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Options for Natural Gas Vehicles in the UK Transport Energy Roadmap

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ABSTRACT

Transport contributes approximately 33% of the UK total final energy consumption, and the energy to support this demand is currently provided by gasoline and diesel through an independent network of refineries and fuelling stations. Overall natural gas contributes over 40% of the UK primary energy consumption, and oil around 33%. Total UK gas demand is of the order of 100bcm of gas. If we were able to replace all of UK transport energy consumption directly with natural gas we would require of the order of 70bcm of gas per annum.

There are suggestions that conversion to a full electric transport infrastructure is a realistic energy scenario. However, as the total energy demand from road transport is comparable to that which is currently supplied as natural gas to the UK and it also equates to over twice the amount of energy currently being transported through the UK national electricity grid, there are issues regarding the feasibility of such an approach.

Natural gas vehicles (NGVs) are a rapidly developing market worldwide, with currently over 12 million vehicles on the road and around 20-30% per annum growth. Contributory factors to their uptake have included emissions reduction, energy security concerns and availability of indigenous resources. Many countries therefore incentivise NGV uptake through fuel prices, tax breaks or subsidies of various sorts. A new range of vehicles is appearing on the road using new technology, and able to easily meet stringent EPA and CARB Standards. HGV, fleet and larger vehicles are particularly benefiting with an expanding infrastructure developing to meet demand. New dual fuel diesel technology and LNG availability is encouraging uptake by hauliers, where payback can be as little as two years. A smaller industry with a number of enthusiastic pioneers is beginning to emerge in the UK on the back of biomethane production and the promise of benefits from the Renewable Transport Fuel Obligation and the Renewable Heat Incentive, two UK government support measures aimed at increasing the use of renewable energy.

Lifecycle emissions analysis shows that CO_2 and greenhouse gas emissions from NGVs can compare with the best evolved alternative technologies. New technologies are emerging which reduce tailpipe methane emissions. The emergence of CNG hybrids and the increasing importance of biomethane further improve the carbon reduction potential.

A high level analysis of infrastructure investment costs indicate that per tonne of carbon saved, NGVs can give a significantly better return (compared to electric vehicles). Large vehicles appear best in this regard, but as technologies advance and biomethane becomes more available, all types of vehicles could benefit. In that trucks are likely to be less amenable to electric vehicle penetration, it is suggested that a realistic scenario would develop a fuelling infrastructure which could target 50% or more of trucks and fleets in the long term, requiring a gas load of up to 20bcm and therefore supporting the use and maintenance of the natural gas distribution infrastructure.

Through a development roadmap this would also be the best way to support a future fuel cell car infrastructure using local methane steam reforming. With biomethane it would also enable the development of a future DCHP and energy hub infrastructure which could be carbon negative if small scale CO_2 sequestration develops.

This paper looks at the technology options which can be used to ensure that natural gas vehicles participate in the path to a future low-carbon infrastructure. These include:

- Establishing a fuelling infrastructure for CNG around the existing gas distribution network
- Establishing a low pressure infrastructure to support a new fleet of low-pressure Adsorbed Natural Gas (ANG) vehicles
- Establishing an LNG-based infrastructure benefiting from the available pressure reduction and cold energy at distribution sites.

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1. Introduction

Road transport contributes approximately 30% of the UK total final energy consumption, and the energy to support this demand is currently provided through an independent network of refineries and fuelling stations.

Overall, natural gas contributes over 40% of the UK primary energy consumption. Total UK gas demand is of the order of 100bcm of gas, which means that total UK energy consumption in equivalent units is of the order of 250bcm of gas.

As 30% of this total consumption is for transport, if we were able to replace all of UK transport energy consumption with natural gas we would require of the order of 70bcm of gas per annum. This is of course an unrealistic scenario, but the scale of the situation is clear.

In 2010 about 350TWh of electricity was transmitted through National Grid's system. In gas equivalent this equates to approximately 31bcm of gas.

The total energy demand from road transport is comparable to that which is currently supplied as natural gas to the UK. It also equates to over twice the amount of energy currently being transported through the UK national electricity grid. This comparison explains why switching the transport demand from its current independent road based network to an existing electricity based infrastructure will cause such system stress and require investment on a level which has not been seen in the country's history.

