Compressed natural gas vehicles are not a clean solution for transport

Review of the latest evidence shows high levels of particle emissions

16th of June 2020

Some claim that compressed natural gas (CNG) vehicles are a clean, low-emission technology and a solution for Europe's air pollution crisis. A review of the latest data on particle pollution from CNG cars, vans, buses and trucks dispels these claims and shows the technology emits high levels of toxic pollutants. The evidence reviewed in this paper shows that:

1. **CNG vehicles produce a large number of particles.** Particle pollution is linked to a number of serious diseases including cancer[1], Alzheimer's[2] and cardiovascular and respiratory illnesses[3]. CNG cars and vans, unlike their diesel and petrol counterparts, are not subject to a particle number emission limit. This is despite Euro 6 CNG cars and vans having been shown to emit a large number of particles; for one van model tested particle number emissions were 50% higher than permitted for diesel or petrol vans[4]. Heavy duty CNG vehicles are not subject to an on-road particle number limit until 2023[5] but have been shown to emit up to 3000 billion ($3x10^{12}$)[6] particles per km which is far from negligible and buses also emit a large number of particles. The highest particle number emissions from CNG vehicles are usually measured during urban driving (i.e. low speeds, cold starts) which is particularly concerning for air quality in cities and urban areas.

2. **CNG vehicles emit especially large numbers of ultrafine particles** as small as 2.5 nm[7]. These particles could potentially be the most harmful to human health as they have been

[1] WHO. (2019) Air Pollution - Key Facts.
[2] Younan, D. et al.. (2020) Particulate matter and episodic memory decline mediated by early neuroanatomic biomarkers of Alzherimer's disease. *Brain.*
[3] WHO. (2019) Air Pollution - Key Facts.
[4] Suarez-Bertoa, R. et. al.. (2019) On-road emissions of passenger cars beyond the boundary conditions of the real-driving emissions test. *Environmental Research*.
[5] Currently only subject to a laboratory engine test particle number emission limit.
[6] Giechaskiel, B. et. al.. (2018) Solid particle number emission factors of euro VI heavy-duty vehicles on the road and in the laboratory. *International journal of environmental research and public health*.
[7] Only particles larger than 23nm are currently measured for diesel and petrol vehicles during official tests, no particle number measurement takes place for CNG vehicles during official tests.

shown to penetrate deep into the body and have been linked to an increased risk of brain cancer[8]. If particles as small as 2.5nm are taken into account, the total amount of particles emitted by CNG cars and vans increases by between 100-500 times[9]. For heavy duty CNG vehicles, extending the measurement range down to 10nm has been shown to increase the total amount of particles by 100%[10] and this is likely to increase if 2.5nm particles are considered.

3. **CNG vehicles can emit large amounts of ammonia which contributes to particle pollution.** On-road testing of Euro 6 CNG cars and vans has shown that these vehicles can emit up to 20mg/km[11] and 66mg/km[12] of ammonia, respectively. As 1mg of ammonia is estimated to form 1mg of particle pollution, ammonia emissions from CNG vehicles can contribute significantly to $PM_{2.5}$ (particles smaller than 2.5 microns in size) air pollution. At present cars and vans are not subject to an ammonia emission limit.

CNG cannot therefore be considered a clean or low emission technology. Policies or financial incentives to promote CNG in order to improve air quality are counterproductive and the only way to truly reduce air pollution from transport and achieve the 'zero pollution ambition' of the European Green Deal is to move away from vehicles with an internal combustion engine and fully embrace zero emission mobility. In order to achieve this and to limit the environmental and health impacts of CNG vehicles, T&E proposes the following policy recommendations:

1. **EU funding frameworks and policy strategies should not classify CNG as a clean vehicle technology or sustainable transport fuel.** A number of EU policy instruments including the Alternative Fuel Infrastructure Directive (AFID), Connecting Europe Facility (CEF) and Clean Vehicles Directive (CVD) allow gas technologies, including CNG, to be labeled as clean and therefore benefit from policy and financial support. This is not in line with the EU Green Deal and is not supported by evidence which shows CNG vehicles emit dangerous pollutants and are therefore decisively not clean. In the future - eg. the Next Generation EU Fund and EU Budget 2021-2027 - only zero emissions technology and infrastructure should be eligible. No binding targets for gas infrastructure or support for local authorities to purchase CNG light or heavy duty vehicles should be allowed.

2. **CNG vehicles should not be counted, labelled or marketed as a 'cleaner, low emission' option for Low-Emission Zones, tolls, taxes or public procurement policies across Europe.** The research summarised above shows CNG is not a low polluting option

[8] Weichenthal, S. et al.. (2020) Within-City Spatial Variations in Ambient Ultrafine Particle Concentrations and Incident Brain Tumors in Adults. *Epidemiology*.
[9] Compared to the 23nm measurement threshold used during regulatory tests for petrol and diesel vehicles.
[10] Giechaskiel, B. et.al.. (2019) Regulating particle number measurements from the tailpipe of light-duty vehicles: The next step?. *Environmental Research.*
[11] Suarez-Bertoa, R. et. al.. (2019) On-road emissions of passenger cars beyond the boundary conditions of the real-driving emissions test. *Environmental Research.*
[12] Kontses, A. et.al.. (2019) Particle number (PN) emissions from gasoline, diesel, LPG, CNG and hybrid-electric light-duty vehicles under real-world driving conditions. *Atmospheric Environment.*

when all pollution from CNG vehicles is taken into account. As such, these vehicles should not be treated as low emission (e.g. when it comes to tolls for commercial vehicles or Low-Emission Zones) where other conventionally fuelled vehicles are banned. Public procurement should not include the purchase of CNG vehicles especially buses as this will fail to improve air quality in towns and cities. Only truly zero or low emission capable technologies (e.g. battery and fuel cell) should be classified as clean given they do not produce tailpipe emissions.

