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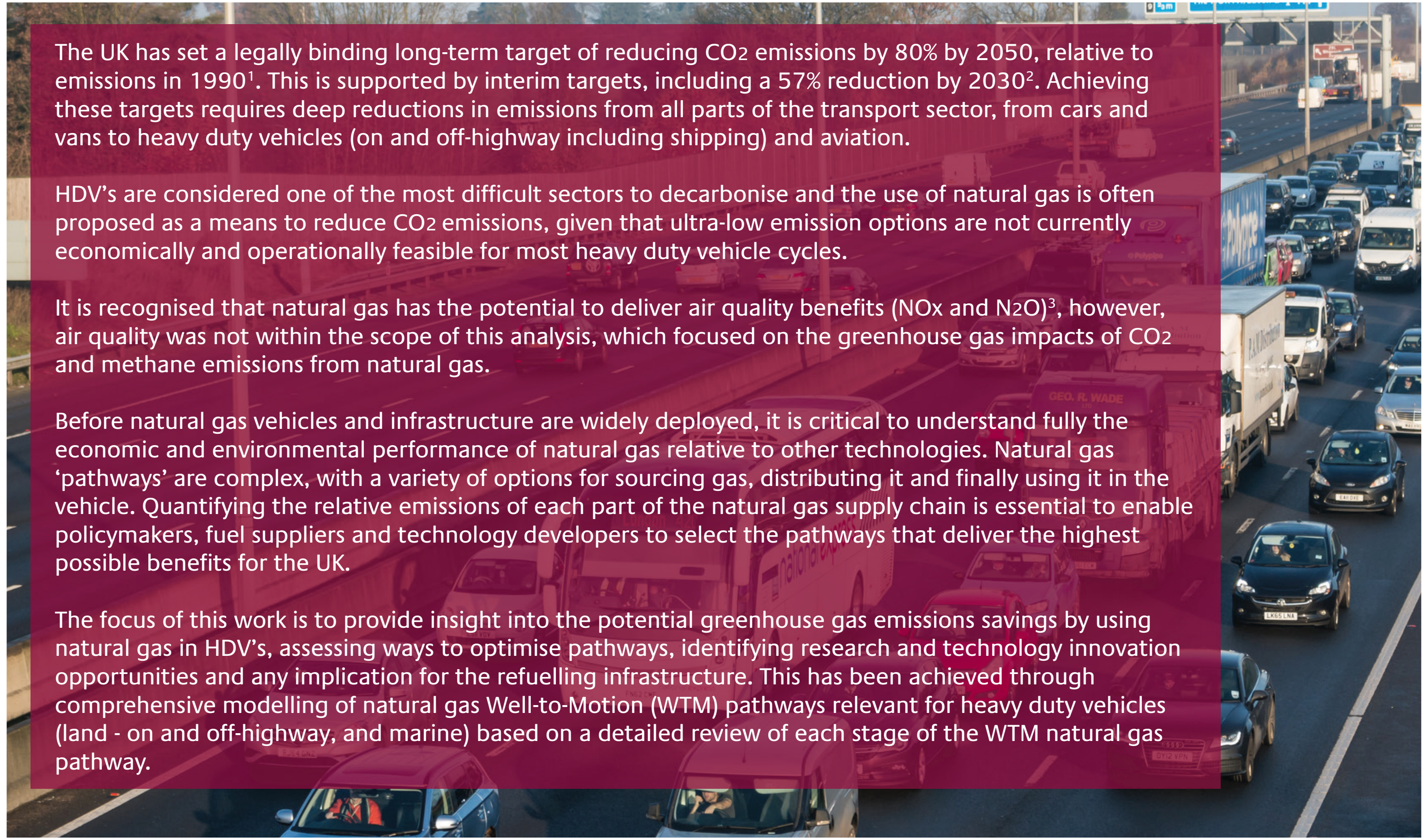
An ETI Perspective

Natural Gas Pathway Analysis for Heavy Duty Vehicles

ETI 10 TEN YEARS OF INNOVATION 2007 — 2017

INTRODUCTION



The UK has set a legally binding long-term target of reducing CO_2 emissions by 80% by 2050, relative to emissions in 1990[1]. This is supported by interim targets, including a 57% reduction by 2030[2]. Achieving these targets requires deep reductions in emissions from all parts of the transport sector, from cars and vans to heavy duty vehicles (on and off-highway including shipping) and aviation.