Energy consumption	MGGe*	Bcm Gas	TWh
Total UK	58000	250	2800
National Grid Electricity Transmission	7000	31	350
National Grid Gas Transmission	22800	100	1100
Road Transport	17000	70	770
HGV	4000	18	200
Cars	10500	42	475

* - MGGe ≡ Million Gallons of Gasoline equivalent

The UK government has made a policy decision to invest in a future electric vehicle infrastructure in order to decarbonise the UK transport economy. A recent study by Redpoint Energy for National Grid suggested incremental costs of investment in electricity infrastructure of up to £700billion in order to support this move. A report for National Grid from the European Commission "Beywatch project" also presented scenarios which indicate that under government projections for uptake of Electric Vehicles by 2050, the electricity transmission and distribution network will require a complete rebuild between 2030 and 2040. This is because the electricity to support an electric vehicle based transport system is required at the extremities of the distribution network so upgrading will be needed at all voltage tiers. Natural gas vehicles as a possible contributor to decarbonising the UK economy do not seem to have been seriously considered by the UK Government. There are however a number of reasons for looking at NGVs in the UK context, particularly in view of the above analysis.

These include:

- The world natural gas vehicle market is growing worldwide at approximately 30% per year. With approximately 15,000,000 vehicles now on the road.
- Technology and manufacturing capability to support this growing demand are bringing down costs and improving efficiencies.
- A carbon reduction of approximately 20% per vehicle over existing vehicle fleets is potentially achievable on average with natural gas as the source of fuel.

- Other Greenhouse Gas (GHG) and particulate emissions are reduced over diesel and petrol.
- Natural gas is provided at the ends of an existing distribution infrastructure which is already scaled to meet this demand.
- The increasing importance of biomethane as a distributed fuel means that the gas network will be increasingly decarbonised.
- Electricity will continue to be derived from a largely fossil fuel mixture up to 2050 at relatively low production and transmission efficiencies.
- The uptake of electric propulsion for larger vehicles, particularly Heavy Goods Vehicles (HGVs) is likely to remain low due to the payload constraints given by the need for large numbers of batteries.
- Approximately one third of all transport fuel in the UK is used to fuel HGVs and commercial and fleet vehicles, all of which are directly amenable to natural gas usage.
- Dual fuel diesel natural gas technology means that HGVs are currently experiencing the most rapid take up of CNG as vehicle fuel.

This paper attempts to paint a high-level picture of the current status of NGVs and assesses the opportunities and threats to the UK from current shifts in transport and energy horizons.

2. Overview of the Market

2.1 International Position

There are currently about 15,000,000 NGVs on the roads worldwide, and this market is growing by approximately 30% per annum. Until the middle part of the last decade, South America dominated the natural gas market, with Brazil and Argentina out in front. More recently growth in Asia has outstripped South America with Pakistan now the World's dominant player. In many cases growth can be explained by the encouragement of the use of local gas reserves to reduce dependence on imported oil. In India extremely rapid growth in NGV adoption was seen when the Indian government decreed that in order to improve air quality in their major cities (Mumbai and Delhi) all public service vehicles must convert to natural gas within a 2-year time period. Government control over natural gas prices made conversion a highly attractive option and a support structure developed almost overnight for vehicle conversions, with owner payback typically less than a year followed by cost savings on fuel of over 50%. The initiative was so successful that conversions happened more quickly than expected and the fuelling infrastructure was initially unable to keep pace with demand. The Indian market was seeded by these developments and has followed at a pace in cities where natural gas is available.

There have been pockets of activity within Europe over the past decade, notably in Italy, Germany and Bulgaria. In fact many of the components which supply the vehicle conversion market in Asia are sourced within Italy. Recent growth in NGV numbers has been bolstered by the move to supply biomethane to markets such as Germany and Sweden. The European market has been sufficiently active to allow OEMs to produce dedicated or bi-fuel vehicles for both the commercial and passenger vehicle market.

There is no real homogeneity to developments in Europe, and growth is strongly influenced by National policies, although NGVA Europe was set up in 2008 to try and influence trans-European take-up. There are however almost 1.5 million vehicles in Europe at present and at over 15% per annum, the growth rate in Europe is higher than it has ever been. In 2009 the European Parliament adopted recommendations which will encourage further the development of alternative fuelled vehicles including natural gas and biomethane. At the heart of this is the requirement to reduce tailpipe CO_2 emissions to 95g of CO_2 per kilometre by 2020.