3. **A particle number emission limit must be introduced for light duty CNG vehicles in the future post-Euro 6 emission standards.** This limit must be set at a low enough level to ensure particle filters are mandatory for all CNG vehicles, as filters are rarely if ever fitted on CNG vehicles at present. Given that particle filters are already fitted to direct-injection petrol,diesel cars and trucks and will be fitted to gas trucks from 2023, swift adaptation of this technology for CNG cars and vans should be possible.

4. **Vehicle emissions testing should include all particles.** Particle number measurement during official tests[13] must go beyond the current 23nm size threshold. Accurate measurement down to 10nm is already possible on the road and in the laboratory. Further improvements to the measurement equipment should be made to allow for the measurement of particles as small as 2.5 nm in the laboratory during type-approval, even if in practice this might require accepting a lower measurement accuracy for these particles. This would ensure that all particles released from vehicle exhausts are regulated which is of great importance given their harm to human health and the environment.

5. **The implementation date of the on-road particle number limit for heavy duty (HD) CNG vehicles (part of EURO VI Step E)[14] should be brought forward and aligned with the implementation date for diesel heavy duty vehicles.** The current provisions give CNG HD vehicles an unfair regulatory advantage by giving CNG an additional 2 years to comply, compared to diesel vehicles.

6. **An ammonia emission limit needs to be introduced for all light duty passenger cars and vans.** An ammonia emission limit already exists for heavy duty trucks, however an ammonia emission limit should also be implemented for cars and vans to ensure that ammonia emissions from all vehicles are reduced.

The upcoming post-Euro 6 emissions legislation that the European Commission has now started working on is the right opportunity to implement the new limits for particle and ammonia

[13] Laboratory (World Harmonised Light Vehicle Test Procedure (WLTP)) and road (Real Driving Emissions (RDE) based type-approval and in-service conformity testing for cars and vans. Laboratory (World Harmonised Stationary cycle (WHSC) and World Harmonised Transient Cycle (WHTC) and on road emission testing using a Portable Emissions Measurement System (PEMS) for type-approval and in-service conformity testing for buses and trucks.

[14] C(2019) 7884 final amending Regulation (EU) No 582/2011.

emissions described above. But strengthening emission limits and test procedures is not enough. The future Euro standards must also deliver zero emission technology as outlined in the European Green Deal by mapping out a clear pathway towards only zero emission new vehicle sales. All new cars and vans must emit zero pollution as well as zero CO_2 emission (via EU CO_2 standards) by 2035 at the latest, and all new heavy duty vehicles by 2040 in order to achieve the EU's goal of net zero CO_2 emissions by 2050. In the context of the current Covid-19 pandemic, the move to zero emission mobility, both in terms of air pollutant and CO_2 emissions, is more important than ever as public health experts warn that polluted air probably makes people more susceptible to viruses[15] and the World Health Organisation has stated that climate change will likely increase the occurrence of infectious diseases.[16]

While switching away from fossil gas to biogas or biomethane is one proposed solution for making gas-powered vehicles cleaner and enabling reductions in CO_2 emissions, T&E has analysed this possibility and has come to the conclusion that it is not a viable solution neither for air quality nor for decarbonising road transport[17]. Firstly, as the chemical composition of fossil gas and biomethane does not vary significantly, switching to biomethane is not expected to result in a significant decrease or elimination of particle emissions[18] or other pollutants such as NOx (nitrogen oxides) .As such, even when powered with biomethane, gas vehicles will continue to contribute to air pollution. Secondly, there is not enough sustainable biogas/biomethane feedstocks (wastes, residues) in the EU to meet the energy demand of EU transport. Even if sustainable feedstocks are exploited to their maximum potential, biomethane could only cover 6.2-9.5% of transport's energy needs.[19] Thirdly, it is impossible to ensure that gas vehicles actually run on biogas or biomethane as the two fuels are essentially interchangeable, there is no monitoring of use or compliance mechanism in place and it is highly unlikely that an effective mechanism could be introduced in the future.

1. Introduction: Particle pollution is a big problem in Europe

Particle pollution is increasingly seen across Europe as the biggest problem for air quality, with the latest report from the European Environmental Agency showing that progress in the reduction of $PM_{2.5}$ pollution (particulate matter smaller than 2.5 microns) has effectively stalled at a point where 7 out of 10 residents of European cities breathe air above the World Health Organisations' recommended particle pollution threshold[20]. This is of serious concern to public

[15] European Public Health Alliance. (2020, 03, 16) Coronavirus threat greater for polluted cities.
[16] World Health Organisation. (2020, 03, 30) Climate change and human health - risks and responses. Summary.
[17] T&E. (2018) CNG and LNG for vehicles and ships - the facts.
[18] Lim, C. (2015) Performance and emission characteristics of a vehicle fueled with enriched biogas and natural gases. *Applied Energy*.
[19] T&E. (2018) CNG and LNG for vehicles and ships- the facts.
[20] EEA. (2019) Air quality in Europe.

health as particle pollution has been linked to a number of serious diseases including cancer[21], Alzheimer's[22] and cardiovascular and respiratory illnesses[23] and thus far no safe level of air pollution can be identified[24]. In cities, road transport is a large contributor to $PM_{2.5}$ pollution, accounting for 29% of $PM_{2.5}$ emissions in Brussels[25], 54% in Madrid[26] and 31% in Warsaw[27].