HDV's are considered one of the most difficult sectors to decarbonise and the use of natural gas is often proposed as a means to reduce CO_2 emissions, given that ultra-low emission options are not currently economically and operationally feasible for most heavy duty vehicle cycles.

It is recognised that natural gas has the potential to deliver air quality benefits (NOx and N_2O)[3], however, air quality was not within the scope of this analysis, which focused on the greenhouse gas impacts of CO_2 and methane emissions from natural gas.

Before natural gas vehicles and infrastructure are widely deployed, it is critical to understand fully the economic and environmental performance of natural gas relative to other technologies. Natural gas 'pathways' are complex, with a variety of options for sourcing gas, distributing it and finally using it in the vehicle. Quantifying the relative emissions of each part of the natural gas supply chain is essential to enable policymakers, fuel suppliers and technology developers to select the pathways that deliver the highest possible benefits for the UK.

The focus of this work is to provide insight into the potential greenhouse gas emissions savings by using natural gas in HDV's, assessing ways to optimise pathways, identifying research and technology innovation opportunities and any implication for the refuelling infrastructure. This has been achieved through comprehensive modelling of natural gas Well-to-Motion (WTM) pathways relevant for heavy duty vehicles (land - on and off-highway, and marine) based on a detailed review of each stage of the WTM natural gas pathway.

KEY FINDINGS

- Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG) have the potential to reduce Greenhouse Gas (GHG) emissions over the well-to-motion pathway by 13% (LNG) - 20%(CNG) for dedicated engines and 16% (LNG) - 24%(CNG) for High Pressure Direct Injection engines per vehicle in the 2035 timeframe in comparison to the reference baseline diesel pathway.
- Cycle specific powertrain technology selection and pathway optimisation are key to providing GHG emission benefits over given usage cycles, with High Pressure Direct Injection and Dedicated gas engines providing the highest benefit.
- Retrofit dual fuel engines have been shown to have high methane emissions, often being worse than baseline diesel powertrains on a GHG emission basis. Effective testing procedures and legislative certainty are required to ensure emissions conformity and facilitate market development.
- Providing methane catalysis at real world operating temperatures, i.e. below 350°C, is essential to prevent uncombusted methane making its way out of the tailpipe in powertrains that cannot control methane slip and is a key technology that enables a pathway benefit.
- Employing 'best practices' at LNG, CNG and L-CNG stations is a key driver to providing pathway benefits. Vapour recovery systems should be implemented at all LNG stations and the economic proposition and expected utilisation should be aligned. CNG stations should be connected to the highest pressure tier of the grid where possible or employed in combination with a L-CNG station as an easy step to reduce emissions associated with compression, at least until the carbon intensity of the grid is significantly lower than today.
- The economic proposition for natural gas in the HGV fleet hinges upon the fuel duty differential and currently only the long haul segment is economic in the near term. Fuel duty tax stability is key to enable market confidence to invest in natural gas vehicles and the necessary supporting infrastructure.

1 Parliament of the United Kingdom, "Climate Change Act 2008," HM Gov., 2008.
2 Committee on Climate Change, "The Fifth Carbon Budget: The next step towards a low-carbon economy," no. November, 2015.
3 Brian Robinson, "Emissions Testing of Gas-Powered Commercial Vehicles", LowCVP, January 2017.

