
f) Greening the MBT industry has the potential to significantly reduce emissions, and cities can support MBTs converting from petrol to gas in a number of ways e.g through funding conversion kits, allocating suitable land for CNG stations and fast-tracking supporting utilities.
g) Biogas has the potential to greatly improve the GHG emissions of gas-powered vehicles. Currently municipalities are underusing municipal waste as a source for biogas, which includes landfill gas and biogas from wastewater treatment plants.

8.3 Recommendations for Further Action

(i) Create greater certainty and confidence in alternative energy technologies for transport among decision makers in cities. Successes and lessons learned in implementing green transport initiatives need to be effectively disseminated between cities. To this end:

- A Green Transport Working Group should be established under the SACN's Transport Reference Group, to facilitate information sharing and coordination, including organising seminars and site visits to different municipal green transport initiatives.
- Technical and financial support for such a working group should be pursued, e.g. from USAID, as part of their support for capacity building and low emissions development projects involving municipalities.
- The use of biogas from municipal waste urgently needs to be demonstrated and implemented as a vehicle fuel. This can build on the momentum around CNG as a potential low-emissions gas fuel for MBTs and buses.
- Biogas should be added to the IRP for the energy sector. The DoE has policies in place for developing renewable energy projects, but biogas for the transport sector is not formally included.
- Municipalities interested in biogas should be invited to join the biofuels development process. Municipalities are key stakeholders and can assist in granting access to landfills and wastewater treatment plants. Involving more than one municipality can help spread the costs of transporting via pipelines.
- The stakeholder network associated with the Green Transport Working Group should be expanded, encouraging wastewater treatment companies (public or private) to join, as well as smaller private organisations, such as farms.
- The financial options (loans and grant programmes) need to be explored. These include local, national and international funding strategies for which green transport could qualify and cover both private and municipal/regional projects. The CDMs and Certified Emissions Reductions can also be used to make biogas projects more attractive to investors, particularly in view of an impending carbon tax.

(ii) To support the conversion of MBTs, cities should consider the following options:

- To work with taxi associations, private sector companies in the gas industry and financial institutions to raise awareness of the business case for converting MBTs, investing in gas refuelling infrastructure and financing MBT conversions.
- To advocate for CNG conversions through the MBT associations, which are clearly core stakeholders and need to be won over to the idea of conversion.
- To play a facilitating role between MBTs associations and gas companies. For instance acting as a neutral broker and platform convener, making suitably located land available for CNG filling stations and fast-tracking supporting utilities.
- To actively drive the creation of refuelling infrastructure and financing of MBTs conversions by entering into a formal joint venture, either a public private partnership or a special purpose vehicle in which one or more municipalities are shareholders. It may be possible to raise finance for these investments through the DBSA, especially given the robust business case for MBTs conversions (conversion costs can be relatively quickly recovered from the gas price).

The shift towards green transport will not happen all at once, and options such as dual-fuel and hybrid-electric vehicles provide a means to manage the risk associated with switching to cleaner technologies. The private sector have already shown a willingness to invest in the technologies, infrastructure and services needed to accomplish this shift. In light of

the public benefits associated with green transport, government needs to assist by creating demand and providing an enabling environment.

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