In recent years parts of the automotive industry have been heralding CNG (compressed natural gas) cars, buses and trucks as a solution to this air pollution crisis, boldy claiming that these vehicles produce virtually no particle pollution. VW maintains that the 'fraction of fine particles is minimal' in the exhaust emissions from driving in CNG mode, available in the hugely popular Golf and Polo models[28]. Truck maker Scania claims that their new CNG XT range truck 'emits 95% fewer particles'[29] compared to diesel counterparts and Volvo Trucks claim that their CNG trucks emit 'very low levels of harmful particles'[30]and finally the Belgian natural gas distributor Fluxys says that CNG vehicles emit 'practically no particles'[31].

However, a review of the latest scientific studies focusing on the number of particles emitted from CNG vehicles including very small currently unregulated particles (<23nm) , rather than just the mass of particles emitted shows that CNG vehicles do in fact emit a large amount of particle pollution and therefore cannot be seen as a clean option when it comes to road transport. This short report will summarise the latest evidence on CNG particle pollution including smaller than 23nm particle emissions and provide key policy recommendations to limit the environmental and health impacts of these vehicles.

[21] WHO. (2019) Air Pollution - Key Facts.
[22] Younan, D. et. al.. (2020) Particulate matter and episodic memory decline mediated by early neuroanatomic biomarkers of Alzherimer's disease. *Brain.*
[23] WHO. (2019) Air Pollution - Key Facts.
[24] HEI. (21st-22nd January 2020) Brussels Meeting on Air Pollution and Health: Recent Advances to inform the European Green Deal.
[25] Brussels Low Emission Zone. (January 2019) Expected effects from the low emission zone on car fleet and air quality in the Brussels region.
[26] Medio Ambiente y Movilidad. (December 2019) Inventario de emisiones de contaminantes a la atmósfera en el municipio de Madrid 2017. Documento 1- Resumen de las emisiones (periodo 1999-2017).
[27] 21% exhaust, 10% non-exhaust. Juda-Rezler. K. et. al.. (2020) Characterization of atmospheric $PM_{2.5}$ sources at a Central European urban background site. *Science of the Total Environment*.
[28] VW. (2019, 01,19) Volkswagen gives some gas with new TGI models.
[29]https://www.scania.com/group/en/home/newsroom/news/2018/first-scania-gas-powered-version-of-xt-delivered-to-belgium.html Accessed 20/05/2019
[30] https://www.volvotrucks.co.uk/en-gb/trucks/trucks/volvo-fe/volvo-fe-cng.html Accessed 20/05/2020
[31] Colleyn, M. (2018, 06, 18) Bruxelles ouvre la voie au gaz pour remplacer le diesel. L'Echo.

2. Particle number pollution from CNG must be regulated and particle filters fitted

2.1 The number of particles, not only their mass, determines the health impact

Firstly, most of the claims of auto manufacturers regarding the supposed 'low' levels of particle pollution from CNG vehicles are based on the reduction of Particulate Matter (PM) compared to diesel. However, this metric does not tell the full story of particle pollution; PM represents the total **mass** of all of the particles emitted from the exhaust but gives no indication on the **number** of particles emitted. The problem with CNG vehicles is that they emit a large **number** of very small particles[32], which are on average much smaller than diesel particles. As these particles are smaller they also have a much lower **mass** and contribute very little to total PM, compared to diesel particles. This difference in particle mass allows manufacturer's to claim that CNG vehicles produce a lot less particles than other internal combustion technologies and that particle emissions from CNG are 'almost completely eliminated'. But this is only true when looking at particle **mass** and not particle **number**. When particle number emissions are taken into account, the emission of particles from CNG can be very high, in some cases higher than the particle number emission limits applicable to equivalent petrol and diesel technology[33].

Furthermore, from an air quality perspective only focusing on particle **mass** and not particle **number** pollution from CNG vehicles is a big problem as there is a growing body of evidence to suggest that the number of particles emitted from vehicle exhausts is a better indicator of certain health effects than particle mass[34]. Most recently, an increase in the ambient concentration of particles by 10,000/cm^3 has been shown to increase the risk of developing hypertension/diabetes by 3-4%, heart failure by 2-5% and brain tumours by 10- 13%[35]. This is equivalent to one new brain tumour case per 100,000 people for every 10,000/cm^3 increase in the number of ultrafine particles. The latest recommendation from experts is that future vehicle emissions standards should move to regulating particle number primarily[36]. As such, it is particle **number** not particle **mass** emissions that should be primarily considered when discussing particle pollution from combustion-engined vehicles, including CNG.