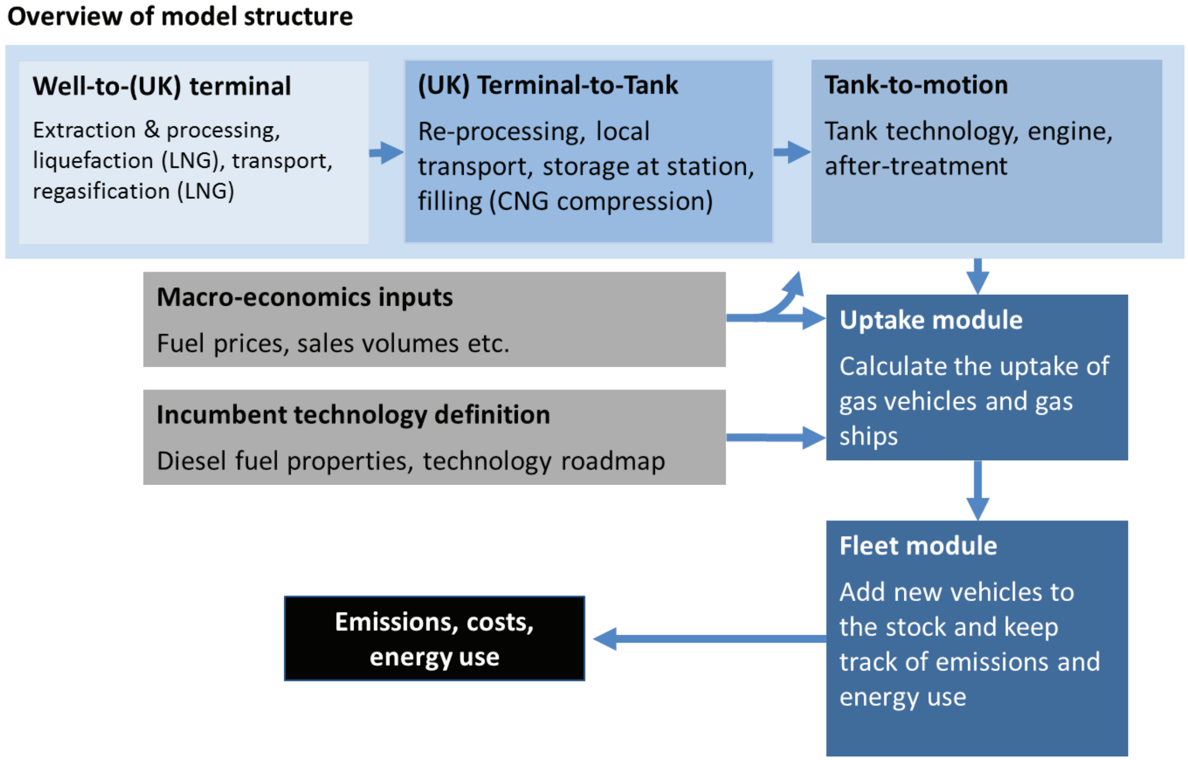
MODELLING METHODOLOGY

The modelled pathway stages are shown in Figure 1.

In modelling the possible technology options and associated emissions in the gas pathway, the analysis was structured into three scenarios (base case, worst case and best case), involving coherent sets of assumptions that define emissions at all stages. The use of three different scenarios reflects the ranges in operational parameters and uncertainties associated with the emissions at each individual stage of the Well-to-Motion pathways. Alternative scenarios are also used to analyse special cases, such as the impact of fuel duty on the economics of gas vehicles.

The base case scenario represents the central trajectory of the natural gas market based on current trends and expected future evolution in the sector and has been developed as a result of an extensive literature review and consultation with industry stakeholders. The worst case and the best case scenarios aim to establish the realistic upper and lower thresholds for Well-to-Motion emissions.

