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A review of prospects for natural gas as a fuel in road transport

1. Introduction and background

The Oxford Institute for Energy Studies (OIES) has published two papers in the last twelve months on the demand outlook for LNG as a marine fuel (Le Fevre, 2018, Sharples, 2019). This paper is a follow-up focussing on road transport for both LNG and CNG which also builds on a 2014 study (Le Fevre, 2014) on the prospects for gas in the European transportation sector. The 2014 paper concluded that, whilst prospects for gas were most promising in the marine sector, growing concern over air pollution from diesel road vehicles was giving added impetus to land based applications, although both the obstacles and range of alternative fuels were greater.

This paper will focus on the road transport sector[1] and seeks to meet the following objectives:

- To summarise the main commercial and environmental factors underpinning the case for natural gas in road transportation. This will include an assessment of the potential impact of biomethane.
- To assess the present and possible future dimensions of the market for natural gas as a road transport fuel globally and in key regional/national markets.
- To examine the role of Government initiatives in encouraging the purchase and use of CNG/LNG fuelled vehicles.

Whilst the outlook for gas in land-based transportation may look less promising than in the marine sector, there are nevertheless some countries where natural gas vehicles (NGVs) have a significant presence. This is most notable in China but also in other countries such as Iran, India and Italy. The research will include a case study of the latter to identify some of the key factors that might be needed in order to develop a market in this area.

The report is structured as follows.

1. Introduction and background to the issue
2. Analysis of global levels of natural gas fuelled vehicles and fuel usage
3. Summary of the main advantages and challenges facing gas as a road transport fuel
4. The potential role for renewable methane
5. The global outlook and beyond
6. Italy Case Study
7. Conclusions

[1] There are some limited prospects in the rail sector though the volumes are not likely to be material.

Energy Insight: 50

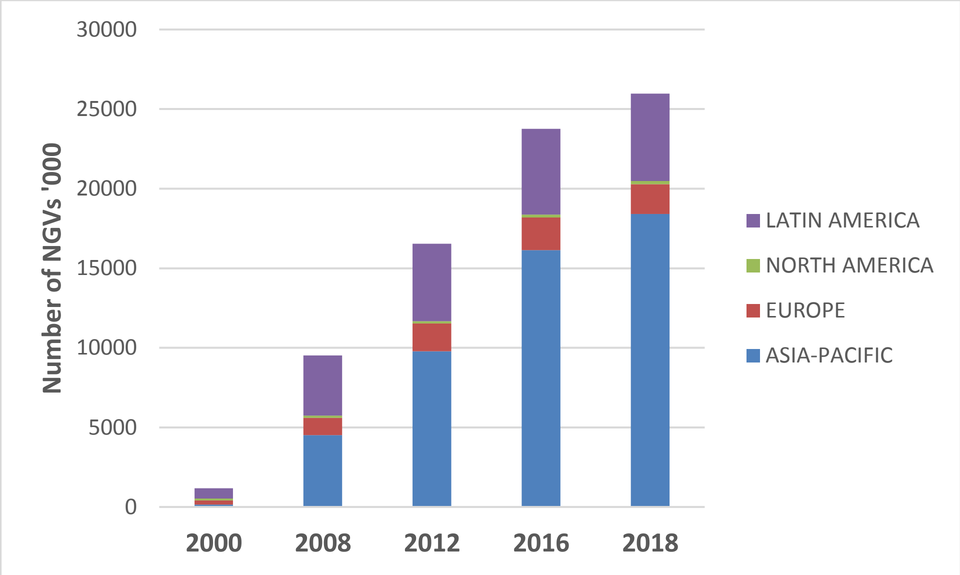
Chris Le Fevre

2. Analysis of global levels of natural gas fuelled vehicles and fuel usage

Natural gas vehicles (NGVs) are defined by NGV Global (formerly the International Association for Natural Gas Vehicles) as all land-based motor vehicles, from two wheelers through to off-road. It includes original equipment manufacturers' (OEM) vehicles, factory-approved conversions and post-sale conversions. Fuels used include compressed natural gas (CNG), liquefied natural gas (LNG) and biomethane or renewable natural gas (RNG) which can be in gaseous or liquid form. Comprehensive statistics on the population of gas fuelled vehicles are provided by NGV Global which estimates that, in 2018,[2] there were around 26 million NGVs operating worldwide though, as discussed below, the consistency of some of the numbers is open to question. This section analyses this information to provide an overview of the main locations for NGVs in both absolute and relative terms. Some limited time series data is also examined.

Figure 1 shows the evolution of the global NGV population over the period 2000 to 2018. It is clear that the sector has grown significantly, and this has been most noticeable in the Asia-Pacific region and, to a lesser degree, Latin America. Over the period 2005 to 2017 the proportion of NGVs in the total vehicle population has increased from approximately 0.5 per cent to 1.5 per cent.[3]

Figure 1: Global NGV numbers by region, 2000 to 2018

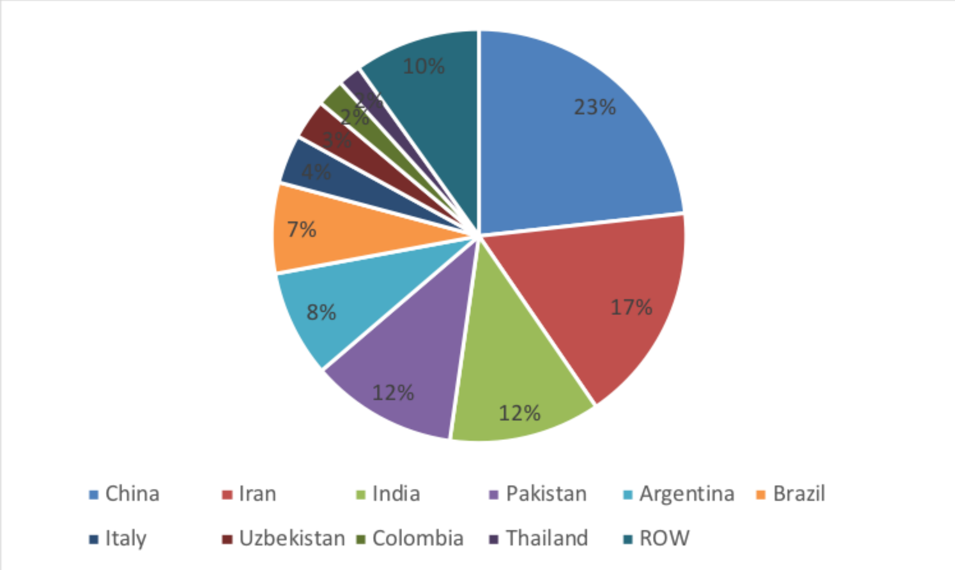


Source: NGV Global http://www.iangv.org/current-ngv-stats/

Figure 2 and Table 1 show the distribution of NGVs by country in 2018. It is noticeable that just six countries account for nearly 80 per cent of the total vehicle population with the top three, China, Iran and India accounting for over 50 per cent. Table 2 also shows the proportion of NGVs in each country demonstrating a wide range in penetration. The highest levels are in Uzbekistan and Iran.[4]

[2] The currency of data for each country varies, in most cases numbers are for the years 2016 to 2018.
[3] This is an approximation based on global fleet numbers provided by the International Organization of Motor Vehicle Manufacturers, OICA. http://www.oica.net/category/vehicles-in-use/ and NGV Global.
[4] Armenia has an even higher level of saturation at 69 per cent though the total number of NGVs is only 300,000.

Figure 2: NGVs by country, 2018.



Source: IANGV

Table 2: Main NGV countries, 2018

Country	Number of NGVs	NGVs as % of total vehicle population	NGVs as % of total NGV pop.
China	6,080,000	3.7%	23.2%
Iran	4,502,000	31.9%	17.2%
India	3,090,139	1.5%	11.8%
Pakistan	3,000,000	14.0%	11.5%
Argentina	2,185,000	9.5%	8.4%
Brazil	1,859,300	2.3%	7.1%
Italy	1,004,982	2.0%	3.8%
Uzbekistan	815,000	40.8%	3.1%
Colombia	571,668	4.7%	2.2%
Thailand	474,486	1.5%	1.8%
Total	23,582,575	n/a	90.1%
ROW	2,580,989	-	9.9%
World total	26,163,564	1.52%	100.00%

Source: IANGV

These numbers should, however, be treated with some caution.

- The consistency of data collection methods and the variations in reporting year of the data for each country varies. In most cases numbers are for the years 2016 to 2018, though in some countries it is earlier than this.
- The definition of what constitutes an NGV can vary from country to country. Some include motor bikes and other small engines such as agricultural machines.
- Vehicles may be dual-fuelled and, in practice, use relatively small volumes of natural gas.
- Some countries do not distinguish between liquid petroleum gas (LPG) and natural gas fuelled vehicles with the former often being the larger proportion.

Whilst completely reliable data on the types of natural gas vehicles is not available, it is clear that most NGVs are small vehicles. According to the International Energy Agency (IEA) (2017), large trucks (Heavy Goods Vehicles - HGVs) fuelled by CNG or LNG accounted for about one per cent of the total stock of NGVs in 2015. Most of these vehicles were to be found in China (there were around 350,000, including buses, at the end of 2017[5]), the USA and the European Union. Looking ahead, the role of gas fuelled HGVs is likely to grow in importance as they represent a more prospective market for NGVs than cars and will be clearly more significant in terms of fuel consumption.

As noted above, the number of vehicles does not necessarily provide a good indicator of actual gas consumption. Statistics on gas usage in transport are available from the IEA[6] but because of the relatively small volumes in many countries they are either not collected or are combined with other fuels such as LPG. The IEA (2018) estimates that global demand for gas in transport was 130 Bcm in 2017, however this definition includes energy consumed in the delivery of fuels through pipelines. Analysis of the sector is shown in Table 3 for the highest consuming countries showing the split between gas used for pipeline transport and road transport. Volumes of gas used in marine transport are either negligible or not recorded.

Table 3: Gas consumption for 'transport' (IEA definition). Top ten countries, 2016 (Bcm)

Country	Road transport	Pipelines	Total
Russia	1.1	34.2	35.3
USA	1.8	19.1	20.9
China	20.8	-	20.8
Iran	8.1	-	8.1
Canada	0.1	4.2	4.3
Argentina	2.9	1.2	4.1
India	3.0	-	3.0
Thailand	2.9	-	2.9
Brazil	1.8	1.1	2.9
Turkmenistan	2.0		2.0

Source: IEA

Table 4 shows the evolution of demand since 2000 illustrating the increasing role of gas in road transport.

Table 4: Gas consumption for 'transport' (IEA definition), 2000 to 2016 (Bcm)

	2000	2005	2010	2015	2016
Road	3.6	11.9	31.8	47.7	48.8
Pipeline transport*	63.3	73.6	71.2	65.4	69.4
Total	66.8	85.5	103.0	113.0	118.2

Source: IEA

*i.e. gas consumed in the delivery of gas through pipelines in compressors etc.

Table 5 takes those countries listed in both Tables 2 and 3 and shows the annual average consumption per vehicle. This is calculated on the assumption that all of the gas is used by road vehicles and is shown in diesel litres equivalent (DLE[7]) and gallons of gasoline equivalent (GGE[8]). It is clear that there is a wide range of values for average consumption. By way of comparison, Table 6 shows the average consumption for all vehicles in the USA in 2017. This shows that whilst the numbers in Table 5 fall within the expected range of vehicle consumption (with the exception of Thailand) the levels of NGV

[5] Energy Aspects (forthcoming).)

[6] The data is from the IEA's World Energy Balance Master File which contains detailed statistics underpinning the WEO.

[7] 1 m^3 of gas = 1.032 litres of diesel.

[8] 1 litre of diesel = 3.32 GGE

consumption are higher than might be expected given the proportion of small vehicles in the total NGV population. There are a number of possible explanations:

- Data anomalies and inaccuracies described above.
- High levels of utilisation for smaller NGVs, for example many NGVs in India are taxis so will have a higher usage rate than privately owned vehicles.
- Lower fuel efficiency for NGVs (in China, for example, many NGVs are low cost conversions of gasoline fuelled cars and, as such, relatively inefficient) plus higher system losses.