2.2 No particle number limit means no particle filters for CNG

CNG passenger cars and vans are not subject to a particle number emission limit. This is despite such a limit being in place for all diesel cars since 2013 and all direct-injection petrol cars from 2015. This legislative loophole gives CNG cars as well as port-fuel injection petrol cars an unfair

[32] DownToTen. Samaras, Z. (2019) Measuring automotive exhaust particles down to 10 nanometers-DownToTen. Integer Emissions Summit & AdBlue Conference Europe 2019. Munich.
[33] Suarez-Bertoa, R. et. al.. (2019) On-road emissions of passenger cars beyond the boundary conditions of the real-driving emissions test. *Environmental Research*.
[34] DEFRA. Particle number concentrations network. Accessed 25/02/2020.
[35] Weichenthal, S. (2019) Emerging health impacts of ambient ultrafine particles and deep learning for air pollution exposure science. ETH-Nanoparticle Conference. Zurich.
[36] CLOVE. (2020, 02, 04) Study on post-Euro 6/VI emission standards in Europe (Part B), presentation to AGVES. Brussels.

advantage compared to diesel, direct-injection petrol or electric cars as CNG vehicles are effectively able to emit an unlimited number of particles. Consequently, particle filters, which reduce the amount of particle pollution released from the tailpipe (but do not eliminate them all together, allowing as many as 600 billion to be emitted for each kilometer)) and are used on all diesel and direct-injection petrol cars, are rarely, if ever, used for CNG cars and vans.

For heavy duty CNG vehicles the latest step of the EURO VI heavy duty regulation (Step E)[37] introduces an on-road particle number emission limit for all heavy duty vehicles. However, compared to diesel vehicles, CNG vehicles are given an additional two years (from 2023) to comply with the particle emission limit, once again giving CNG vehicles an unfair advantage compared to other propulsion technologies and allowing these vehicles to continue emitting huge amounts of particle pollution for three years longer than necessary. Moreover, as we will see, the current measurement procedure could still allow them to avoid fitting a filter.

Given that particle filters are already fitted to petrol and diesel cars and trucks and might be fitted to CNG trucks from 2023, swift adaptation of this technology for CNG cars and vans should be possible.

3. Large numbers of particles are emitted from all types of CNG vehicles

The next section discusses the emissions of currently regulated larger than 23nm solid particles. For unregulated smaller than 23nm solid particles please see section 4.

3.1. CNG trucks can emit more particles than is allowed for passenger cars

While truck manufacturers make claims that CNG trucks emit 'very low levels of harmful particles' [38] A recent truck emission testing project has shown that particle number emissions from trucks driving on urban and rural roads can be much higher than is allowed for diesel and petrol passenger cars.

A recent project called the 'Dedicated to gas study'[39], focused on pollutant emissions from heavy duty gas vehicles. The two CNG trucks tested were both the same Euro VI 26 tonne rigid truck model except one was an older generation of the other. The road based PEMS tests under a light load of 60%[40] show that particle number emissions stay below the $6x10^{11}$/km PN limit applicable to light duty cars and vans. However, when the load is increased to 100% of the maximum payload, PN emissions exceed this threshold under all driving conditions with particularly high emissions during urban driving of more than three times the allowable PN emissions of cars and vans. Unfortunately, the author's of this study presented the PN result in particles emitted per

[37] C(2019) 7884 final amending Regulation (EU) No 582/2011.
[38] https://www.volvotrucks.be/nl-be/trucks/volvo-fe/volvo-fe-cng.html. Accessed 15/07/2019.
[39] Cenex. Lejona. V. (2019) Dedicated to Gas. An Innovate UK research project to assess the viability of gas vehicles.
[40] 60% of maximum payload.

kilometer, not kilowatt hour, making a comparison to the legal heavy-duty PN emission limit which is expressed in particles per kilowatt hour impossible.

The laboratory based World Harmonised Transient Cycle (WHTC) tests[41] (Figure. 1) also showed that both trucks emit large numbers of particles, particularly during urban and rural driving. The urban driving particle number emissions were almost 3 x 10^{12} /km and during rural driving emissions were around 2 x 10^{12} /km. In comparison, the particle number emission limit for petrol and diesel cars and vans is 6 x10^{11} /km, around 50% less than emitted from these two trucks.[42] Worryingly, the test data also shows that the newer model of the truck emits more particle pollution during urban and motorway driving than the older generation. While some of the difference could potentially be due to test-to-test variability, the newest generation of trucks should have the best and 'cleanest' engine and emission control technology and should reasonably be expected to have lower particle emissions than the previous generation model. Here, this does not appear to be the case, with the newest generation truck producing more particle pollution. The results of this study not only show that CNG trucks can produce a large amount of particles but also suggests that particle pollution from certain CNG trucks during urban and motorway driving might be increasing - a step backwards for air quality. This is particularly concerning given that many urban areas are already struggling with high levels of particle pollution.

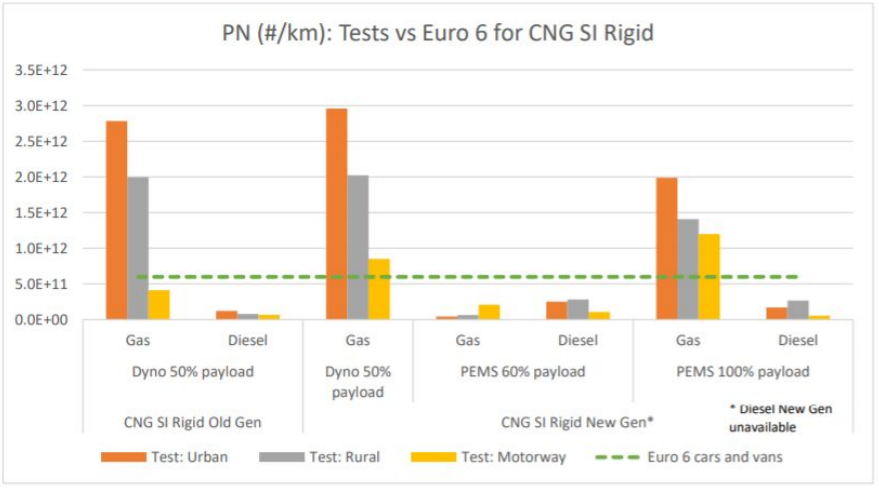

Figure 1. Results of WHTC dynamometer testing of two 26 tonne CNG trucks from the 'Dedicated to Gas study'[43]. Particle number emissions are particularly high during urban and rural driving. The green line denotes the particle number emission limit for Euro 6 cars and vans.