Figure 1 - Overview of the Well-to-Motion model

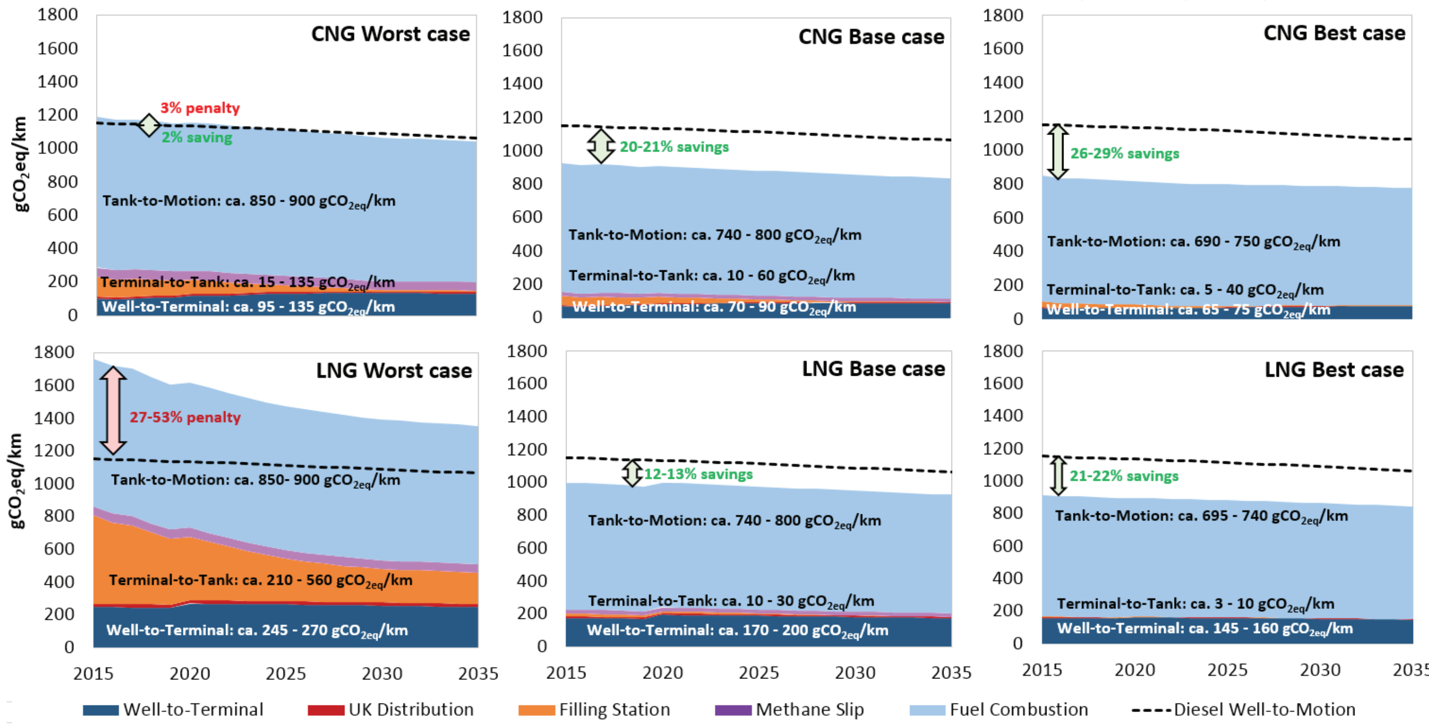


The total Well-to-Motion emissions savings from using natural gas depend on the source of gas, the powertrain technology and the duty cycle. Taking a dedicated natural gas long haul HGV as an example, the LNG pathway can achieve 12-13% emissions savings on a Well-to-Motion basis in the base case. A small increase in the LNG pathway emissions in 2020 marks the expected start of LNG imports from the USA with higher Well-to-Terminal emissions. There is uncertainty associated with the start of US LNG imports, with recent industry trends suggesting that imports may start before 2020. However, as the natural gas HDV uptake is expected to remain relatively low until 2020, this uncertainty will not translate into a significant difference in total emissions.