2.2 USA Position

The current USA position is:

- There are about 110,000 NGVs on U.S. roads today
- There are about 1,000 NGV fuelling stations in the U.S.

The American position on NGVs changes rapidly, with new initiatives and developments continuously reported. There are strong incentives to purchase alternative fuelled vehicles in the USA and these extend to natural gas vehicles. The uptake is however occurring mainly for larger vehicles – commercial vans, trucks and buses. Anecdotal evidence suggests that in 10 years time 15% of trucks in the USA could be running on LNG or CNG. The move towards natural gas for fleet vehicles is being stimulated by energy security concerns and a desire to reduce dependence on foreign energy, with new shale gas discoveries giving long-term confidence in the market for natural gas. Emissions regulations set by the EPA and CARB (California Air Resources Board) have also provided incentives to reduce tailpipe emissions. For example 80% of incremental costs can be recovered if CARB limits are met by a vehicle.

Although there are numerous manufacturers that offer factory-built natural gas trucks, vans, transit buses and school buses, there are fewer options for consumers who need light-duty cars, vans and pick-up trucks, however here are indications of a newly emerging market.

Public transportation across the country has been using CNG for decades. Currently, about 12-15% of public transit buses in the U.S. run on natural gas (either CNG or LNG – liquefied natural gas). That number is growing - nearly one in five buses on order today will run on natural gas.

Two significant announcements have served to catalyse OEM production in the USA. In 2009 AT&T announced the purchase of 8000 Ford E series Cargo vans, and an intention to ultimately purchase 15000 alternative fuelled vehicles. AT&T's investment (USD $565 million) represents the largest U.S. corporate commitment to CNG vehicles to date. Telecommunications competitor Verizon also announced its intention to convert 1600 fleet vehicles, mainly Ford 250 vans to CNG. These are two of the largest fleet operators in the USA and their decision is believed to have prompted GM to launch what were the first fully integrated CNG cargo vans.

2.3 UK Position

In the 1990s the UK had a developing network of natural gas filling stations, and an active vehicle conversion programme. As in Europe there was a limited set of OEM vehicles produced specifically for the UK. The UK NGV market effectively died when the Government did not provide the necessary tax incentives on natural gas for transport to allow owners to recoup investment in conversion and infrastructure costs.

The UK natural gas vehicles have continued almost as a cottage industry with operators such as CNG Services and haulage company Hardstaff forging a path which has kept the door open for a resurgence in the market. Hardstaff deserve a particular mention for their support of the large vehicle market. Their filling stations have provided reliable sources of both CNG and LNG and more recently liquid biomethane (LBM) for their fleet of HGVs. Their award winning development of Dual Fuel technology along with Loughborough University puts them in the forefront of this important advance in engine technology which will allow the low cost conversion of standard diesel engines to run on up to 95% natural gas. Along with Clean Air Power, the UK can now boast 2 pioneers of this important technology.

As with Europe, a renewed interest in natural gas vehicles is emerging from the increasing importance of biomethane.

Sheffield City Council is currently conducting a demonstration programme running light vans and other council vehicles on biomethane. The council has signed an agreement to install a temporary filling station, to demonstrate the environmental benefits of biomethane powered vehicles. The biomethane gas filling station and associated delivery equipment are supplied by Chesterfield BioGas, also based in Sheffield. The project is being run in partnership with Chesterfield Biogas, Volkswagen and Mercedes, and is jointly funded by the Area Based Grant and the Alternative Fuels Infrastructure Grant Programme. There is considerable National interest in the outcome of this trial which will give important information on both economic and environmental benefits of biomethane for vehicles.

In July 2008, Gasrec opened the UK's first liquid biomethane plant at Albury, in association with Hardstaff, producing 5000tpa of biomethane, enough for 150 HGVs. The introduction of biomethane and biomethane to grid has been instrumental in kick-starting the growth in NGVs across Europe.

The creation of flagship projects such as that of Sheffield and Albury is important in developing an interest in biomethane. The renewable heating incentive will also encourage grid injection and help to bring the cost down and make projects economical.