Table 5: Gas consumption for 'transport' (IEA definition excluding pipelines). Top ten countries

Country	Number of NGVs	Gas consumption 2016 (Bcm)	Average consumption	
			in DLE	in GGE
China[9]	6,080,000	20.81	3,533	11,743
Iran	4,502,000	8.08	1,853	6,158
India	3,090,139	2.97	993	3,300
Pakistan	3,000,000	1.96	676	2,246
Argentina	2,185,000	2.86	1,351	4,490
Brazil	1,859,300	1.79	994	3,303
Italy	1,004,982	1.35	1,386	4,608
Uzbekistan	815,000	0.10	127	421
Colombia	571,668	0.71	1,285	4,272
Thailand	474,486	2.88	6,260	20,809

Source: IANGV, IEA and author's calculations

Table 6: Annual average fuel consumption by vehicle type in the USA 2017

Vehicle type	Average consumption in GGE
Class 8 Truck	12,889
Delivery Truck	1,974
Light Truck	683
Taxi	2,813
Car	480

Source: www.afdc.energy.gov/data/

In summary, it is clear that the global number of NGVs has been growing though the majority are concentrated in a relatively small number of countries. The reasons for this varying level of NGV penetration are considered in more detail in Chapter 5. It would also appear that, to date, most NGVs are cars and other light vehicles and only one per cent are HGVs. It is, however, this latter sector that is most promising for future natural gas demand and so past consumption levels may not be a good indicator.

3. The main advantages and challenges facing NG as a transport fuel

The advantages and challenges of natural gas over other transportation fuels were covered extensively in an earlier report (Le Fevre 2014). This chapter provides an update on the key issues:

- The environmental advantages.
- The financial case.
- Vehicle and fuelling availability.

[9] Analysis by Energy Insights (forthcoming) suggests that gas consumption in China in 2017 was around 33 Bcm. Whilst this number includes gas consumed in the shipping sector it suggests an even higher average consumption figure for road vehicles.

One area that has evolved significantly since the 2014 paper is the role of biomethane as a transport fuel and this is considered in a separate section.

3.1 The environmental advantages of natural gas as a transport fuel

Unlike the marine sector, government measures to reduce the environmental impact of road traffic have been a significant policy feature for many years. Legislation to improve fuel efficiency (and so reduce CO2) and limit atmospheric pollution have been introduced by a number of countries and/or cities – though, as would be expected, there are a wide range of measures in place around the world. The main emphasis for fuel efficiency measures has been for smaller vehicles though HGVs are also increasingly subject to such strictures. Manufacturers have responded to these requirements through improved engine and vehicle design but the scope for using natural gas as a fuel to provide significant improvements over conventional fuels is not as clear cut as in the marine sector, particularly as reducing sulphur emissions is not an issue.

The environmental impacts of comparative vehicle fuels are typically measured on the basis of emissions at the well to tank (WTT) and tank to wheel (TTW) stages to provide a holistic 'well-to-wheel' (WTW) measure. Natural gas can generally demonstrate a better environmental performance than diesel and petrol although how these impacts are measured and presented is an area of continuing debate and not all studies agree. In particular some studies (for example, Transport and Environment, an organisation that has tended to campaign against NGVs,[10] 2018) have suggested that methane leakage might increase the overall level of emissions. Methane has a much higher global warming potential than CO2 (see Le Fevre 2017 for details) and additional emissions arise both from losses in the upstream and at the combustion stage where gas-fired engines are not able to fully combust all the methane and this escapes into the atmosphere (referred to as 'methane slip').

3.1.1 Cars

The most usual comparison of environmental performance is in terms of emissions of CO_2 equivalent per unit of distance travelled. Table 7 summarises research done by the European Commission's Joint Research Centre (2014) and a more recent study by Thinkstep (2017). This latter study was funded by the Natural Gas Vehicles Association (NGVA) and provided detailed estimates of this impact of methane emissions which are estimated to be 27 per cent of the WTT emissions and six to eight per cent of total WTW greenhouse gas (GHG) emissions for a CNG vehicle.[11]

This amount should be reduced as engine designs are adapted specifically for natural gas as a fuel, though dual fuel engines are still likely to be susceptible to some degree of methane slip. The same study estimates methane emissions of 0.05 - 0.2 per cent during fuel dispensing.

Table 7: Well-to-wheel GHG emissions for cars using different fuels in CO_{2eq}/km

Mode	Study	Petrol	Diesel	LPG	CNG	LNG
Car	JEC	125-185	115-145	154-160	137-185	-
Car	Thinkstep	169	140	-	131	-
VW Golf	T&E	130	132	-	123-141	-
Car 2020	JEC	83-132	79-106	106-110	94-122	-
HGV	Thinkstep	-	1074		908	912

Source: Thinkstep (2017). Note figures for LNG HGVs are based on HPDI engines

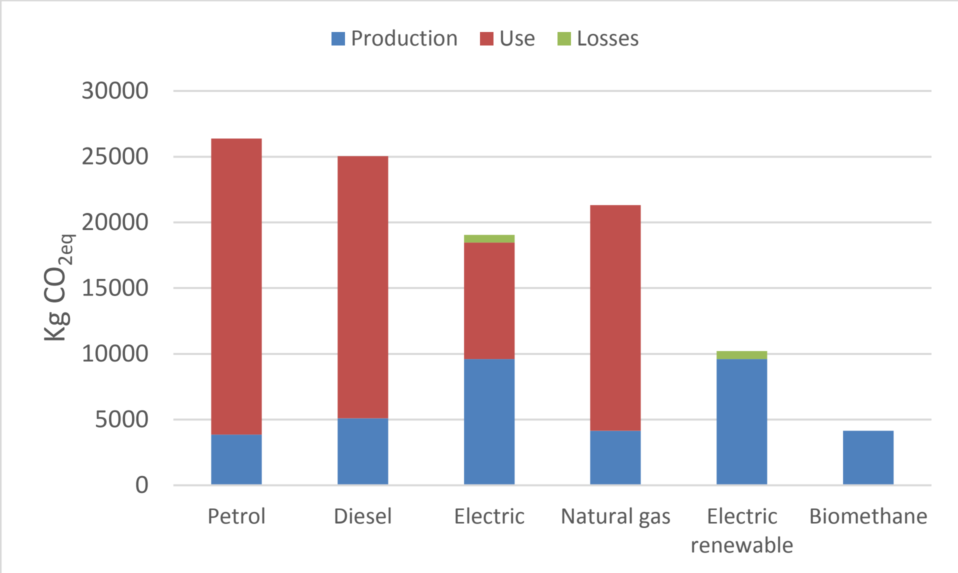
An alternative approach to comparing fuels is shown in Figure 3. This is based on SNAM's analysis of the Thinkstep data to derive a comparison that combines both vehicle production and use – the former is often ignored making electric vehicles, apparently, more attractive than other sources. The

[10] See for example https://www.transportenvironment.org/publications/natural-gas-vehicles-%E2%80%93-road-nowhere

[11] 45 per cent arising from production, processing and liquefaction, 32 per cent from transmission, distribution and storage, 15 per cent from LNG feedstock transportation, and eight per cent from dispensing. The WTT element can vary significantly with different gas sources.

calculations are based on an assumed average annual distance driven of 15,000km and 10 years for the vehicle's useful life. SNAM incorporated the production cost of vehicles (that of CNG cars is above petrol but below battery electric vehicles) to calculate the GHG emission reduction cost of €1.11/kgCO2eq for electric vehicles and €0.44/kgCO2eq for CNG vehicles compared to the diesel alternative.

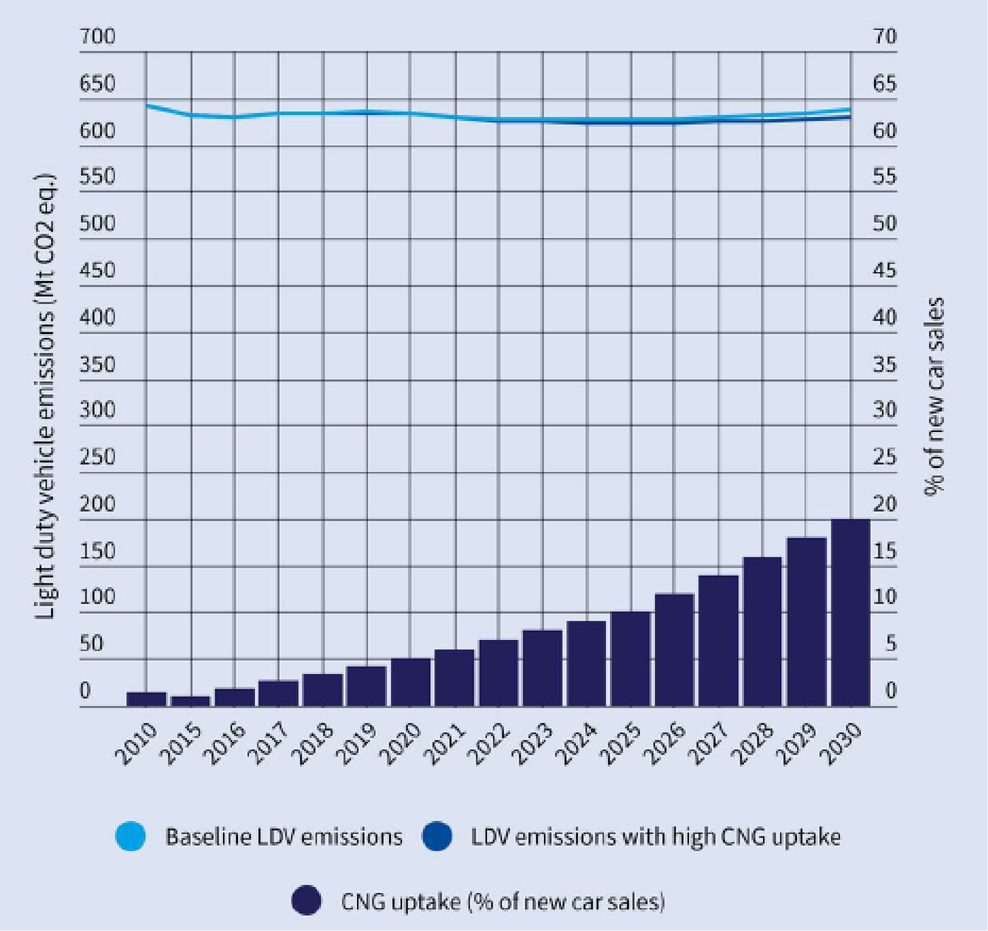
Figure 3: Full vehicle environmental impact for alternative fuels



Source: SNAM (2018), Thinkstep (2017)

It would appear that there are environmental benefits from using natural gas versus conventional fuels. However, when compared with electric vehicles using renewable power or biomethane, CNG does not look a realistic long-term option for smaller vehicles. The European Federation for Transport and Environment (T&E, 2018) has stated that a progressive build-up in CNG vehicles in Europe to 20 per cent of new car sales by 2030 would reduce the WTW GHG emissions of passenger cars by just 1.5 per cent (see Figure 4). By ignoring whole life-cycle effects referred to above, these numbers may be not present the full picture. Nevertheless, they are being used to underpin the case made to policy makers in Europe that incentives to buy and use CNG cars are difficult to justify.