The CNG pathway offers somewhat higher emissions savings in the base case due to the lower Well-to-Terminal emissions. These are almost completely offset by the higher Terminal-to-Tank emissions in 2015 for stations connected to the medium pressure tier of the natural gas grid. However connecting to the the LTS (high pressure Local Transmission System) grid offers a significant benefit due to reduced compression energy required. In addition, the Terminal-to-Tank emissions decrease significantly towards 2035 as the UK electricity grid is decarbonised, yielding between 20-21% Well-to-Motion emissions savings in the CNG pathway for a dedicated natural gas long haul HGV. The total Well-to-Motion savings in the LNG and CNG pathways in each of the modelled cases are shown in Figure 2 for a dedicated natural gas HGV on a long haul duty cycle.

In the worst case scenario, an LNG dedicated natural gas long haul HGV may cause 27-53% higher Well-to-Motion emissions compared to an equivalent diesel HGV. This is mostly due to high use of liquid nitrogen in an underutilised station, venting of boil-off from the HDV tank before each refill and high methane slip from gas engines. However, some of this can be avoided relatively easily if station designs include vapour recovery and stations are only installed in areas with sufficiently high LNG demand. For CNG pathways, the worst case scenario emissions are never more than 3% higher relative to diesel. The emissions component with the highest uncertainty is the efficiency loss compared to a diesel counterpart. However, no data is currently available for the latest generation OEM offerings which are expected to be much better compared to the current generation of dedicated gas HGV's. Dual fuel HPDI (High Pressure Direct Injection) variants are also expected to provide significant improvements in efficiency, and these have the potential to have no efficiency losses compared to their diesel counterparts.

Figure 2 - Comparison of the total WTM emissions for an LNG and a CNG long haul vehicle with a dedicated natural gas engine in all scenarios



FLEET OVERVIEW

Business Case

Analysis of the business case for natural gas HDVs highlights several use cases which are commercially attractive to fleet operators. In 2020, long haul and distribution fleet operators using dedicated natural gas HDV are expected to repay the purchase price premium for natural gas HDVs after a single year of operations due to the running cost saving. This is assuming the diesel/gas price spreads based on DECC Fossil Fuel Price Assumptions (2015)[4] remain. Currently, the payback period is somewhat higher at 2-2.5 years because of low utilisation rates of CNG stations leading to a lower natural gas discount relative to diesel, i.e. the spread between the price of CNG and diesel at the filling stations is likely to increase when the turnover rate of the CNG stations reaches optimal level (close to 75%). Furthermore, low diesel prices and relatively high efficiency losses from natural gas trucks operating on 'unoptimised' duty cycles also contribute to the current longer payback periods.

Although running cost savings are lower in other on-road HDVs segments, dedicated trucks were found to be economically feasible in all segments in 2020. The business case is least compelling for dual fuel trucks, particularly those with low diesel substitution ratios (i.e. vehicles where natural gas only replaces a proportion of the diesel fuel).

The business case for natural gas on-road HDVs depends strongly on the current fuel duty differential between natural gas and diesel road fuels. Removing the fuel duty differential is likely to significantly reduce the attractiveness of natural gas to fleet operators making dual fuel vehicles economically uncompetitive in all segments. Dedicated trucks would be economically viable only in the long haul segment, as this is the only segment with annual mileages sufficiently high to repay the purchase price premium through fuel savings alone. Linking fuel duty to the CO_2 content of the fuel could be an alternative approach when the scale of vehicle deployments no longer justifies the current differential. This could help reduce forgone tax revenues from gas vehicles, while still providing attractive economics to fleet operators to encourage continued deployment. However, a period of fuel duty tax certainty will be required for fleet and fuel station owners to make the necessary capital investments

4 Department of Energy & Climate Change, "DECC 2015 Fossil Fuel Price Assumptions," no. November, p. 23, 2015.

Fleet Emissions

The underlying reasons for emissions savings (whether positive or negative) across the entire fleet are the same as for an individual HDV but savings at a fleet level also depend on the future sales of natural gas HDVs and hence the speed with which they replace diesel vehicles in the fleet. Land HDV fleet emissions are shown in Figure 3. The ranges shown are derived by varying assumptions about the share of fleet operators that consider natural gas options for their fleets and are therefore included in the choice model. The "No natural gas" scenario assumes the use of diesel with the average biofuel blend and greenhouse gas content as defined by DECC UK Government GHG Conversion Factors for Company Reporting (2016)[5]. Emission savings in the best case scenario can reach 8% on a fleet level without further incentives being applied. On the other hand, the worst performing pathways lead to marginally higher emissions compared to the diesel HDV fleet. This is the result of emissions increases in the LNG pathways in this scenario due to poor environmental practices, which can be easily avoided with high quality refuelling infrastructure and low methane slip vehicles.