[41] Tested on dyno with 50% payload.
[42] The authors of the study provided the PN emission results in #/km instead of #/kWH making a comparison to the heavy duty PN emission limits impossible
[43] Cenex. Lejona. V. (2019) Dedicated to Gas. An Innovate UK research project to assess the viability of gas vehicles.

Another scientific study by the European Commission's Joint Research Centre (JRC) on heavy duty emissions[44] looked in detail at the particle number emissions of four Euro VI CNG trucks of between 2.5-27 tonnes in mass during on-road and laboratory tests. Weighted particle number emissions for these vehicles were high at between 8 x 10^{11}- 3 x 10^{12} /km, depending on the vehicle and type of test[45] (Figure 2). In line with the results of the 'Dedicated to gas study' the largest number of particles were emitted during cold start (1x10^{12}- 5x10^{12}/km) and urban driving (8x10^{11}-2x10^{12}/km) for all but one of the four trucks tested, suggesting that large particle emissions during urban driving may be widespread across the heavy duty CNG fleet.

Given that both independent studies have shown that particle number emissions from CNG trucks can be high especially during urban driving, CNG trucks cannot be seen as a clean alternative to other internal combustion technology. The only truly clean solution are zero-emission trucks which are already starting production this year. The Daimler's eCanter (7.5 tonne) is already in production[46], and will be followed by heavier e-trucks from Renault (16 and 26 tonne)[47] and Volvo (16 and 27 tonne)[48] this year meaning that soon many zero emission alternatives will be available for up to 27 tonne trucks.

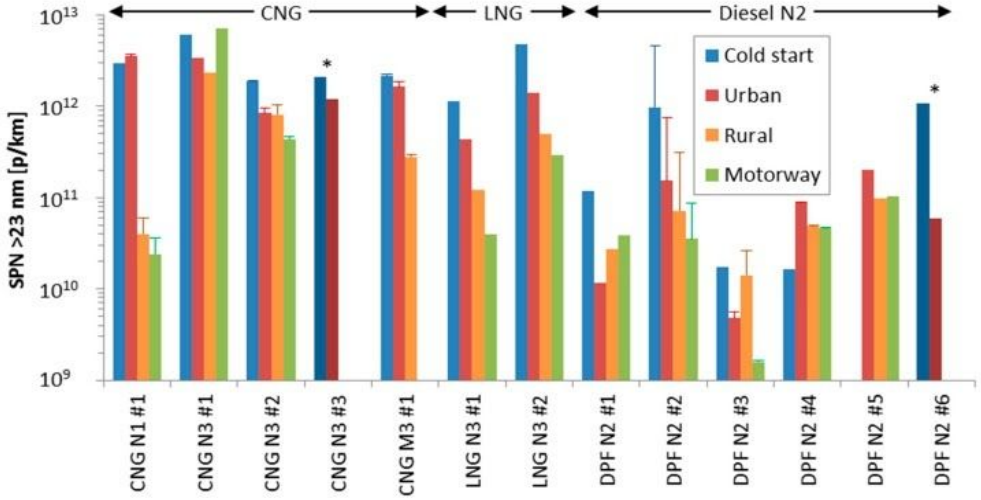

Figure 2. Particle number emissions result during cold start, urban, rural and motorway driving from 4 CNG trucks and a CNG bus obtained from a study conducted by the European Commissions' Joint Research Center.[49] For three of the CNG trucks as well as the CNG bus particle number emissions are particularly high during cold-start and urban driving. While the JRC study also looked at emissions

[44] Giechaskiel, B. et. al.. (2018) Solid particle number emission factors of euro VI heavy-duty vehicles on the road and in the laboratory. *International journal of environmental research and public health*.
[45] The results were weighted 14% cold start and 86% mean value of urban, rural and motorway as per the heavy duty engine type-approval procedure.
[46] Daimler. (2017, 12, 04) FUSO eCanter- first all-electric trucks in series production delivered to customers in Europe.
[47] Green Car Congress. (2020, 03, 11) Renault Trucks starts serial production of its electric trucks.
[48] Electrive.com. (2019, 11, 06) Volvo FL and Volvo FE electric trucks start sales in Europe.
[49] Giechaskiel, B. et. al.. (2018) Solid particle number emission factors of euro VI heavy-duty vehicles on the road and in the laboratory. *International journal of environmental research and public health*.

from Liquified natural gas (LNG), for which particle emission results were broadly similar, as well as diesel trucks, only results of CNG trucks are considered in this report.

3.2. CNG buses are also a source of particle pollution

The same report by the JRC on heavy duty emissions[50] also showed that particle emissions from Euro VI CNG city buses can be high, with particularly high emissions also measured during urban driving. The on-road testing recorded average urban particle number emissions of 1 x 10^{12} / km for the city bus tested, once again higher than permitted for diesel and petrol cars and far from non-existent. While data on particle number pollution from Euro VI CNG buses is very limited, the JRC data on PN emission of a CNG Euro 6 bus presented in Figure 2. shows that CNG buses have the potential to emit large numbers of particles, especially during cold start and urban driving[51]. As such, CNG buses cannot simply be blanket labelled as 'clean' based on particle mass measurement alone as this metric does not give a full picture of particle pollution from these vehicles. To enable a fair and full comparison of emissions between different propulsion technologies (including electric) particle number emissions must also be considered.