Figure 4: The impact of CNG car purchases on vehicle emissions in Europe



Source: Transport & Environment 2018

3.1.2 HGVs

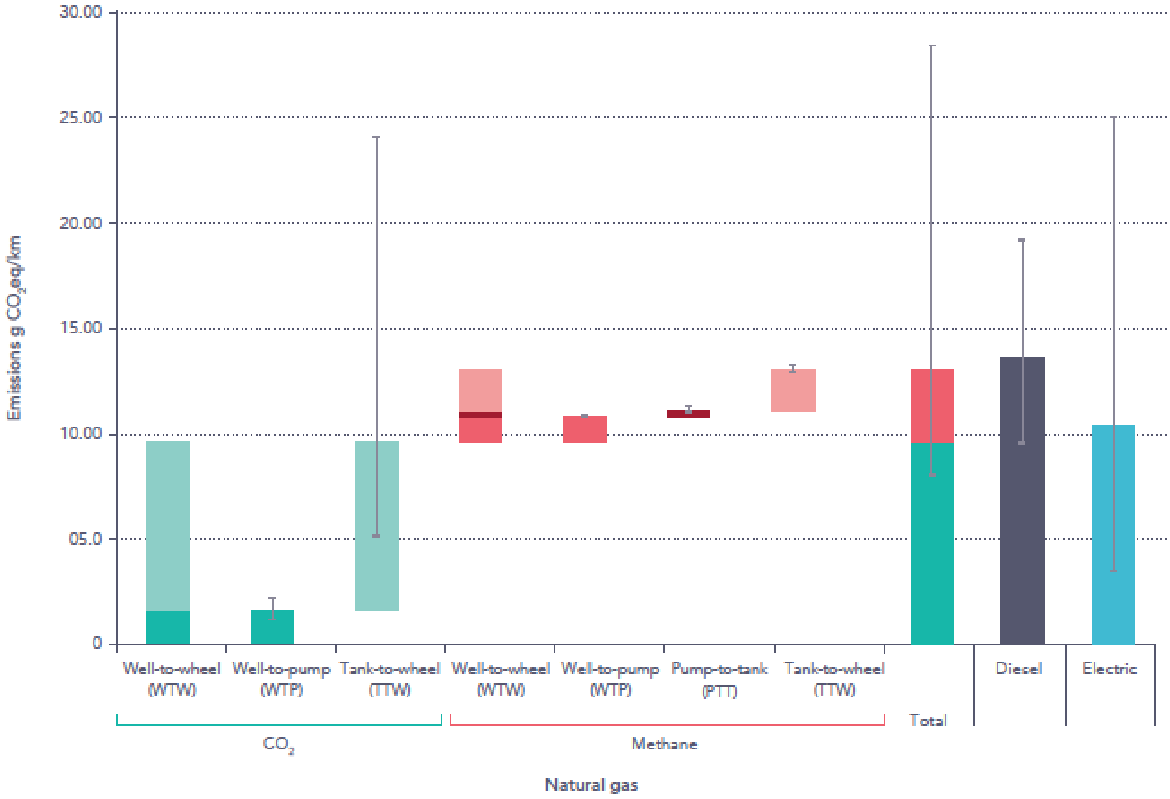
The earlier paper published by the OIES (Le Fevre 2014) noted that the greater prospects for natural gas, both in terms of growth rates and volumes consumed, were likely to be with heavy goods vehicles where LNG was likely to increasingly feature as an option. The environmental impact of different fuels in the HGV sector has been harder to measure under real world conditions although a number of recent studies have started to emerge. The Thinkstep (2017) analysis of HGV emissions is shown in Table 8 (including a blend of natural gas with biomethane) and a more recent study from the Sustainable Gas Institute at Imperial College (SGI, Piers et al 2019) in Figure 5. Both studies agree that emissions from natural gas fuelled trucks could be around 15 per cent below those of diesel trucks. However, the SGI report notes that, in some circumstances such as dual fuel trucks used for urban deliveries, GHG emissions can be greater. This explains the wider range of emissions for natural gas in Figure 5.

Table 8: Well-to-wheel GHG emissions for HGVs using different fuels in CO_{2eq}/km

Mode	Diesel	CNG	LNG	80% CNG + 20% SNG	80% LNG + 20% SLNG
HGV	1074	908	912	738	749

Source: Thinkstep (2017). Note figures for LNG are based on HPDI engines

Figure 5: Emissions from the well-to-wheel life cycle of average LNG trucks for alternative fuels



Source: Spiers et al, 2019

Natural gas in HGVs is more attractive from an atmospheric pollution standpoint though new diesel engines such as those designed to meet the Euro VI fuel standard[12] are narrowing the gap. Grigoratos et al (2019) state that these engines are achieving much lower particulate emissions and nitrogen oxides (NO_x) emissions than previously. Nevertheless, NO_x emissions can still be up to 80 per cent lower for spark ignition gas engines used for long distance (motorway) haulage (Spiers, 2019) and noise levels are around 50 per cent lower.[13] Dual fuel (gas/diesel engines) generate higher levels of both GHGs and atmospheric pollutants than modern diesel engines and so are relatively unattractive from an environmental perspective.

To date, electric vehicle applications in the HGV sector have been fairly limited due to the costs of the batteries and their size which has limited the effective payload. This has enhanced the longer-term prospects for gas as a fuel. There is growing interest in electric freight vehicles[14] though mostly for local use due to range restrictions. Lithium battery costs have fallen by 80 per cent in the past 10 years and a study by Mareev et al (2017) suggests that under some scenarios battery electric trucks could be cost competitive with diesel, albeit for lower (80 per cent) payloads. A continuation in these trends for battery technology could be a significant game-changer for gas's prospects in the heavy goods vehicle sector.

Overall it can still be argued that natural gas has some environmental advantages over other fossil fuels, and this has led to some preferential support from governments. This has included subsidies for

[12] https://www.dieselnet.com/standards/eu/hd.php.
[13] https://www.ngvglobal.com/blog/vw-utilise-100-scania-lng-trucks-greener-logistics-0920.
[14] See for example https://www.drax.com/technology/can-electricity-power-heavy-duty-vehicles/ and https://www.ukhaulier.co.uk/news/road-transport/trucks/fully-battery-electric-driven-truck-for-heavy-duty-distribution-mercedes-benz-eactros-starts-in-the-murg-valley-emission-free-and-quiet-transportation/./

infrastructure and vehicle purchase and lower duty on fuel. Whether these moves represent good value for money has been questioned[15] and because natural gas does not provide a clear path to full decarbonization and existing fuels have improved in terms of both lower CO_2 and reduced atmospheric emissions the environmental case for conventional (i.e. fossil) natural gas in transportation is not overwhelming.

3.2 The economic case for natural gas a transport fuel

The economic case for using natural gas depends on the trade-off between the slightly higher capital cost of the CNG or LNG vehicle and the price differential with petrol or diesel. Unlike the marine sector, where wholesale price differentials are the key factor, differential taxation rates can play a much greater role in many countries. In Europe, for example, most countries levy lower rates of duty on CNG/LNG than on diesel (Mariani, 2016). The cost of refuelling infrastructure can also be an important consideration in some cases. The IEA (2017) quote payback periods of two to four years in countries where there is a significant differential in fuel prices and the costs of refuelling infrastructure are either subsidised or low as a result of high-volume usage.

For HGVs the choice between LNG and CNG has tended to be determined by range requirements with the latter providing up to 1600 km compared with 500-1000 km for CNG[16] and vehicle configuration.[17] Refuelling costs can also differ significantly depending on the density and configuration of gas pipeline networks and the extent of LNG availability. In this regard it is interesting to compare China and the USA (see sections 5.3 and 5.4) where LNG and CNG are the preferred fuels respectively.

Some examples of paybacks in particular countries follow:

- In the UK the fuel duty on natural gas and biomethane is 50 per cent below that on diesel. In November 2018 the government announced that this differential (which covers all alternative fuels) has been extended to 2032.[18] Waitrose (UK) operates around 60 dedicated CNG trucks – some with a range in excess of 800 km – and the company claims that their lower running costs will generate between £75,000 to £100,000 in lifetime savings compared with a diesel vehicle.[19] They aim to run their fleet exclusively on biomethane by 2028 which will attract government incentives.
- In Germany, a study by Shell (2019) has calculated the discount to diesel prices that would be required to achieve a break-even over five years. The results depend on both mileage and engine type (which impacts on both capital cost and fuel efficiency) and suggest a fuel discount of between 25 and 30 per cent would achieve break-even for vehicles travelling an average distance of between 110,000 and 150,000 km per year. These required differentials could fall to 17-19 per cent as future engines increase in efficiency. Required distances to achieve break-even would also fall.
- In the USA, where vehicle fuel excise duties are generally a much lower proportion of total cost than Europe, Golar estimate that at an oil price of $85/bbl the additional cost of a NGV truck can be recovered within four years.[20] Clean Energy Fuels (CEF) provide a more bullish estimate for the same market. They calculate that the $40,000 incremental cost of a gas fuelled HGV can be recovered in two years assuming 20,000 gallons annual consumption and CNG/LNG prices retailing at around $1/gallon less than diesel. With levels of shale gas production forecast to grow in coming years this financial advantage could persist for some time.

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[15] Spiers et al 2019 and Transport & Environment 2018.

[16] In 2017 a Stralis NP 4×2 tractor unit pulling a tri-axle box van trailer and running at a gross vehicle weight of 30 metric tons has just completed a 1,728 km road journey without needing to refuel.

[17] CNG tanks cannot fit on a 6x2 tractor unit – see https://www.gasrec.co.uk/cng-lng/

[18] https://www.ngvglobal.com/blog/uk-fuel-differential-freeze-a-boost-for-ngv-hgvs-1110#more-56245.

[19] https://www.edie.net/news/6/John-Lewis-and-Waitrose-to-power-delivery-fleet-on-bio-methane-by-2028-green-gb-week/.

[20] This is based on a $27,000/year for regular diesel and $11,500/year for LNG at about $7.60/MMBtu. (Article in Natural Gas World, 1.10.18)

Subsidies towards vehicle purchase can also help boost the economic case as has happened in Italy and Spain (T&E 2018) and, as described below, companies in the USA have started to provide financing support to truck owners switching to natural gas. With the exception of the USA, however, in most countries the economic case for gas is, to a large extent, dependent on state support. The risk that this support may not be available in the long term is a risk that is likely to deter a number of potential users.

3.3 Vehicle and fuelling availability

In the past the rate of uptake of NGVs was constrained by the relatively small number of gas-fuelled vehicles and the limited number of refuelling stations.

Whilst NGV cars are still not widely available outside certain markets such as China and Italy, in the HGV sector good progress has been made. Early versions of dual-fuelled trucks were not a great success; there were operational problems together with significant methane slip. Dedicated vehicles are now much more widely available in Europe from manufacturers such as Volvo, Scania and Iveco which have all introduced new gas HGVs in 2017/18. Smaller commercial vehicles are also becoming available. In the UK, for example, Blue Bus Innovations now operate CNG minibus vehicles powered by IVECO's 3.0-litre, 140 hp engine.[21]

Availability of refuelling infrastructure is no longer considered to be a major constraint in many countries. In Europe a number of companies have built facilities part-funded by the European Union's 'Connecting Europe Facility (CEF) for Transport'[22] programme. For example:

- Uniper is planning eight NGV refuelling stations in Germany, three in Belgium and three in France.
- In April 2018, Berlin-based Liquind 24/7 announced it would be investing €16 million in ten LNG stations following a grant of over €3 million.[23]
- The Swedish Environmental Protection Agency has provided grants under the Climate Leap (Klimatklivet) programme to expand NGV fuelling networks. Gasum received €9.3 million towards building 16 new LNG filling stations around Sweden and €12.7 million as part of a €45 million liquid biogas (LBG) production plant.[24]

Broader examples of Government support include Germany where the Federal Government now provides support towards the cost of new LNG and CNG fuelled HGVs. The scheme grants a subsidy €8,000 for CNG and €12,000 for LNG vehicles as long as it does not exceed 40 per cent of the vehicle cost.[25]

To summarise, the economic case for gas in road transport requires cheap gas in relation to competing fuels – this can be achieved either by an over-supplied market as in the USA, or state subsidies (including higher duties on competing fuels) as is the case in most other countries. The environmental case is most compelling when biomethane is used and the scope for this is considered in the next chapter.