In all principal scenarios, the fleet penetration of natural gas HDVs is in the range of 15-37% by 2035, based on a comparison of ownership costs between gas and diesel vehicles.

5 Department of Energy & Climate Change, "UK Government GHG Conversion Factors for Company Reporting." 2016.

Fleet Emissions

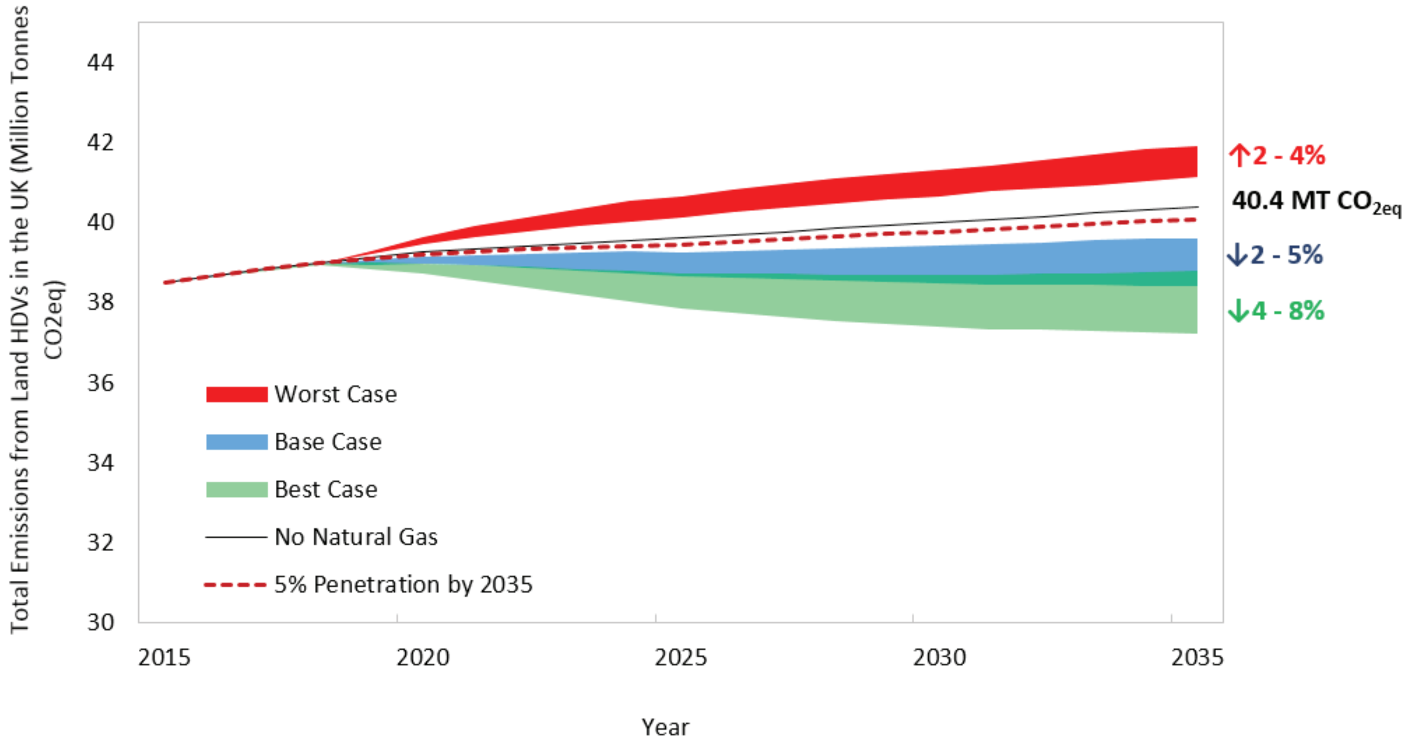
The current refuelling infrastructure, i.e. the number of filling stations in the UK, would be able to sustain a number of vehicles equivalent to roughly 5% of trucks in the UK. This suggests that major investments in infrastructure are required to support the uptake of natural gas HDVs in the principal scenarios, with up to 300 new stations being required by 2035[6]. The majority of these investments can be funded by refuelling station operators, since these stations are profitable given sufficient gas demand from the vehicles they serve. Equally, a thorough optimisation of natural gas pathways is required to achieve the top of the identified emissions savings ranges. Specifically, this should encompass best practices during natural gas extraction and processing, decarbonisation of the UK electricity production, prevention of methane slip and production of highly efficient natural gas engines.