Given the potentially high particle number emissions from CNG buses, the recent purchase of CNG buses by cities in Poland[52], Spain[53] and Italy[54] as well as other EU member states is a possible risk for urban air quality. City buses are almost exclusively driven in urban areas next to where people live, work and breathe, therefore poor urban emissions performance has the potential to impact a large number of people. Particle pollution from public road transport is unnecessary and already completely avoidable. Truly zero emission electric buses are already available for purchase from manufacturers such as Irizar, Solaris, VDL and Volvo and the number of electric buses in Europe has increased 11 fold in the last five years[55]. Given that there is already a large amount of zero emission buses successfully in use today, there is absolutely no reason for cities to continue to purchase polluting CNG buses when completely zero emission alternatives are available.

3.3. CNG vans exceed the particle number emission limit for diesel and petrol vans

However, it is not just CNG heavy duty trucks and buses that have a particle emission problem. Testing of a Euro 6b CNG van during real world driving conditions (RDE), again by the EU's Joint

[50] Giechaskiel, B. et. al.. (2018) Solid particle number emission factors of euro VI heavy-duty vehicles on the road and in the laboratory. *International journal of environmental research and public health*.
[51] Giechaskiel, B. et. al.. (2018) Solid particle number emission factors of euro VI heavy-duty vehicles on the road and in the laboratory. *International journal of environmental research and public health*.
[52] NGV Global News. (2018, 07, 20) Man to supply 110 Lion's City CNG buses to Warsaw in 2019.
[53] SMMT. (2018, 07, 25) Spanish capital buys CNG bus fleet.
[54] Sustainable Bus. (2018, 07, 29) More than 300 CNG buses in Tper (Bologna) fleet. And 2019 will be LNG's year.
[55] Green Car Congress. (2019, 10, 20) Number of electric buses in Europe has increased from around 200 to 2200 in 5 years.

Research Centre, measured very high PN emissions of up to $1x10^{12}$ /km[56]. This is more than 50% higher than the $6x10^{11}$ / km legal limit which is applicable to equivalent diesel and petrol vehicles [57] indicating that particle number emissions from CNG vans during real world driving can also be very high. The average emissions on all RDE tests for this van were $6x10^{11}$/km on the verge of the particle number emission limit applicable diesel and petrol vans[58]. These results show that CNG vans can still produce a large amount of particles during real world driving conditions and therefore cannot be considered as 'clean' when it comes to pollutant emissions.

3.4. Particle pollution from CNG cars highest during cold-start and urban driving

While particle number emissions from CNG passenger cars are generally reported as below the $6x10^{11}$/km limit[59,60], the emission performance of CNG vehicles varies greatly depending on the type of vehicle and test undertaken. Testing led by the Czech Technical University and Czech University of Life Sciences of four CNG Euro 6 cars on 5 different laboratory tests[61] measured a range in particle emissions of between $9x10^{9}$-$9x10^{11}$/km depending on the test undertaken, showing that under certain driving conditions CNG cars can emit more than the legal particle number emission limit for diesel and petrol cars. This is concerning, as what really matters for air quality and public health is that emission limits are respected under all driving conditions by all cars, but this does not always appear to be the case for CNG. Worryingly, the highest average particle number emissions for the four CNG cars tested were measured during cold start ($4.6x10^{11}$/km) and urban driving (4.9×10^{11}/km)[62], which is particularly concerning for urban air quality.

However, the particles discussed thus far are only half of the particle pollution story, the smallest and potentially the most harmful particles are usually not even measured.

4. The smallest particles are usually not even measured

Particle emissions measured during most emissions' tests, such as the ones discussed above, do not actually include all of the particles emitted from vehicle exhausts. The current method for measuring particles prescribed by the EU regulation only measures solid particles larger than

[56] Suarez-Bertoa, R. et. al.. (2019) On-road emissions of passenger cars beyond the boundary conditions of the real-driving emissions test. *Environmental Research*.
[57] Not currently applicable to CNG cars or vans, this is covered in detail in section 4.
[58] Average emissions on the RDE test are within the diesel and petrol particle number emission limit if a conformity factor of 1.5 is applied, to account for any increased error of the Portable Emission Measurement System (PEMS) used to measure on-road emission compared to laboratory based equipment.
[59]Giechaskiel, B. et.al. (2019) Regulating particle number measurement from the tailpipe of light-duty vehicles: The next step?.*Environmental Research*.
[60]Kontses, A. et.al.. (2020) Particle number (PN) emissions from gasoline, diesel, LPG, CNG and hybrid-electric light-duty vehicles under real-world driving conditions. *Atmospheric Environment*.
[61] Vojtíšek-Lom, M. et.al.. (2018) On-road and laboratory emissions of NO, NO_2, NH_3, N_2O and CH_4 from late-model EU light utility vehicles: Comparison of diesel and CNG. *Science of the Total Environment*.
[62] Vojtíšek-Lom, M. et.al.. (2018) On-road and laboratory emissions of NO, NO_2, NH_3, N_2O and CH_4 from late-model EU light utility vehicles: Comparison of diesel and CNG. *Science of the Total Environment*.