[21] http://www.ngvglobal.com/blog/uk-bus-operator-first-to-run-cng-minibuses-1107#more-56161.
[22] https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport.
[23] https://www.lngworldnews.com/eu-funds-german-lng-fueling-project/./
[24] https://www.naturalgasworld.com/gasum-to-develop-swedish-lbg-unit-65004.
[25] http://www.ngvglobal.com/blog/natural-gas-for-trucks-promoted-by-german-transport-ministry-0617#more-54069.

4. Does renewable methane provide a solution[26]?

The environmental benefits of biomethane over fossil based natural gas are substantial (Lambert, 2017). Figures from The Natural & Bio Gas Vehicle Association (NGVA) (2018) suggest CO_2 savings ranging from 84 per cent to 182 per cent when compared to conventional fuels.[27] Baldino et al (2018) have compiled the GHG intensities for gaseous fuels used in the transport sector for different biomethane feedstocks from various studies and compared these with natural gas.[28] These show a GHG intensity for biomethane ranging between 26 gCO2e/MJ for power to gas based on renewable solar power to negative emissions of -264 gCO2e/MJ for gas from livestock manure.

The potential for biomethane in transport is critically dependent on two factors:

- Is there confidence that the required volumes of biomethane will be available?
- If there is, do competing demand sectors (e.g. power generation) have a greater claim to use biomethane as a source of supply?

The question of availability is a function of the physical volumes of feedstock and the relative costs of the different pathways. There are a wide range of forecasts for future levels of biomethane that might be available in Europe:

- A study by consultants Ecofys (since renamed Navigant) sponsored by gas transporters and biomethane producers (van Melle et al, 2018) predicts that by 2050 it would be possible to produce 122 Bcm of renewable gas comprising 98 Bcm of biomethane and 24 Bcm of renewable hydrogen. The 98 Bcm of biomethane consists of 63 Bcm from anaerobic digestion and 35 Bcm from thermal gasification. An update to this study (Navigant, 2019) showed that under an "optimised gas" scenario these volumes could be 272 Bcm of renewable gas with 136 Bcm each coming from biomethane and renewable hydrogen. However, the analysis foresees a very limited role for biomethane in road transport with 56 Bcm from this source going to international shipping with the heavy road transport sector consuming 24 Bcm from renewable hydrogen.
- Baldino et al (2018) have calculated the total technical potential for biomethane production in Europe and how this might translate into actual volumes available for the transport, heating, and power sectors at different subsidy levels. Technical potential for biomethane in electricity generation is calculated to be around 35 Bcm per annum. This compares with just under 30 Bcm for biomethane in transport or heat. This lower number reflects the fact that some biomethane is of insufficient quality to be injected into the gas grid. The authors calculate that this quantity of biomethane could meet seven per cent of European transport energy demand by 2050. The authors note that the actual availability of biomethane for grid injection (i.e. for use in transportation or heating) is significantly below the technical potential even at high levels of subsidy mainly due to the very high cost of gathering renewable methane from livestock. For example, a subsidy of €2.5/m^3 is calculated to generate a supply of some 15 Bcm of biomethane for grid injection. This is equivalent to around $70/MMBtu – or eight to ten times the wholesale price of gas at the TTF trading hub in early 2019.[29] Of course, some volumes of biomethane can be generated at costs below this. For example, the UK premia for biomethane under the Renewable Heat Incentive (RHI) are between two and four times early 2019 wholesale prices and this level of support could lead to biomethane production of over 1.5 Bcm by 2021.[30] In

[26] This chapter primarily concentrates on developments in the European market.

[27] Biomethane from municipal waste and synthetic methane show 84per cent to 97 per cent improvement. Biomethane from liquid manure shows a 182 per cent improvement.

[28] See Lambert (ibid) for an explanation of the alternative technologies for producing biogas, bio-SNG and biomethane.

[29] Based on $1/MMBtu = $0.0362/cubic metre and a TTF price of $7-8/MMBtu

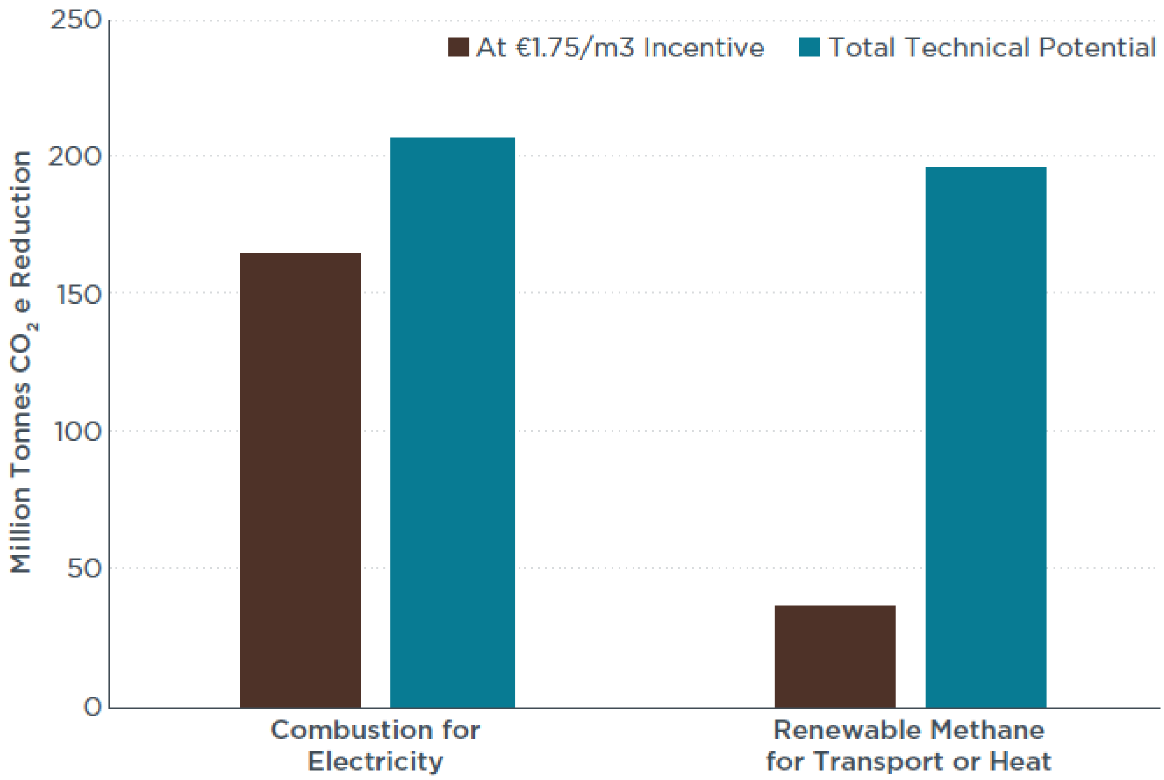
[30] https://www.dena.de/fileadmin/dena/Dokumente/Veranstaltungen/EBC_2017/Vortraege_EBC/panel1-2-Burns.pdf Not all of this gas will be used directly in transport as the scheme allows for the gas to be injected into the grid and still get the subsidy.

Italy an incentive scheme for the production of biomethane for transport uses provides producers with a payment of €0.62/m^3 (approximately $19/MMBtu) over a period of 10 years.[31] Industry sources expect this payment to be sufficient to meet the projected level of methane demand of 1.1 Bcm per year in the transport sector.

- Searle et al (2018), have suggested that the cost of developing renewable methane is such that subsidies (or very low relative fuel duties) would be required to make the option attractive.

Turning to the question of whether competing demand sectors (e.g. power generation) have a greater claim to use biomethane as a source of supply, Baldino et al have calculated the GHG mitigation potential for biomethane at a subsidy level of €1.75/m^3. These results are reproduced in Figure 6 for 2050 which also shows the total technical mitigation potential when biomethane is either injected into the gas grid or used directly in power generation. This analysis indicates that the latter application generates a better return in terms of GHG mitigation.

Figure 6: 2050 Greenhouse gas mitigation potential of renewable methane for transport or heating compared to power generation at a €1.75/m^3 subsidy



Source: Baldino, 2018

The authors conclude:

> 'In transport, we find that renewable methane is a particularly expensive decarbonization strategy. Policy support of €1.50/m^3 would be needed to encourage a small amount of renewable methane in transport, and €4/m^3 of policy support would be needed to drive a substantial level of penetration. These support levels are roughly equivalent to subsidies of €1.50 and €4 per litre of diesel equivalent or a carbon price of €580– €1,350 per tonne of CO_{2e} abated.'

[31] "Decreto interministeriale 2 marzo 2018" available on the Italian government website at following link: https://www.mise.gov.it/images/stories/normativa/DM-biometano-2-marzo_2018_FINALE.pdf

Searle et al (2018) writing on behalf of the International Council on Clean Transportation (ICCT) support this view concluding that it is more cost effective to use gas from livestock manure, sewage sludge and gasification processes for power generation. In the transport sector the authors state that power to liquids has several advantages over power-to-methane as it is cheaper and can be used more widely. In the longer-term they expect hydrogen to also play a role.

The Ecofys study, which is much more optimistic on the volumes of biomethane that could be available in Europe, allocates only a very small volume to transport. The authors expect the small vehicle market to be dominated by electric traction and have allocated just 5 Bcm of biomethane production for heavy duty transport, as an alternative to biofuels. This is based on a calculation of the total costs of switching all small and large trucks to either biofuels or renewable gas[32] which is estimated at €115 billion per annum for biofuels (advanced renewable diesel) and €121 billion per annum for renewable gas. The update to this study published by Navigant (2019) confirmed a very limited role for biomethane in road transport by 2050 with 56 Bcm from this source going to international shipping. The heavy road transport sector is expected to consume 24 Bcm which would come from renewable hydrogen. The total cost savings from an "optimised gas" scenario compared to the "minimal gas" scenario are €217 billion per annum of which €14 billion is in the transport sector. The authors conclude "While (bio-) CNG is an attractive option to lower the greenhouse gas intensity of transport today, no large role for bio-CNG in 2050 road transport is expected."

More broadly, the IEA do not expect renewables to play a significant global role in the transport sector (IEA 2018c) and any use of renewables is mostly expected to be in the form of bio-fuels and renewable electricity consumption in road transport. An earlier IEA study (2017) forecasts biomethane demand of 0.7 EJ (18.5 Bcm) in 2050 used mostly in CNG and LNG truck fleets.

Despite this challenging outlook there is still expected to be a role for biomethane in some countries. Italy plans to develop a significant biomethane based transport sector around the existing CNG market (see the case study in Chapter 6). Sweden recently reported that 91 per cent of its gas for vehicles is from renewable sources though volumes are relatively modest at 140 million cubic metres.[33] The NGVA has forecast a production potential for biomethane of 45 Bcm by 2030. This is expected to come from anaerobic digestion (19 Bcm), synthetic methane from power to gas (13 Bcm) and gasification (13 Bcm). It is anticipated that nine Bcm of this production will be used in transport.

The conclusion is, therefore, that whilst biomethane has strong environmental credentials, using it as a fuel for transport is hard to justify in terms of both cost and availability. Where sustainable supplies of biomethane are available it is usually more appropriate to use this gas in applications where there are not lower cost alternatives. Given that there are other routes to decarbonising transport (electric vehicles and, in the longer term, hydrogen), it is questionable whether policy makers would pursue this route. The possible exceptions to this is where there is already a significant level of gas usage in transportation that makes a switch to biomethane potentially attractive or, in the case of HGVs, where a viable electric solution still seems some way off. So, for various reasons, some biomethane usage in transport is likely to persist, not least because many state-based incentive programmes include biomethane within a general renewable fuel programme.[34] Whether these programmes represent the most cost-effective, long-term means of decarbonising transport is an area requiring further research.

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[32] This includes renewable hydrogen.

[33] https://www.ngvglobal.com/blog/natural-gas-fuel-in-sweden-is-91-renewable-0302#more-110054.