However, a number of policy changes need to occur in the UK to enable this market to develop:

- There needs to be a tradable market in Renewable transport fuel certificates (RTFC's)
- The road fuel duty of CBM (compressed biomethane) needs to be reduced (it is currently the same, 23.6 p/kg as for CNG)
- Local authorities should make garden and kitchen waste available for biomethane production
- Ensure no flaring of biogas
- Tailpipe well-to-wheels GHG labelling of vehicles should be commonplace

The entry of a number of OEMs into the UK market is illustration that the market attractiveness is increasing. These vehicles are a mixture of dedicated, bi-fuel and dual fuel vehicles. Also on the horizon are CNG hybrid vehicles which will help to ensure that efficiency improvements for the CNG market keep pace with those for conventional diesel and gasoline.

3. Emissions and Environment

Natural gas vehicles fuelled by conventionally produced gas have an environmental advantage over diesel and petrol. However they will have difficulty competing against highly efficient electric vehicles on pure environmental terms, although the advantage is not insurmountable while electricity is produced from fossil fuels. However, as the proportion of biomethane increases so will the environmental advantage of CNG or compressed biomethane (CBM) vehicles. In fact at 100% biomethane, these vehicles are near carbon neutral. This will not be the case for electric vehicles until 100% of grid electricity is produced from renewable sources.

Exhaust emissions from NGVs are generally much lower than those from gasoline-powered vehicles. For example, the natural gas-powered Honda Civic GX is recognized by the U.S. EPA as the cleanest commercially available, internal-combustion vehicle in the world. The Civic GX is rated by the California Air Resources Board (CARB) as meeting the very stringent AT-PZEV standard. The CNG powered Civic produces 95% fewer emissions of non-methane hydrocarbons, and 75 percent lower emissions of nitrogen oxides than its gasoline counterpart. Dedicated NGVs produce little or no evaporative emissions during fuelling and use. In gasoline vehicles, evaporative and fuelling emissions account for significant portion of the emission associated with operating a vehicle. One concern for NGVs in the past has been methane or unburnt hydrocarbon tailpipe emissions. These have improved dramatically with modern ECU and exhaust catalyst systems.

The actual emission benefits of introducing natural gas vehicles into a fleet will vary depending on the type of NGVs used and whether the emission comparison is based on the emissions of the vehicles being replaced or new motor vehicles. Fleets that replace in-use medium and heavy duty diesel vehicles with new natural gas vehicles will see the most significant reductions in emissions since medium and heavy duty trucks put out much more emissions than light duty vehicles. Replacing a typical older in-use vehicle with a new NGV can provide the following reductions in exhaust emissions:

- Carbon monoxide (CO) reduced by 70 percent – 90 percent
- Non-methane organic gas (NMOG) reduced by 50 – 75 percent
- Nitrogen oxides (NOx) reduced by 75 – 95 percent
- Carbon dioxide (CO_2) reduced by 20 – 30 percent

However, there may be significant variations between exactly similar vehicles, because of the state of maintenance of the vehicle, whatever the fuel.

When considering emissions and environmental impacts, it is important to account for impacts over the whole lifecycle. i.e. emissions arising from vehicle manufacture plus emissions due to extraction, conversion, distribution and use of fuel over the vehicle life. Comparisons often refer to emissions at point of use, which are of course important in terms of local air quality, but can grossly distort the overall impact of a particular technology. As an example, electric vehicles are often referred to as zero emission, referring to their lack of emissions at point of use. However the total environmental impact needs to take into account the power generation mix which produced the electricity, and the construction, recycling and disposal needs of the power train.

Perhaps the best and most comprehensive tool for estimating the emissions impacts of transportation types is the Argonne National Laboratories GREET (Greenhouse gases, Regulated Emissions and Energy use in Transportation) model. GREET enables the analysis of vehicle fuel-cycles, i.e. well-to-wheels (WTW) analysis, for future fuel/vehicle systems. For a given transportation fuel/ vehicle technology combination, GREET calculates the fuel-cycle energy consumption, greenhouse gases (GHGs) emissions and emissions of five pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx) and particulate matter (PM). A simple scenario analysis using current default US based power generation mixes was run and a selection of outputs is presented in the table below:

	Total Energy	CO_2	NOx, total	NOx, urban	PM2.5
Dedicated CNG Vehicle, Normal NG	2.1	-20.3	-18.7	-23.4	-16
LNGV Dedicate Normal NG	5.8	-18.4	1.3	-21.3	-37.2
LPGV Dedicated	-3.5	-14.7	-8.5	-15	-24
Fuel Cell Vehicle NG H2	-36	-49.3	-58.6	-70	44
Fuel Cell Vehicle CNG	-34.5	-48.8	-65	-82	-52
Grid Independent Hybrid CNG*	-31	-45	-38	-37	-29
Electric Vehicle	-30.7	-29.1	-8	-54	261

* if running on 50% biomethane the CO_2 reduction could be over 70%

Note there is no allowance made for the impact of biomethane on lifecycle emissions of CO_2 in the above table. It should also be borne in mind that US power generation is more coal dependent. However, the first of these factors would significantly improve the relative emissions case for CNG when a UK scenario is input. Interestingly the best future options in terms of overall emissions and air quality appear to be for CNG derived fuel cell vehicles, indicating a possible long term future for gas distribution in a hydrogen future. The electric vehicle types seem to benefit in terms of total energy relative to CNG vehicles. However this should not be a concern. The important factors are the source of the energy and the availability of an infrastructure to deliver it to the point of use. This already exists for gas and will still need to be built for grid-connected electric vehicles. Note the lifecycle PM2.5 increase for electric vehicles reflects the increase in power generation requirements using a current fuel mix scenario.

A study by MIT on a variety of future engines and fuels looked at life cycle aspects of greenhouse gas emissions against an evolved baseline 2020 ICE. The conclusion from the MIT study is that NGVs are shown potentially to have the lowest GHG emissions for the future vehicles examined. However this assumes that CNG is derived from fossil sources rather than a biomethane – fossil fuel mix, which would further improve the position for NGVs.

A recent technology development can be used to illustrate some of the emissions reduction potential already being realised. Dual fuel technology is now being increasingly used in trucks on both sides of the Atlantic, allowing low-cost conversions of diesel trucks to low-cost natural gas. The potential CO_2 savings using conventional natural gas can be seen in the table below. If biomethane is substituted for conventional CNG these numbers increase significantly. Further analysis of this scenario is also recommended.

Substitution Rate %	CO_2 reduction%	Saving per vehicle per Year (Kg)
50%	13.75%	16315
60%	16.42%	19483
70%	19.17%	22746
80%	21.92%	26009
85%	23.33%	27682
90%	24.67%	29272

Dual Fuel Technology CO_2 per mile travelling for Diesel Gasoline NGV for Truck Van Passenger vehicle. CO_2 per year.[1] Long Haul Vehicle: based on 75,000 miles per year and 7.5mpg

4. Infrastructure

Fuelling Station economics are complex and are highly dependent on a number of factors including vehicle type and driving patterns, station throughput, fuelling window, maintenance costs and gas and electricity prices. There will also be a different economic case for CNG and LCNG derived fuelling.

The installed cost of equipment needed to establish a fast fill station, including compressor, priority panel and cylinder cascade, dispensers and fuel management fuelling station supplying of the order of 1000cum/hr is typically of the order of $500,000. Assuming 12 hour operation, this would supply of the order of 360,000cum/month, or around 90,000 diesel gallon equivalents, sufficient to service around 100 HGV. In theory this would service around 1000 commercial vehicles or 3000 cars at full utilisation, but in reality filling station logistics would prevent such a throughput. An option for smaller fleets is a lower cost slow fill station. Maintenance costs of a CNG station are estimated to be of the order of 5% of the upfront costs of a large station, or 8% of the upfront costs of a small station.

LNG derived stations are similar in magnitude of cost, where LNG is shipped to an on station storage facility Considerable research in underway in the USA to develop fuel flexible LNG/CNG integrated stations. Hardstaff in the UK operate a filling station with both LNG and CNG options.

The current move towards LNG for HGVs in the USA and in the UK provides another opportunity for distributed production of LNG. The concept of using turbo-expanders and cold energy at pressure reduction stations is well known and there are products on the market which provide such small-scale liquefaction. Use of expansion energy which is currently wasted could contribute further to carbon reduction targets.

An analysis by CNG services in the UK on fuelling station economics has shown that fleets can be highly competitive assuming station throughput targets are met. Once the annual fixed costs are recovered, the running cost of a CNG van is estimated to be around 5 p/km. Prior to this point costs are 8.5 p/km. In simple comparative terms, as infrastructure costs are built into the fuel price for diesel, and assuming 30 miles per gallon and a price of £6.00/gallon, the cost per km for a diesel van is about 15p.