Even with fully optimised pathways, the fleet-level savings are noticeably lower than savings presented in Figure 2 on a single vehicle level. The fleet-level savings are lower partly because uptake of natural gas land HDVs is limited to 37%[7] of the total land HDV fleet and also because some of the land HDV powertrains (e.g. dual fuel) offer lower savings compared to the dedicated trucks used as the example in Figure 2.

6 The number of the required stations is calculated based on the natural gas consumption of the entire land HDV fleet assuming the natural gas vehicle uptake in the base case and the station dispensing capacities of three different types of fuel station.

7 This is the upper limit for the fleet share of Natural Gas land HDVs in 2035 according to the uptake model calculations based on the economic inputs. Higher penetration within this timeframe is possible in theory, but is not realistic based on the analysis of the economic proposition of natural gas vehicles.

Figure 3 - Emissions from the entire UK fleet of land HDVs (on-road, off-road, buses), including both natural gas and diesel solutions in the principal scenarios.



RESEARCH AND TECHNOLOGY NEEDS

Methane slip reduction remains an important development area for natural gas HDVs, and is more relevant to dual fuel and lean burn dedicated variants than stoichiometric dedicated versions. Evidence from the Low Carbon Truck Trial[8] suggests that dual fuel trucks, which are Medium Pressure Sequential Injection retrofit solutions, are up to 25 times over the Euro VI requirement for methane tailpipe emissions. More controlled, higher pressure direct injection would likely lead to less methane slip from the combustion chamber, but this remains a challenge that OEMs need to overcome. Optimisation of the fuel injection timing and the cylinder pressure may also help reduce methane slip, but an efficient low temperature catalyst is required to meet EURO VI standards at cold start (temperatures below 350°C). New low temperature methane catalysts are particularly required for dual fuel land vehicles and for ships, whose engine exhaust temperatures may never reach the optimum operational temperatures for current catalyst systems over the duty cycle they operate, especially in dual fuel operation.

In addition to new technologies for reducing methane slip, robust testing procedures for N_2O emissions are required. N_2O may be emitted in very small quantities from the Selective Catalytic Reduction systems of diesel vehicles, but can significantly increase GHG emissions due to its very high GWP_{100} of 298[9]. This is of particular importance to the High Pressure Direct Injection dual fuel variants that will still require SCR systems. N_2O is generated from the aftertreatment system when SCR catalysts are used to reduce the NOx tailpipe emissions, and is particularly evident in warm cycles rather than in cold cycles. The type of SCR catalyst used also has an effect, N_2O can be expected to contribute up to 10% of overall GHG emissions in a copper SCR system and half this for a Vanadium system. However, this is very much dependant on engine and aftertreatment configuration and this should serve as an example of an oversized high conversion efficiency system; these values would be less in systems that utilise Exhaust Gas Recirculation[10].