[34] See for example the Italy case study below, Sweden (IRENA 2017) and the UK's RTFO programme, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/694277/rtfo-guidance-part-1-process-guidance-year-11.pdf.

5. The global outlook and beyond

This chapter looks at some broad-brush forecasts for NG usage in transport and then looks at some specific regions/countries where progress is most likely. Some specific issues are also discussed in relation to these regions.

5.1 Global forecasts

The IEA provides both short-term (IEA 2018a) and long-term (IEA 2018b) forecasts for gas demand in transport. These are shown in Table 9 (adjusted to remove the proportion of demand allocated to gas used in pipeline transport and to allocate the residual demand between marine and land transport). The long-term forecast is based on the IEA's New Policies Scenario. There are some inconsistencies between the two sets of forecasts: the short-term estimate is that transport demand will reach 140 Bcm by 2023 whilst the long-term (World Energy Outlook) forecast gives a range of 168 Bcm to 207 Bcm by 2025 for different scenarios. A 28 Bcm or more increase over two years looks unlikely at present rates of growth though predictions relating to this sector are undoubtedly far less certain due to its relative infancy. A separate IEA study of the HGV sector (2017) forecasts 2 EJ (37 Bcm - up from more than seven Bcm today) of natural gas and 0.7 EJ (18.5 Bcm) of biomethane by 2050. Growth in the HGV sector has, understandably, a much greater impact on total gas demand.

Table 9: Forecast of demand for gas in transport (IEA New Policies scenario)

Transport	2017*	2023	2025	2040
Road	53	55	96	196
Marine	8	9	10	49
Pipelines	70	75	76	83
Total	131	140	182	328

Source: IEA World Energy Outlook and Gas Market Report, 2018, and author's estimates
*Estimated.

DNV (2018), has published global and regional forecasts for transport demand to 2050. The study estimates that the total demand for energy for transport will grow from 110 EJ today (2,627 MTOE, of which road transport is 2,030 MTOE), peaking at 2,818 MTOE in 2026 and then declining to 2,149 in 2050 (of which road transport is 1,480 MTOE). The decline is primarily due to increasing efficiency. The biggest factor being electric vehicle (EV) uptake, as an EV is three to four times more efficient than a combustion engine. Continued improvement of combustion engines and digitalization will also play a role.

For HGVs, DNV expects an increase from 270 million vehicles in 2016 to 530 million by 2050. By 2045, half of all new HGV sales are forecast to be EVs though 49 per cent of fuel consumption will still be oil, with electricity (36 per cent), biofuel (six per cent) and gas and hydrogen (around four per cent each) accounting for the remainder.

As noted above, the role of renewables is unlikely to be significant in global terms according to the IEA (2018c) report on renewables. In the short-term they expect the share of renewables in transport to grow only minimally from 3.4 per cent in 2017 to 3.8 per cent in 2023. Most renewable fuel is expected to be biofuels though renewable electricity consumption in road and rail transport modes increases by 65 per cent over the forecast period, albeit starting from a low base.

One persistent theme in this paper has been the localised nature of the NGV market. It is, therefore, perhaps more instructive to examine the outlook in those countries/regions that are likely to play the most significant roles in terms of uptake and levels of demand. These are presently judged to be Europe (and Italy in particular), USA, China, India and, to a lesser extent, Latin America and the Middle East.

5.2 Europe

In 2018, NGVA published the forecasts shown in Table 10. This shows a demand for natural gas in road vehicles of 30 Bcm by 2030 compared with an estimated 1.9 Bcm in 2018. Nine Bcm of this demand is expected to be supplied in the form of biomethane from a variety of sources. Total biomethane production in Europe is forecast, by the NGVA, to be 45 Bcm. The NGVA bases its projections on the argument that the use of renewable gas in road transport can provide a strong accelerator towards carbon neutrality in the sector. It notes that an 80 per cent renewable/conventional mix would make gas used in transport carbon neutral. This implies approximately 24 Bcm of forecast biomethane production to be used in transport and NGVA implicitly accepts this is unlikely as its base forecast assumes a 30/70 split. The logic is, therefore, that a switch to NGVs can still be justified even though 70 per cent of the fuel will be from conventional sources as this will reduce GHG emissions from 96 million tonnes to 52 million tonnes.

Section 4 notes that, whilst the technical potential for biomethane in transport could be in the region of 30 Bcm by 2030, the costs involved suggest that biomethane should be utilised in other sectors such as heating or power generation. Given that electric vehicles present a clearer path to decarbonisation in transport, the NGVA forecasts seem highly optimistic for cars and other light vehicles. However, as noted above biomethane remains a favoured option for large vehicles and these users may increasingly opt for CNG as this presents an easier route for blending conventional and renewable gas.

Table 10: Forecast of NGV numbers and demand for gas in transport for Europe

Vehicle type	Number of vehicles ‘000		Market share 2030	Volume (Bcm)	
	2018	2030		By gas	2030
Car	1,300	12,600	12%	CNG	20
Bus	16	110	33%		
CNG Truck	9	190	25%		
LNG truck	2.5	280		LNG	10

Source: NGVA

This trend is already evident in many countries in Europe that are increasing gas usage in transport in the truck and bus sectors. A number of large haulage companies have started to make significant moves towards gasifying their vehicle fleets. Examples include:

- French haulier Jacky Perrenot has 550 Iveco Stralis NP trucks and plans to increase this to 1000 by 2020.
- Jost Group from Belgium plans to have 35 per cent (approximately 500 HGVs) of its fleet running on LNG by 2020.
- DHL announced, in 2018, that it was switching its long-haul fleet to LNG powered Stralis tractors. The vehicles will have two LNG tanks and a range of 1,500 km.[35]
- Ocado, a UK food distributor, ordered 29 IVECO Stralis CNG trucks in July 2018. This was the largest order to date of NGV trucks in the UK.[36] The trucks will run on ‘blended biomethane’ provided by Gasrec.[37]

One of the main drivers behind the development of the LNG supply chain has been the Blue Corridors project. The project is now completed and claims to have promoted the purchase and operation of 140 LNG trucks consuming about 14,2000 tons of LNG and the construction of 12 refuelling stations.[38] Funds are now being provided by the EU’s Connecting Europe Facility programme and individual governments have accessed this to promote the development of infrastructure and, in some cases, the purchase of vehicles.[39]

The small vehicle sector is also growing – albeit from a small base - with Italy, Germany and Belgium showing increased registration in 2018 compared to 2017.[40] Progress, however, suffered a setback in

35 http://www.ngvglobal.com/blog/dhl-selects-natural-gas-powered-trucks-for-long-haul-0618#more-54082.
36 http://www.ngvglobal.com/blog/ocado-uk-orders-29-iveco-stralis-np-cng-trucks-0712#more-54521.
37 http://www.ngvglobal.com/blog/ocado-and-gasrec-partner-to-power-hgv-fleet-with-blended-biomethane-rng-0109#more-57032.
38 https://www.lngworldnews.com/lng-blue-corridors-project-ends-as-targets-reached/./
39 https://www.lngworldnews.com/eu-funds-german-lng-fueling-project/./
40 https://zukunft.erdgas.info/gas-im-markt/gas-im-verkehrssektor/lng-verfluessigtes-erdgas.

August 2018 when VW announced it was suspending CNG vehicle deliveries until 'later in 2019' due to a shortage of certification engineers arising from tighter regulatory scrutiny in the wake of the 'diesel gate' crisis.[41]

Whilst some continued growth is likely, mainly in the heavy vehicle sector, the high levels predicted by the NGVA would appear unattainable. As noted in section 3, the economic case is critically dependent on a continuation of existing preferential fuel taxes and, in some countries, the availability of purchase subsidies. The availability of cost effective biomethane and the role of government incentives regarding its use (i.e. transport versus power and heat) will also play an important role.

5.2.1 Italy

Italy is something of a special case in Europe. It has had significant CNG usage in road transportation for many years. There are over 1,000 gas refuelling stations, one million NGVs and annual gas consumption in transport was around 1.4 Bcm in 2018. Future growth is predicated on moving towards using biomethane. Chapter 6 presents a case study of the Italian market in order to identify the critical success factors for development of a comprehensive gas-based transportation sector.

5.3 United States

Unlike Europe, the economic case for NGVs is not critically dependent on state or federal support but has been largely driven by the increasing availability of low-cost gas arising from the growth in shale gas production. The EIA states that natural gas consumption in the transport sector was two Bcm in 2017 (EIA 2018) and most of this was estimated to be in the HGV sector. Whilst initial expectations were that LNG fuelled vehicles would play a growing role in long distance haulage this has not proved to be the case. Where there are no pre-existing liquefaction facilities, LNG is relatively expensive compared to CNG and, without some form of taxation or other incentive targeting LNG, it is difficult to make an economic case. CNG, on the other hand, seems to be making some progress. A CNG/LNG refuelling network is already largely in place with most interstate highways having a facility every 200 miles.

Clean Energy Fuels (CEF) is one of the major providers of natural gas to the sector and, being publicly quoted, provides some useful insights into how the market is evolving. CEF sells through a network of more than 550 owned/operated public and private stations in 43 US states and Canada. Sales are primarily to road hauliers, but the company also supplies airport support vehicles, refuse trucks and some 16,000 municipal buses.[42]

There is significant growth potential in the market given that CEF estimates that only about 15,000 of the 3.2 million long-haul trucks in the US are using natural gas. As noted above, the initial hopes for LNG do not appear to have been realised and the fall in oil prices in 2015/6 has effectively led to a stalling in growth in CEF's LNG sales. CNG sales, on the other hand, are showing some growth and improvements in range of CNG vehicle to 600 miles (965 km) have helped.[43]

Table 11 shows the evolution of fuel sales (in GGE) from CEF's recent U.S. Securities and Exchange Commission (SEC) filings. The marginal contraction of the LNG market is clear and the company announced plans to close 42 refuelling stations in 2017 citing 'slow, volatile or unpredictable growth [in] heavy-duty trucking'. Nevertheless, there is still growth, albeit relatively slow, in the CNG sector and to stimulate the market further CEF and Total have introduced the 'Zero Now' financing programme. This allows fleet operators to buy or lease (over five or six years) a natural gas truck at the same cost as a diesel truck and lock in a fuel price that is substantially below that of diesel for the life of the lease.

[41] https://www.naturalgasworld.com/vw-to-suspend-ngv-deliveries-reports-63383?utm_medium=email&utm_campaign=Daily%20Natural%20Gas%20World%20-%20Latest%20News&utm_content=Daily%20Natural%20Gas%20World%20-%20Latest%20News+CID_f096190729d9df418a0795462b535e1d&utm_source=Campaign%20Monitor&utm_term=Volkswagen%20To%20Suspend%20Gas%20Vehicle%20Deliveries.

[42] Natural Gas world, Vol 3, Issue 17, 27 September 2018.

[43] The comparative range for an LNG truck is around 1,600 km.

Separately UPS has announced plans to invest $130 million in an additional five CNG fuelling stations and 700 new CNG vehicles.[44]

Table 11: Clean Energy Fuels - retail sales data 2015-2018

Fuel (million GGE)	2015	2016	2017	2018 (9 months)
CNG	229.2	259.2	283.4	220.0
LNG	70.5	66.8	66.1	46.8
RNG	8.8	3.0	1.9	0
Total	308.5	329.0	351.4	266.8

Source: CEF Corp 10-K, http://investors.cleanenergyfuels.com/financial-information/sec-filings

There is some limited biomethane production in the US mainly from landfill. Most of this gas goes into the pipeline system though some is used as a vehicle fuel. Total reported biomethane capacity as at October 2018 was 275 million GGE (approximately 0.8 Bcm) and between 0.1 and 0.2 Bcm of these volumes was used as transport fuel.[45] Typical projects utilise the gas for municipal and other public service vehicles.

In terms of future demand, the 2018 Annual Energy Outlook from the EIA forecasts continuing increases in both compressed and liquefied gas consumption to 2050 due to growing use in heavy goods vehicles and rail freight. In the later years of the projection period demand for LNG in shipping is also included. Table 12 shows the reference case forecast.