Home fill technology has been available since 2005 in the USA and Europe and involves installation of a small slow-fill compression unit which can typically be run overnight. Costs are typically of the order of £2000, but a separate meter would also be needed as different taxation rates are likely to be in force for gas for transport use.

The tables on the following page illustrate firstly the total fuel consumption and CO_2 savings which can be expected from conversion to natural gas vehicles in the UK and secondly an analysis of a simple scenario in which take up is limited to a significant proportion of HGV and commercial vehicles and a much smaller passenger vehicle market penetration. This is not an unreasonable scenario. In fact with the right combination of circumstances it might be a pessimistic one.

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[1] Note: 1 litre of diesel emits 2.61kg CO_2

Vehicle Type	Miles pa / vehicle	Efficiency Mpg	Annual consumption gallons	CO_2 saved tonne/ vehicle	CO_2 saved per mile, kg	vehicles total, UK	total miles (millions)	Total fuel Mgallons	Fraction of total vehicles	CO_2 saved tonnes pa
Heavy duty dual Fuel	75000	7.5	10000	30.0	0.4000	400000	30000	4000	0.24	12,000,000
Commercial Vehicle large	30000	20	1500	4.5	0.1500	1000000	30000	1500	0.09	4,500,000
Commercial Vehicle (small)	20000	28	714	2.1	0.1071	1000000	20000	714	0.04	2,142,857
Car (diesel)	12000	40	300	0.9	0.0750	5000000	60000	1500	0.09	4,500,000
Car (petrol)	12000	35	343	1.0	0.0857	26000000	312000	8914	0.54	26,742,857
Electric car (SMART)	10000			0.5	.05					

Table: Comparison of CO_2 savings from different vehicle types assuming diesel and petrol are replaced by Natural gas**. Note: If biomethane is used, CO_2 savings will be greatly enhanced**.

Vehicle Type	NGV uptake percent	CO_2 saving tonnes pa	number of vehicles	vehicles / station	Number stations	station investment	tonnes CO_2 pa /£	tonnes CO_2 over 5 years/£	cost per tonne of CO_2 saved	Gas Demand Mcm gas
Heavy duty dual Fuel	50.00%	6,000,000	200000	100	2000	400,000,000	0.0150	0.075	13.33	9000
Commercial Vehicle large	50.00%	2,250,000	500000	250	2000	400,000,000	0.0056	0.028	35.56	3375
Commercial Vehicle (small)	30.00%	642,857	300000	500	600	120,000,000	0.0054	0.026	37.33	964
Car (diesel)	5.00%	225,000	250000	1000	250	50,000,000	0.0045	0.0225	44.44	338
Car (petrol)	5.00%	1,337,143	1300000	1000	1300	260,000,000	0.0051	0.025	38.89	1805
Electric		2.5				5000	0.0005	0.0025	400.00	

Table : High Level analysis of infrastructure costs. Note CO_2 savings are only assumed for first 5 years. In each case this should be amortised over life time of investment with realistic depreciation rates etc, but the comparison is intended as a simple one to be viewed in relative terms.

5. Roadmap to the future

An electric future scenario which extends not just to vehicles but to the zero carbon home would ultimately result in a removal of the need for both gas transmission and distribution in the UK. However investment costs in such a future are immense. To transfer all vehicle and heating use in the UK to electric would require a complete rebuild of the electricity infrastructure, in order to triple its capacity. If gas distribution were to disappear any hope of distributed generation would also be removed other than from renewably derived electricity (solar, wind, hydrogen). The potential for the use of biomethane contributing to UK emissions reduction would also disappear.

Analysis has already shown that lifecycle CO_2 emissions from NGVs can be lower than EVS. In the UK the increasing potential of biomethane will reduce lifecycle emissions further. The renewable heating incentive (RHI) is greatly encouraging the use of biomethane as its use in gas grid derived heat greatly exceeds the efficiency of its use in power generation.