23nm, despite particles as small as 2.5 nm emitted out of vehicle exhausts[63]. This means that a large proportion of particle pollution from cars, vans, buses and trucks is currently ignored. These miniscule particles are smaller than a typical virus and there is a growing body of evidence to suggest that these particles are a significant risk for public health. Medical studies have shown that these particles are able to deposit in the lungs and airways with very high efficiency[64] and are able to travel from there to other areas of the body such as the brain[65]. The most recent evidence has linked these particles to an increased risk of brain cancer[66].

As part of the future vehicle emission standards for light duty and heavy duty vehicles (post Euro 6/VI), the measurement threshold for particles has been proposed for extension from the current 23nm threshold to 10nm. However, the data discussed in the following section suggests that this will not be enough to ensure implementation of particle filters on all CNG vehicles, which are critical for reducing particle pollution, with further measures necessary to ensure this.

4.1. CNG cars emit a lot of very small particles

Only measuring particles larger than 23nm significantly underestimates the total number of particles emitted from vehicles with an internal combustion engine, particularly those fuelled by CNG as a large proportion CNG particles are smaller than 23nm[67]. The EU-funded DownToTen research project, which specialises in the measurement of ultrafine particles, has measured the emissions of several Euro 6 CNG cars and vans. Their research shows because the smallest particles are currently not measured, a large proportion of particle pollution from Euro 6 CNG cars is ignored.

One of the cars tested, a Euro 6b CNG/petrol dual-fuel passenger car (figure 3) emitted between 100-500 times more particles when particles as small as 2.5nm[68] were measured (compared to the usual 23nm cut-off size) during type-approval WLTC (World Harmonised Light Vehicles Test Cycle) and NEDC (New European Drive Cycle) tests while running on CNG fuel. This meant that while the car met the particle number emission limit of $6x10^{11}$ / km, when only particles larger than 23nm were measured, the car exceeded the limit by between 5-8 times when the measurement was extended to particles as small as 2.5nm, with total particle emissions in the range of $3x10^{12}$-$5x10^{12}$/km. Furthermore the car emitted the same amount of total particles or more when

[63] DownToTen. Samaras, Z. (2019) Measuring automotive exhaust particles down to 10 nanometers-DownToTen. Integer Emissions Summit & AdBlue Conference Europe 2019. Munich.
[64] ICRP respiratory deposition model as presented in DownToTen. Samaras, Z. (2019) Measuring automotive exhaust particles down to 10 nanometers-DownToTen. Integer Emissions Summit & AdBlue Conference Europe 2019. Munich.
[65] Oberdörster, G. et.al.. (2004) Translocation of inhaled ultrafine particles to the Brain. *Inhalation Toxicology*.
[66] Weichenthal, S. et al.. (2020) Within-City Spatial Variations in Ambient Ultrafine Particle Concentrations and Incident Brain Tumors in Adults. *Epidemiology*.
[67] Giechaskiel, B. et. al.. (2018) Solid particle number emission factors of euro VI heavy-duty vehicles on the road and in the laboratory. *International journal of environmental research and public health*.
[68] DownToTen. Samaras, Z. (2019) Particle emissions measurement on CNG vehicle focusing on sub-23nm. TAP conference.

running on compressed natural gas compared to petrol confirming that CNG is not a cleaner option.

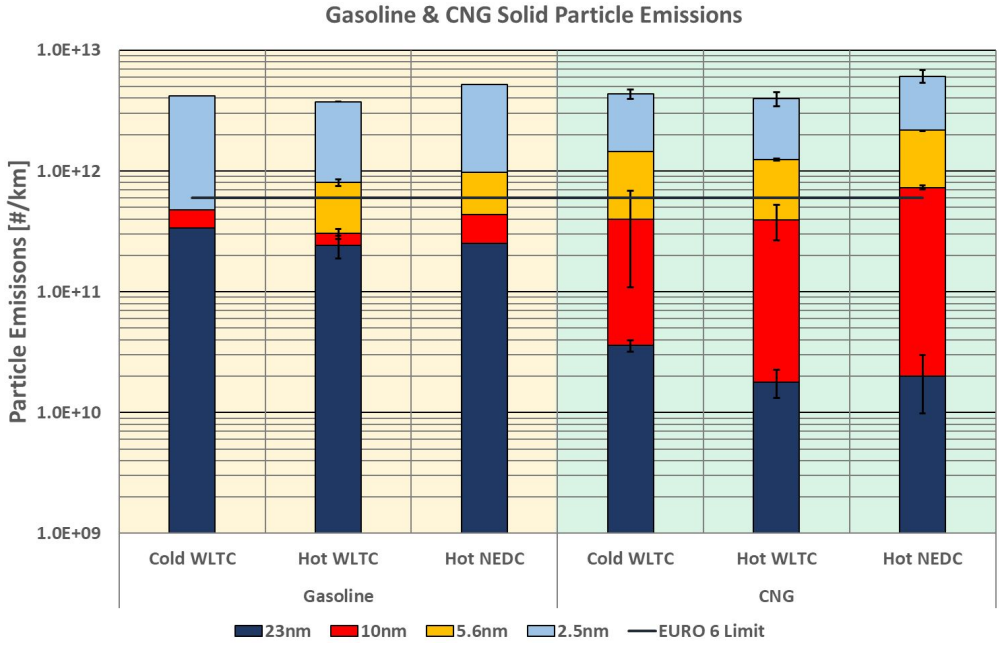

Figure 3. WLTC and NEDC testing of a dual-fuel petrol and compressed natural gas car by the DownToTen project[69] confirms that CNG is not cleaner when it comes to particle emissions when particles of all sizes are measured (logarithmic scale).