Table 12: Forecast gas demand for transportation fuel in the USA (Reference case)

Transportation fuel (bcm)	2017	2025	2040	2050
CNG/LNG	2.0	6.6	10.9	16.6

Source EIA, Annual Energy Outlook

Whilst the demand projections are relatively modest the assumption of a constant rate of growth is unlikely to prove correct. Demand for gas fuelled trucks will continue to be driven primarily by economics and, if future levels of gas production falter, the present price differentials may not be as attractive. Furthermore, growth in clean alternatives such as EVs and hydrogen (both of which are assumed to grow at similar rates) could increase their share in the HGV sector as the technology improves.

5.4 China

China, with over 6 million NGVs and 3,000 natural gas filling stations is the largest gas fuelled transport market in the world. Natural gas consumption in the transport sector is reported to be around 23 Bcm in 2015 (representing 12 per cent of China's total gas consumption[46]) though there were wide regional variations in market shares – above 20 per cent in Beijing and just three per cent in Shanghai. A more recent estimate from Energy Aspects (forthcoming) puts 2018 demand (including shipping) at 36 Bcm and the National Development and Reform Commission of China (NDRC) forecasts this to increase to 55 Bcm by 2020.

Growth in demand on the transport sector over the four years to 2015 was around 17 to 18 per cent annually and has outpaced the growth rates of both diesel (seven per cent) and gasoline (12 per cent) (Wainberg et al, 2017). Growth rates have, however, fluctuated quite widely during this period reflecting variations in the discount of both CNG and LNG retail prices to that of gasoline and diesel. Prices for transport are generally not regulated to the same extent as other sectors and increasing demand in other sectors has reduced the favourable differentials in transport. Analysis by O'Sullivan (2018) shows that transport prices are significantly above gas prices in other sectors and that there is wide regional variation. In Wuhan province, for example, prices in 2017 were in the region of $17/MMBtu compared

[44] http://www.ngvglobal.com/blog/ups-plans-130m-investment-in-natural-gas-stations-and-vehicles-0621#more-54102.

[45] https://www.anl.gov/es/reference/renewable-natural-gas-database

[46] China Energy Statistical Yearbook 2015.

to $14/MMBtu for industrial users and a little over $10/MMBtu for residential users. In April 2017 Hunan province stopped regulating prices of gas used in taxis and buses causing concerns about sharp price rises to transport companies. Prices in gas producing areas are significantly below those in the main gas consuming cities.

CNG usage in cars was encouraged by government sponsored purchase subsidies as part of the new energy vehicle programme. This programme also encouraged the increased use of electric vehicles and there are signs that EVs are being increasingly favoured over CNG cars with subsidies for the latter being phased out. This trend could be further enhanced by the fact that about 80 per cent of CNG cars are converted gasoline or diesel vehicles and, as a result, have lower combustion efficiencies and higher levels of methane slip. Whilst these vehicles could be helping reduce atmospheric pollution, they could also be increasing global warming potential.[47]

In addition to the large number of CNG fuelled cars, there is widespread use of LNG by HGVs. Energy Aspects reports that there were 350,000 LNG HGVs at the end of 2017 consuming similar levels of gas to the CNG fleet. The growth in LNG trucks is, in part, due to the availability of relatively low-cost LNG from an extensive cryogenic supply chain developed as a result of a lack of pipeline capacity. LNG is shipped by truck from both import terminals and domestic small-scale liquefaction plants to industrial users and for transportation fuel. Wood Mackenzie estimates that around 12 per cent of total gas demand is shipped in this manner.[48] Sales of LNG HGVs received a further boost from restrictions on diesel freight movements introduced in 2017 to reduce atmospheric pollution, although again LNG price increases at the end of 2017 led to lower LNG truck sales in 2018.

The outlook for LNG demand in the HGV sector should be fairly positive given continuing restrictions on the use of diesel trucks to limit atmospheric pollution. On the other hand, major growth in EV usage is expected and this could dampen growth. Furthermore, LNG demand for trucks could be hit as cleaner diesel HGVs are being introduced and the availability of LNG by truck may reduce as a growing pipeline network undercuts this market.

The foregoing suggests that the National Development and Reform Commission's (NDRC) forecasts of gas demand in transport growing to 55 Bcm in 2020 may be over optimistic and a range of 45 Bcm to 63 Bcm by 2030, quoted by Wainberg (2017) which includes shipping demand, is more likely. With an increased emphasis of EV usage in small vehicles, it is also likely that most of this increased demand will be in the form of LNG.

5.5 India

Air quality is a major political and environmental concern in urban India – particularly in cities in the so-called National Capital Region[49] (NCR) and the states of Maharashtra and Gujarat. CNG has been seen as an important contributor to battling against this problem. Public transport (auto-rickshaws and buses) was required to switch to CNG by the Indian Supreme Court in 2001.[50] In 2015 the same court required taxis in Delhi to convert to CNG.

There are also economic advantages from using CNG which retails at around 60 per cent of the petrol price.[51] This has led to increased switching to CNG vehicles in the private car market, which saw a year on year increase in sales of 50 per cent to November 2018. Manufacturer Maruti Suzuki reports selling over 55,000 CNG vehicles in the first half of 2018.[52] Sen (2017), points out that CNG demand is

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[47] See Hu et al in https://yncenter.sites.yale.edu/sites/default/files/files/Huning_ae_2018.pdf.

[48] https://www.bloomberg.com/news/articles/2018-11-05/china-gas-craze-gets-help-from-trucks-as-pipelines-can-t-keep-up.

[49] Delhi and the neighbouring states of Haryana, Uttar Pradesh and Rajasthan.

[50] https://www.indiatoday.in/magazine/states/story/20010820-delhi-switches-to-cng-but-problem-of-implementation-raises-doubts-774047-2001-08-20.

[51] https://www.business-standard.com/article/companies/rising-petrol-and-diesel-prices-perk-up-cng-car-sales-in-first-half-of-fy19-118110501345_1.html.

[52] https://www.ngvglobal.com/blog/maruti-suzuki-achieves-green-milestone-with-half-million-cng-vehicle-sales-1211#more-56683.

vulnerable to competition from alternative fuels if the duty regime were to change. This vulnerability is likely to be enhanced by an increasing Government focus on encouraging the use of EVs.

India's CNG consumption has been growing at about six per cent annually from 2012 to 2015. 2015 consumption was around 2.8 Bcm of CNG,[53] most of which was in the NCR, Mumbai and the state of Gujarat.[54]

There has also been a concerted push towards using CNG in trucks with a number of manufacturers now providing gas-fuelled versions although lack of support for new vehicle purchase and delays in providing infrastructure are acting as a brake on growth (Sen 2017). This could change, however, with the country expected to increase the number of CNG stations from 1,400 to 10,000 within ten years[55] coupled with increasing restrictions on the use of diesel trucks. On the other hand, the roll-out of CNG infrastructure may be too slow to give truck owners the confidence to switch fuels. The level of uncertainty is reflected in the wide range of growth estimates reported by Wainberg (2017) of between five and 17 Bcm by 2030. The lower forecast suggests that growth is likely to be confined to cars and other light vehicles in urban locations whilst the upper end of the range anticipates a big switch to gas in the road freight sector.

5.6 Other regions

NGV usage in **Latin America** grew strongly in the 2002-2004 period although, since 2006, numbers have remained relatively static. The two largest markets are Argentina and Brazil accounting for around four million NGVs in 2017. According to Stratas,[56] the Brazilian market, where NGVs are primarily taxis, is largely saturated. This is reflected in fairly static demand numbers which have grown from 2.5 Bcm in 2010 to just 2.85 Bcm in 2016. Growth in Argentina is constrained by competing demand sectors for domestically produced gas and demand has stayed around four Bcm throughout the period from 2010 to 2016.

In the longer-term, the **Middle East** region could grow in importance as countries seek to reduce levels of oil consumption in transport. The freight sector is increasingly expected to switch to gas in countries such as Saudi Arabia. The IEA (2017) forecasts 13 Bcm gas demand by HGV vehicles by 2050 from almost zero in 2017.

6. Italian case study

Unusually for Europe, Italy has had significant CNG usage in road transportation for many years. This chapter presents a case study of this market in order to identify some insights into the critical success factors for development of a comprehensive gas-based transportation market.

6.1 Italian CNG market size and structure

The Italian CNG transportation market stands head and shoulders above other European markets in terms of number of vehicles, refuelling infrastructure and volumes consumed. Figures from SNAM (2018), show that there are over 1,000 refuelling stations, 1 million NGVs and annual consumption was 1.4 Bcm. The percentage share of natural and liquid petroleum gas vehicles in the passenger car fleet was 7.8 per cent - the next highest were Belgium and Portugal at around 0.5 per cent and most of these are likely to be LPG cars (ICCT, 2017).

Unlike many other countries, the number of vehicles has continued to grow, as shown in Figure 7, although the share of CNG vehicles in new registrations has fluctuated between 1.7 per cent and 5.4 per cent over the 10 years to 2018.

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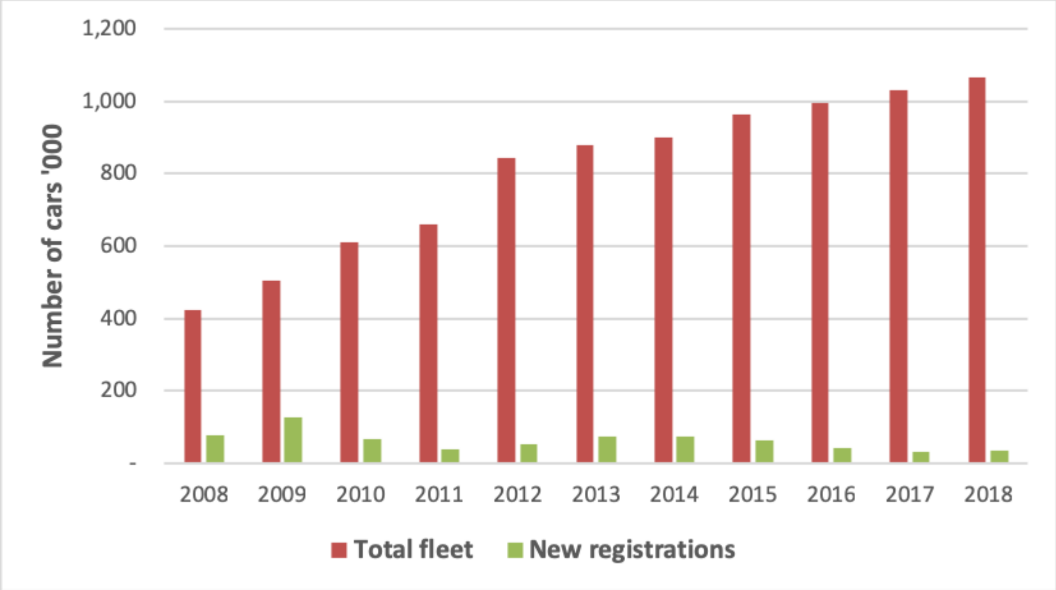
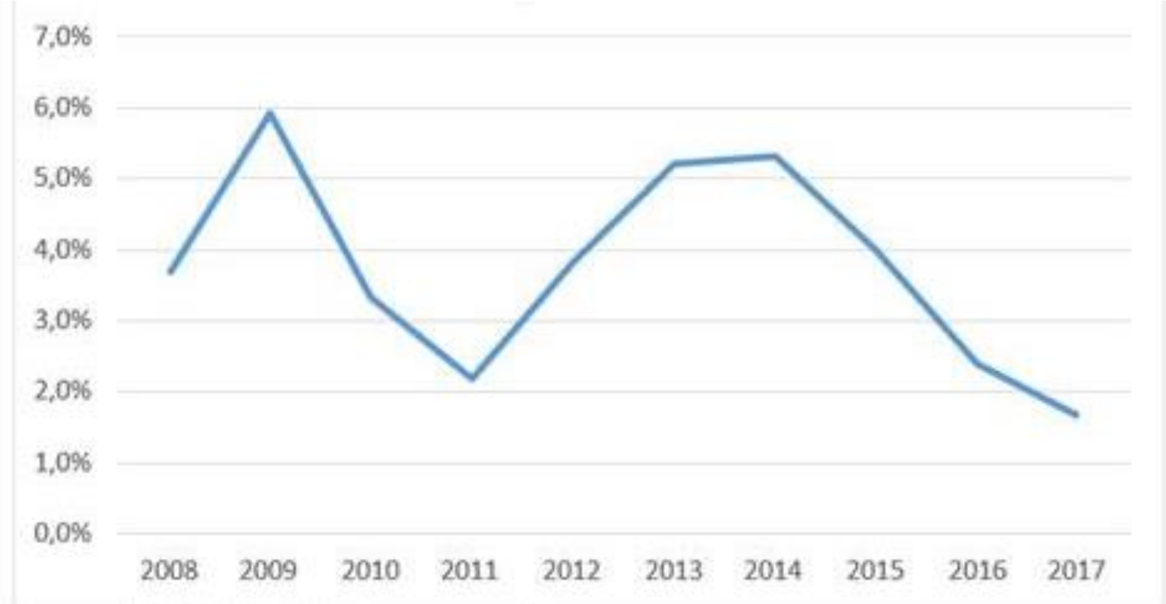
[53] https://www.ppac.gov.in/index.aspx.
[54] Natural Gas World, Vol 3 issue 21, 19.11.18.
[55] Natural Gas World, Vol 3 issue 21, 19.11.18.
[56] https://stratasadvisors.com/Insights/031617-Latin-America-CNG.