The simple scenario presented in section 4 shows that if a 50% uptake of HGVs and commercial vehicles is assumed, a total gas demand of around 15-16bcm per annum can be supported. It also appears that this can be achieved at lower investment costs per vehicle. Indeed in terms of investment per tonne of CO_2 saved it would appear that natural gas vehicles are over an order of magnitude lower in cost. This is not a unique analysis. The UK Government decision to subsidise SMART EVs to the extent of £5000 per vehicle for 2.5 tonnes of CO_2 saving over 5 years, can be compared to subsidising a dual fuel HGV to the extent of £390,000 for an equivalent saving, even ignoring infrastructure costs associated with EVs.

There has been a rapid move to NGV use for heavy fuel intensive vehicles in the USA, whether CNG or LNG derived. This is likely to continue and an uptake of over 15% is expected even over the coming decade. This probably provides the best opportunity for NGVs in the UK too. HGVs are a good initial target for a variety of reasons:

- An infrastructure of sorts already exists with a few pioneering operators demonstrating the economic benefits
- The range of a HGV on CNG (dual fuel with diesel backup) is not compromised.
- EVs are a very unlikely scenario for HGVs – batteries are heavy and bulky and are likely to take up valuable payload. They are also slow to recharge or to change out – haulage logistics would suffer significantly.

Additionally fleet vehicle economics, particularly with biomethane under a renewable transport fuel obligation, are currently being proven.

The concept of a future hydrogen economy has been extensively discussed as a route to a fully decarbonised economy. Although in the very long term renewable production of hydrogen is the only way to fully decarbonise the economy, there are a number of reasons why NGVs will support the route to a decarbonised economy. These alone could be a justification for a move to NGVs as a bridge to this point:

- Hydrogen is currently produced by reforming of natural gas and other hydrocarbons. Compact reformers which can be scaled according to production demand are a highly efficient way of producing hydrogen at the distributed level, removing the need for expensive transportation of hydrogen.
- If hydrogen is produced from biomethane and CO_2 sequestration is employed, the hydrogen production can be carbon negative, i.e. significantly better than hydrogen production from renewables with subsequent hydrogen transportation.
- Using a gas grid, hydrogen can be produced at point of use. Without a gas grid transporting natural gas or biomethane, the hydrogen economy becomes much less likely.
- Honda's cutting edge GX Civic NG has formed the basis of the design for their production fuel cell vehicle the FCX. Honda have also pioneered the concept of the home energy hub, based on home reforming of natural gas, producing hydrogen for both power generation and vehicle refuelling.

A complete move to electric vehicles along with a decay in local distributed demand for gas in the UK will ultimately preclude the distributed hydrogen economy.

The level of load which even a partial uptake scenario, using trucks and commercial vehicles will support could bolster the threat to gas, particularly if a roadmap is clearly defined to show how this strategy can support the UK energy economy to 2050 and beyond. A gas demand for transport of 15bcm for the scenario in Section 4 is of the order of 25% of current gas distribution in the UK. If further uptake and technology advances allow a wider vehicle base, this could increase. It is not unrealistic for example that all trucks could ultimately depend on natural gas as a fuel.

Another technology development which provides the opportunity for further decarbonisation and reduced grid investment cost is Adsorbed Natural Gas (ANG). In the past year new adsorbent materials have appeared on the market, which although currently expensive allow an effective doubling in the fast fill capacity over the carbon adsorbent technology which has been in development previously. If vehicles can be filled at 50 bar, this allows the direct use of pressure in the pipeline system doing away with the need of any gas compression. This technology advance potentially allows the capture of a greater market share of smaller vehicles as it allows on-vehicle storage in flat tanks which does not take up load space, unlike the CNG cylinders of past and current conversion programmes.

6. Conclusions

There are a number of opportunities for NGVs to make a mark in the UK. With the huge potential for biomethane and the declared intent of a future distributed electric economy, removing the need for gas transmission and distribution will hinder the potential of future DCHP and renewable distributed heat and power. NGVs are one way of protecting the UK energy network against such a threat.

The cost per tonne of carbon reduction through NGV uptake, particularly where biomethane forms part of the scenario, is substantially less than that for electric vehicles.

HGVs running on LCNG and LNG are already demonstrating the potential for NGVs. The encouragement of NGV uptake in the transport infrastructure of the UK will not only help to decarbonise the UK economy in the short term, but also provide a long term route to a hydrogen economy which will be lost if electrification continues to be the primary solution.