8 Brian Robinson, "Emissions Testing of Gas-Powered Commercial Vehicles", LowCVP, January 2017.
9 IPCC, Climate change 2007 - The Physical science basis. 2007.
10 http://www.erc.wisc.edu/documents/symp17/2017_Cat_Paulson.pdf
11 LowCVP, "HGV accreditation scheme," 2016. [Online]. Available: http://www.lowcvp.org.uk/projects/commercial-vehicle-working-group/hgv-accreditation-scheme.htm. [Accessed: 23-Aug-2016].

No dual fuel solutions that meet EURO VI emission requirements are currently available. In the case of dual fuel conversions, the testing procedures for recertifying retrofitted vehicles are also not in place. This means that currently it is not possible to determine whether converted diesel EURO VI HGVs meet EURO VI requirements for natural gas HDVs or not. Thus, legislative certainty in this area is desirable to facilitate the dual fuel HDV market development, and avoid a situation where high methane emissions from converted engines negatively impact the perception of natural gas vehicles overall. The first step towards this has already been taken by introducing an accreditation scheme for aftermarket technologies[11]. The scheme introduces the process for testing the emissions of retrofitted systems under realistic HGV operating scenarios.

The suitability of engine technology in each segment very much depends on the operating cycle. More transient cycles, such as the bus or municipal HGV suit dedicated or higher pressure direct injection dual fuel engines. Fuel consumption, substitution ratio and efficiency losses are also heavily dependent upon the types of cycle the vehicle is operated over and is something which is required to be drawn out in more detailed pieces of work to identify specific segment needs.

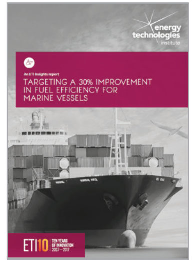
IMPLICATIONS FOR THE UK ENERGY SYSTEM

The expected fleet emissions savings from natural gas vehicles of 2-5% by 2035 in the base case are not sufficient on their own to deliver the deep reductions to meet carbon budgets/climate goals for the UK. Thus, substantial efficiency improvements in Internal Combustion Engine HGVs are required alongside any fuel switching. At the same time electric powertrains could offer substantially higher savings in duty cycles for which they are suitable e.g. busses and urban deliveries. This accounts for a large number of vehicles but a small amount of the overall sector CO_2 emissions but could be adopted due to individual city legislation limits on air quality.

The choice between using natural gas as a bridge technology versus placing greater focus on vehicle/logistical efficiency and ultra-low emission solutions depends on the level of greenhouse gas savings to be achieved. In that context, natural gas offers a useful additional CO_2 reduction measure for vehicles where zero emissions solutions are not yet viable (such as in large, long haul HGVs). In addition, the fact that natural gas infrastructure is profitable, given sufficient utilisation, means that the rollout of natural gas vehicles is not dependent on large amounts of additional public support (aside from maintaining the duty differential). This reduces the risk to policymakers associated with having to effectively choose between natural gas and other GHG emission reduction options, since natural gas vehicle deployment can be led by the private sector. Instead of large-scale financial support, the role of policymakers and regulators should be to ensure fuel duty stability and that vehicles and refuelling stations meet high environmental standards. This would enable overall GHG emissions savings towards the upper end of the ranges shown in this study.

FURTHER READING

ETI publications can all be accessed on the ETI's website: www.eti.co.uk



Targeting a 30% improvement in fuel efficiency for marine vessels

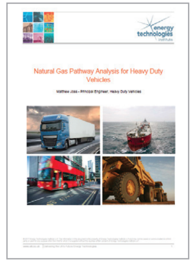
http://www.eti.co.uk/insights/targeting-a-30-improvement-in-fuel-efficiency-for-marine-vessels

An affordable transition to sustainable and secure energy from light vehicles in the UK

https://d2umxnkyjne36n.cloudfront.net/insightReports/2920_Transport_Report.pdf?mtime=20161111094039

Options Choices Actions - UK scenarios for a low carbon energy system

http://www.eti.co.uk/insights/options-choices-actions-uk-scenarios-for-a-low-carbon-energy-system



Natural Gas Pathway Analysis for Heavy Duty Vehicles

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