Figure 7: CNG vehicle fleet and new registrations in Italy: 2008-2018



Source: https://www.eafo.eu/vehicles-and-fleet/m1

Figure 8: Share of NGV new car registrations in Italy: 2008 to 2017.



Source: UNRAE 2017 https://ita.calameo.com/read/000675349e365faddcb9c

The proportion of CNG vehicles in the total Italian vehicle fleet, in 2018, was 2.4 per cent. In 2016, the fleet was dominated by cars accounting for 87 per cent of all NGVs. Trucks accounted for just over nine per cent and other vehicles such as buses, tractors and three wheelers, the remaining two per cent (SNAM, 2018). Table 13 shows the details for all vehicles in Italy in 2016 and Table 14 shows the breakdown of new registrations in 2016.

Table 13: Vehicle fleet (excluding motor cycles) by fuel source – 2016 (thousands)

2016	Petrol	Diesel	LPG	CNG	Electric-Hybrid	Total
Cars + LDVs	18,506.1	16,315.1	2,211.4	911.5	127.5	38,071.6
Trucks	206.2	3,842.8	41.3	85.6	4.1	4,180.0
Buses	0.5	92.4	0.3	4.1	0.5	97.8
Other Vehicles	95.3	676.2	6.7	4.1	6.5	788.7
Total	18,808.1	20,926.4	2,259.8	1,005.2	138.5	43,138.1

Source: UNRAE 2017 http://www.unrae.it

Table 14: New vehicle registrations (excluding motor cycles) by fuel source – 2016

	Petrol	Diesel	CNG	LPG	Total*
Passenger Cars + LDVs	643,165	1,058,886	43,797	101,619	1,847,467
Buses	0	2,447	119	0	2,566
Trucks	4,465	183,993	6,938	2,861	198,257
Other	2,551	19,164	413	277	22,405
Total	650,181	1,264,490	51,267	104,757	2,070,695

Source: UNRAE 2017 http://www.unrae.it

Note: *There were also 16,000 vehicles fuelled by other means

There is significant geographical variation in fleet distribution. 43 per cent of the fleet is located in and around the major cities of Milan, Rome, Turin and Naples. It is also notable that the proportion of electric vehicles in Italy is very low by European standards. At 0.2 per cent, the country has the lowest plug-in electric vehicle share in Western Europe. The percentage in Germany and the UK is 0.7 per cent and 1.5 per cent respectively (ICCT 2018). In 2017 only 4,800 electric and electric-hybrid vehicles were bought although this increased to 9,200 in 2018.[57] This amounted to just 0.6 per cent of new vehicle registrations in that year (up from 0.2 per cent in 2017). Equivalent numbers for Germany and the UK were 2.6 per cent and 1.9 per cent respectively, and for the EU as a total it was 2.0 per cent.

6.2 Role of key players and government

These sectors are characterised by three important factors:

- A proactive gas company, acting as a champion, promoting the construction of refuelling facilities and the dissemination of information.
- Vehicles manufacturers with a wide range of models.
- Government incentives at both a national and regional level – although, as described below, there are variations in the level of regional support.

National gas transmission company, SNAM, has been highly proactive in promoting NGVs as part of its sustainability programme. The company argues that there are environmental benefits in terms of lower atmospheric and CO_2 emissions both directly from using NGVs and indirectly as a result of being able to transport vehicle fuel through its existing network of pipes as opposed to road tankers.[58] It is also clearly of benefit to increase network sales and utilisation.

[57] https://www.eafo.eu/vehicles-and-fleet/m1 UK and Germany EV registrations in 2018 were nearly 55,000 and 60,000 respectively.

[58] http://www.snam.it/export/sites/snam-rp/repository/ENG_file/investor_relations/reports/annual_reports/2017/Sustain-indexed-2017/06-natural-gas-and-climate-change.pdf.

In 2017 the company established a subsidiary, Snam4Mobility, to promote the natural gas for transport distribution network in Italy through direct investments and agreements with other operators. It also aims to expand the refuelling network to improve coverage in regions that are presently less well served.[59] SNAM4Mobility has signed partnership agreements with the fuel retailing arms of ENI and API[60] aimed at developing and operating new CNG and LNG stations over a 20 year period.[61] ENI has already developed 180 CNG stations.

SNAM has also helped establish NGV System Italia (NGV Italy) to coordinate and promote actions to develop a viable, long-term NGV sector. The group was responsible for ensuring standards and regulations were in place for both vehicles and refuelling systems. There was also a wide-ranging research programme promoting innovation in gas-fuelled engines, vehicle components, refuelling and storage systems and the management of NGV Fleets.

SNAM and Baker Hughes are also developing a micro-liquefaction infrastructure to serve the NGV and marine sector. Their plans envisage investing between €50 and €80 million in up to four plants which will produce 140,000 tonnes of LNG and bio-LNG.

Regarding the role of the vehicle manufacturers, there are a range of CNG cars available although most are manufactured either by Fiat (FCA group) or VW. The most popular CNG models registered in 2017 were the Fiat Panda and Punto and the VW Golf and UP! – accounting for 90 per cent of NGV purchases (SNAM, 2017). List prices for natural gas vehicles compared with the comparative petrol or diesel model show a premium of between 12 and 20 per cent for the most popular models.[62]

The role of Government has also been crucial in developing the sector, not least to help counter the purchase premium noted above. The Government opted to promote CNG and LPG fuelled cars in the early 2000's as an alternative to petrol for both environmental and fuel security reasons. It was also likely that the Government saw an opportunity to provide some support for the domestic automobile manufacturing sector whilst staying within EU rules on state aid.

The two most important promotional tools have been:

- A scheme introduced in 2004, and then expanded in 2007, providing incentives ranging from €1,500 to €3,500 for new LPG and CNG vehicle registrations and an additional bonus of up to €1,500 when a car of 10 years old or more was exchanged or scrapped.[63] These incentives have subsequently been reduced although the government has recently introduced direct subsidies for the purchase of LNG and CNG trucks.
- Much lower fuel duties making CNG prices equivalent to 0.62 €/diesel equivalent litre – less than half of the diesel price according to Transport and Environment (2018).

At a regional level, CNG (and LPG) vehicles are exempt from road tax in a number of regions including Lombardy, Piedmont, Lazio and Campania.[64] However, disparities between regions and patchy refuelling networks, have acted as a brake on developments in some areas.

The 'Biomethane Decree', introduced in March 2018[65], promotes the use of biomethane in the transport sector as part of wider support scheme covering the production and distribution of advanced biofuels. Producers of 'advanced biomethane' are paid a premium to enable them to compete with conventional

[59] http://www.snam.it/en/Natural-gas/Snam4Mobility/./
[60] https://www.naturalgasworld.com/snam-inks-2nd-cng-partnership-37815.
[61] https://www.naturalgasworld.com/snam-to-develop-cng-stations-for-eni-57261.
[62] https://www.motori.it/listino/. The VW Golf was not available as a CNG model at the time of completing this report so comparative price numbers exclude this vehicle.
[63] https://cleancities.energy.gov/files/u/news_events/document/document_url/6/ngv_policymaking.pdf.
[64] In Lazio and Campania road tax is 75 per cent below that for petrol and diesel cars.
[65] Promozione dell'uso del biometano nel settore dei trasporti [Promotion of the use of biomethane in the transport sector], Ministero dello sviluppo economic, March 2, 2018, https://www.mise.gov.it/index.php/it/90-normativa/decreti-interministeriali/2037836-decreto-interministeriale-2-marzo-2018-promozione-dell-uso-del-biometano-nel-settore-dei-trasporti

fuels. This premium, which applies to 1.1 Bcm of new projects each year, will be reviewed annually. The scheme was approved by the European Commission under EU State aid rules and the inclusion of biomethane reflects the large number of NGVs in the country's vehicle fleet.

One other aspect of government policy that may have helped NGVs is the relative lack of momentum behind promoting electric vehicles.[66] This may be about to change following an announcement, in June 2018, of plans to put in place incentives to support the acquisition of electric and hybrid vehicles.[67] This was followed by new regulations, due to take effect in March 2019, providing subsidies towards the purchase of EVs coupled with higher vehicle taxes on petrol and diesel engines.[68]

6.3 Prospects for the future

Italy has demonstrated that, with appropriate incentives, a widespread refuelling network, a range of vehicles, and a CNG passenger vehicle market that exhibits both scale and sustainability can be developed. The key question is whether this can provide a platform for a broader based gas in transportation market – both for cars and other vehicles.

For passenger cars, the increasing importance of minimising CO_2 emissions suggests that the only viable, long-term route is for a progressive switch into biomethane and, as noted above, this raises two inter-related questions:

- Is there confidence that the required volumes of biomethane will be available, and
- if there is, do any competing demand sectors (e.g. power generation) have a greater claim to use biomethane as a source of supply?

The biomethane decree described above, which will run from 2018 to 2022 and will provide up to 1.1 Bcm annually, is clearly an important element in seeking to meet these objectives. The president of the Italian Biogas Association (CIB), Piero Gattoni, has claimed that Italy has the potential to produce eight to 10 Bcm of biomethane annually by 2030.[69] SNAM (2017), has forecast a CNG market of 2.5 million NGVs consuming four Bcm by 2025 and more than 10 million NGVs consuming 10 Bcm by 2040. It is presumed that this envisages a switch from LPG to CNG as well as from petrol although there must be some doubt over the achievability of these numbers if EVs are given increasing support.

As noted in chapter 4, there are some challenges in making the case for using biomethane in transport and it is to be noted that as a result of previous incentive schemes the present 2.5 to three Bcm of biomethane[70] goes mainly to the power sector.[71] Nevertheless, the fact that there is already a robust CNG market, and the new decree is specifically targeting transport,[72] will provide a clear exemplar of whether and how biomethane can succeed as a transport fuel.

The growth of natural gas in passenger cars in Italy has, to date, not been matched by usage in HGVs although an LNG based market is starting to develop. There may be further scope for utilising the existing refuelling network for CNG in freight transport but a clear picture on the role gas might play in road haulage is not yet apparent.

To conclude, the lessons from Italy are that the right mix of state support, OEM provision and gas company investment can enable the establishment of a gas fuelled transport market. Furthermore, use of gas contributes towards a decarbonised transport system based on a growing usage of biomethane. It is also clear that this achievement took many years to establish and was, in part, due to a unique combination of state support that would be difficult to justify in today's, more financially, constrained

[66] This may, in part, have been influenced by the Fiat CEO Marchionne's long held antipathy towards EVs. See https://www.reuters.com/article/chrsyelr-ceo-evs-idUSL1N0O71MS20140521.
[67] https://www.bloomberg.com/news/articles/2018-06-25/italy-wants-to-go-worst-to-first-in-e-cars-price-10-billion.
[68] https://cleantechnica.com/2019/01/03/ev-subsidies-going-up-in-italy-down-in-china/./
[69] 'Italy Makes its traffic greener', Natural Gas World, Volume 3, Issue 10, June 7, 2018.
[70] Some of this may be untreated biogas.
[71] 'Italy Makes its traffic greener', Natural Gas World, Volume 3, Issue 10, June 7, 2018.
[72] Which has higher targets for decarbonisation than other sectors

environment. Other countries seeking to replicate the approach would probably conclude that moving directly towards EVs would produce similar or better results in terms of emissions as would utilising biomethane in other sectors.

7. Conclusions

This paper has examined the prospects for gas in road transport as a follow-up to the recent paper on marine based applications. There are, of course, a number of important differences between the two sectors. Most obviously there is a role for both LNG and CNG in land transport whilst LNG is the sole option in marine. LNG is mainly used in HGVs, buses and trains but not in cars, whilst CNG can be used in most types of road vehicles.

The land-based market differs widely from country to country and this is borne out by global data which shows a huge range in uptake of NGVs between different countries. Just four countries account for over 60 per cent of the global population of NGVs (Figure 2).

There are presently low carbon alternative fuel options in road transport - most notably electricity – that are not yet available in marine. This, in turn, leads to a wide range of state-based incentives for alternative fuels - some more favourable to NGVs (e.g. Italy) than others. In addition, fuel quality standards in many countries mean that there is no global push equivalent to the IMO restrictions on sulphur and NOx. In fact, the environmental drivers in road transport mirror the split noted by Stern (2017) between Europe, where the key driver is decarbonisation, and most other countries where the focus is on air quality.

Recent evidence suggests that cleaner diesel engines mean that in Europe (and N America) the atmospheric emissions ‘gap’ between gas and petroleum-based fuels is less apparent than it was – particularly for urban applications. If this is borne out by further testing, it significantly reduces one of the strongest arguments for gas in HGV transport.

The study on gas in marine noted that LNG did not provide a zero-carbon option. Many governments recognise this and are less interested in promoting gas because the electrification of transport arguably provides greater potential for a zero-carbon outcome. Where state support is made available, it has often focussed on the provision of refuelling infrastructure which covers all alternative fuels and, on its own, is unlikely to be sufficient. Fuel tax discounts have also been made available although, as noted below, these are exposed to the risk of changes in Government policy.

Unlike the marine sector, there is greater scope for using biomethane in the transport supply chain, and this plays well into the decarbonisation agenda in Europe. However, significant state support would be necessary to achieve this and, where supplies are limited, alternative uses such as heating or power generation may be preferred. More generally, environmental lobby groups are likely to argue against continuing subsidies for any form of gas in transport as they represent relatively poor value for money. Nevertheless, biomethane does present a realistic low carbon option for heavy vehicles in the near-term – particularly in Europe. It remains to be seen how widespread this usage becomes and the extent to which it enables a continuing role for natural gas as a blended component. In the longer-term renewable hydrogen may be the most favoured route to decarbonise road freight.

The case study on Italy has shown that where incentives on both fuel and vehicle purchase are provided this can establish a platform for developing a biomethane based supply chain in road transport. How successful this effort proves to be, and the costs involved, will provide useful lessons for other countries.

Outside Europe and, in particular, in major urban centres in Asia, the air quality benefits of natural gas have been the main driver in promoting market growth. There are signs that this benefit is starting to be eclipsed by EVs in the small vehicle sector and future growth is more likely to be concentrated in the HGV sector. There is still significant uncertainty as to how significant gas use in HGVs will prove to be. The pace of development of electric goods vehicles will again be a crucial factor.

There are economic attractions in using gas as a road fuel, either as a result of low basic commodity prices as in the USA, or more usually where there are favourable tax differentials versus petrol and/or diesel. In the latter case, clear guarantees that these differentials will be maintained are essential to underpin an investment case. Typical break-even periods for new HGVs are in the two to three year range for vehicles with high (i.e. in excess of 100,000 km per year) levels of utilisation.

There is wide range of forecasts of future demand in the sector reflecting many of the uncertainties described above. There is the sense that, in many markets, demand for gas in the light vehicle sector may be at or close to a peak as investment in, and support for, EVs increases. Most of the growth, therefore, is likely in the HGV sector where electric traction is only recently making some inroads. In gas volume terms, increasing HGV usage is much more significant than for passenger cars. The extent to which electric technology can increase its market share in road freight will be critical in determining the demand for gas in transport although, in some parts of the world, a lack of charging infrastructure could act as a constraint for many years to come.

Table 15: Estimated demand in 2030 for gas in road transport

Region	Demand in Bcm	
	2017 (estimated)	2030 (forecast)
China	36	30
India	3	10
N America	2	10
Europe	2	15
ROW	10	15
Total	53	80

Taking these factors together, a conservative estimate of demand in the sector is shown in Table 15. This is based on the country reviews in section 5 and an assumption that most of the growth will be in the HGV sector. The global total of 80 Bcm (some of which will be in the form of biomethane) is some way below the IEA New Policies Scenario (NPS) projections of 130 Bcm by 2030. Given the relatively low base at present, minor shifts in annual growth rates make either numbers quite feasible. Developments in the next two to three years should indicate which outcome is more likely.

NGV Glossary

- AVERE: European Association for Battery, Hybrid & Fuel Cell Electric Vehicles
- Bcm: one billion cubic metres.
- Bcma: one billion cubic metres per annum.
- Biogas: gas produced from the anaerobic digestion of organic matter such as animal manure, sewage, and municipal solid waste.
- Biomass: any organic material which has stored sunlight in the form of chemical energy. As a fuel it may include wood, wood waste, straw, manure, sugarcane, and many other by products from a variety of agricultural processes.
- Biomethane: biogas which is upgraded to vehicle fuel quality.
- CI: Compression ignition.
- CH_4: Methane.
- CN: Cetane number.
- CNG: compressed natural gas, made by compressing natural gas (which is mainly composed of methane [CH_4]), to less than 1% of the volume it occupies at standard atmospheric pressure. It is a fossil fuel substitute for gasoline (petrol), diesel, or propane/LPG.
- CO_2: Carbon dioxide, the principal greenhouse gas.
- CONCAWE: The oil companies' European association for environment, health and safety in refining and distribution.
- DICI: Direct injection compression ignition.
- DISI: Direct Injection Spark Ignition.
- E10: gasoline fuel with up to 10% v/v ethanol (or 3.7 wt% oxygen content), according to EN228.
- E20: gasoline fuel with up to 20% v/v ethanol (or up to 7.4 wt% oxygen content).
- E85: gasoline fuel with 85% v/v ethanol.
- EJ: exajoule – equivalent to 23.88 million tonnes of oil equivalent.
- ENTSOG: European Network of Transmission System Operators for Gas which manages and coordinates transmission system operators (TSO) activities regarding the functioning of the internal market and cross-border trade for gas.
- Euro VI fuel standard: European emission standards for new heavy-duty diesel, natural gas and LPG engines effective from 2013/2014.
- EUCAR: European Council for Automotive Research and Development.
- EV: Electric vehicle – can be either a hybrid (HEV) or plug-in (PEV).
- FAME: Fatty acid methyl ester - scientific name for bio-diesel made from vegetable oil and methanol.
- FC: Fuel cell.
- FCEV: Fuel cell electric vehicle.
- FID: Final investment decision.

- Fischer-Tropsch: the process, named after its original inventors, that converts syngas to hydrocarbon chains.
- GGE: gallons of gasoline equivalent.
- GHG: Greenhouse gas.
- GVW: Gross vehicle weight.
- GW: Gigawatt, i.e. 1 billion watts.
- GWh: Gigawatt hour - a unit of energy equivalent to a Gigawatt of power over the duration of one hour. In this report 1 mcm = 10.83 GWh
- HDV: Heavy duty vehicle - another term for an HGV.
- HEV: Hybrid electric vehicle.
- HGV: Heavy goods vehicle - also referred to as a Heavy Duty Vehicle. Precise definition of what constitute an HGV varies from country to country but typically these are lorries with a GVW in excess of 10 tonnes.
- HPDI: High-pressure direct injection engine – can run on natural gas or in dual fuelled mode.
- HVO: Hydrotreated vegetable oil.
- IANGV: International Association for Natural Gas Vehicles – now known as NGV Global
- ICE: Internal combustion engine.
- IEA: International Energy Agency.
- IMO: International Maritime Organisation.
- JRC: Joint Research Centre (of the EU Commission).
- LBM - Liquefied biomethane.
- LDE: litres of diesel equivalent.
- LDV: Light-duty vehicle – includes passenger cars and small vans.
- LNG terminal: facility for importing ship borne LNG. Normally the LNG is stored at the terminal before regasification and injection into the transmission system.
- LNG: Liquefied natural gas, natural gas liquefied by cooling to minus 162 degrees Centigrade.
- LPG: Liquid petroleum gas.
- mcm; million cubic metres.
- mcm/day: million cubic metres per day.
- Methane fuels – common name for CNG and compressed biomethane, LNG and liquified biomethane, all of them are with methane content of over 90%, up to 99%, the methane content depends from the country specific gas quality standards.
- Methane slip: CH_4 emissions from the dispensing or incomplete combustion of natural gas in transportation.
- MMBtu: Million British thermal units.
- MON: see RON.
- Mt: million tonnes.
- Mtpa: million tonnes per annum.

- MTOE: Million tonnes of oil equivalent.
- MWh: megawatt hour - a unit of energy equivalent to a megawatt of power over the duration of one hour.
- N_2O: nitrous oxide, a very potent greenhouse gas.
- NEDC: New European Drive Cycle.
- NGV: natural gas vehicles.
- NGV Global (formerly the International Association for natural gas vehicles)
- NGVA - the trade association for for natural and bio gas vehicles in Europe
- NO_x: a mixture of various nitrogen oxides as emitted by combustion sources.
- NPS: New Policies Scenarios – An IEA scenario used for forecasting.
- OEMs: original equipment manufacturer – i.e car and truck manufacturers such as VW Audi and Scania.
- OICA: International Organization of Motor Vehicle Manufacturers.
- PEV: plug-in electric vehicle (i.e. no combustion engine).
- PHEV: plug-in hybrid electric vehicle.
- PISI: port injection spark ignition.
- PM: particulate matter - microscopic emissions from diesel engines that have been shown to cause breathing difficulties and to have a carcinogenic effect .
- RAV: regulated asset value.
- RON: research octane number – a measure of the octane number that is meant to be indicative of normal road performance. The motor octane number (MON) is indicative of high speed performance. The octane rating is a measure of how resistant the gasoline is to knocking and higher performance engines require higher octane gasoline.
- SGI: Sustainable Gas Institute at Imperial College
- SI: spark ignition.
- Therm: imperial unit of energy used in GB gas pricing – 1 therm is equal to 29.3071 kWh.
- TTW: tank-to-wheels, description of the burning of a fuel in a vehicle.
- TWh: a unit of energy equivalent to a terawatt of power over the duration of one hour.
- Vehicle parc: number of vehicles available for use at any one time.
- WLTP: worldwide harmonized light duty vehicle test procedure.
- WTT: well-to-tank - the cascade of steps required to produce and distribute a fuel (starting from the primary energy resource), including vehicle refuelling.
- WTW: well-to-wheels - the integration of all steps required to produce and distribute a fuel (starting from the primary energy resource) and use in a vehicle.
- xEV: x-electrified vehicle, collective name for all electrified configurations.

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