A large proportion of the particles emitted from this car were below 10nm in size. Emissions of particles larger than 10nm on the cold WLTC tests (used at type-approval) were around ten times lower than when particles as small as 2.5nm were measured and still below the $6x10^{11}$/km limit. This means that extending the current particle measurement threshold to include particles larger than 10nm only would miss a large proportion of the particles emitted from this vehicle and would be insufficient to ensure that a particle filter would need to be fitted to this car. In order to ensure that a particle filter was fitted to this car the particle number emission limit of $6x10^{11}$/km would need to be reduced significantly and, if possible, particle measurement should be extended to 2.5nm to ensure that all particles are measured and regulated. For particles of between 2.5-10nm in size this may require accepting a lower measurement accuracy compared to that which is required for larger than 10nm particles.

Another vehicle, tested by the DownToTen group, a Euro 6 CNG van tested on the WLTC test cycle with both cold and hot engine start tests, had much higher particle emissions than the car discussed above. This meant that while the PN emission limit was respected when particles down to 23nm were measured, once the particle measurement was extended to both 10nm and 2.5nm

[69] DownToTen. Samaras, Z. (2019) Particle emissions measurement on CNG vehicles focusing on sub-23nm. TAP conference.

the van would not have passed either test[70]. Similar results were reported by the JRC from WLTC testing of two CNG cars; a Euro 6b and a Euro 6d prototype[71]. When particles larger than 10nm were also measured the total number of particles increased by 127% for the Euro 6b car and 152% for the Euro 6d compared to when only particles larger than 23nm were measured. Furthermore, while the Euro 6b vehicle met the $6x10^{11}$/km PN limit for particles larger than 23nm, this was not the case when particles larger than 10nm were included. The Euro 6d prototype met the PN emission limit when both 23nm and 10nm particles were measured suggesting that for this car, as with the dual fuel car tested by the DownToTen group, further measures than just the extension of the measurement threshold to 10nm are necessary to ensure the implementation of filters on these vehicles.

4.2. CNG heavy duty emits a lot of small particles too

Small particle emissions are also an issue for CNG heavy duty vehicles. The JRC found, based on the last 3-4 years of their own testing work, that the emissions of 10-23nm particles were almost 100% higher than emissions of only larger than 23nm particles for CNG heavy duty vehicles[71,72].

Furthermore, a study at the Southwestern Research Institute compared the particle number emissions of a Euro VI 2014 Volvo MD13TC heavy duty diesel engine with a CNG 2012 Cummins ISX12G heavy duty engine. The study found that emissions of particles larger than 25nm[73] from the CNG engine were between 2-8 times higher than the diesel engine, depending on the type of test performed. On one test the CNG engine emitted almost 5×10^{12} particles / kW h. This is almost ten times higher than the particle number limit for diesel trucks of 6×10^{11}/ kWh. When particles smaller than 25nm were measured the particle emissions of the CNG engine were even higher, emitting between 5-10 times more of these ultrafine particles than the diesel engine[74].

The evidence presented above clearly shows that the amount of small particles emitted from CNG heavy duty vehicles can be huge, directly contradicting claims by vehicle manufacturers that CNG cars and trucks emit very little or no particles. The current measurement of particles only down to 23nm in size effectively omits a large proportion of CNG particle pollution as a large proportion of particles emitted from CNG vehicles are smaller than the currently measured size. This clearly demonstrates that in order to fully account for all of the particles emitted from CNG vehicles it is necessary to increase the lower particle size measurement limit from the current 23 nm to 2.5nm.

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[70] DownToTen. Andersson, J. et.al.. (2019, 06, 17-20) Update on sub-23nm exhaust emissions using the DownToTen sampling and measurement systems. ETH conference on Combustion Generated Nanoparticles. Zurich. Switzerland.

[71] Giechaskiel, B. et.al.. (2019) Regulating particle number measurements from the tailpipe of light-duty vehicles: The next step?. *Environmental Research.*

[72] Giechaskiel. B., et.al.. (2018) Solid particle number emission factors of Euro VI Heavy-Duty vehicles on the road and in the laboratory. *Int. J. Environ. Res. Public Health.* Similar results were also observed for LNG HD vehicles.

[73] As these tests took place in the U.S. where there is no legal requirement to measure PN emissions a 25nm threshold was used for measuring PN emissions instead of the 23nm threshold used in Europe.

[74] Southwest Research Institute. Khalek, A, M. et.al.. (2017) Particle Number and Ash Emissions from a Heavy Duty Natural Gas and Diesel w/DPF Engine. 21st ETH Conference on Combustion Generated Nanoparticles. Zurich.

5. CNG cars and vans also cause secondary particle pollution

5.1. CNG cars and vans can also emit large amounts of ammonia which contributes to secondary particle formation

Not all particle pollution from cars is directly emitted as particles from the exhaust. Ammonia, a clear pungent gas emitted from vehicle exhausts forms so-called 'secondary' particles once it is emitted into the air. In fact, it is estimated that each milligram of ammonia can result in the formation of 1 milligram of $PM_{2.5}$ (particles smaller than 2.5 micrometers)[75] when mixed with ambient air. Unfortunately, while there is data showing that ammonia emissions are an issue for some passenger cars and vans, including CNG, only ammonia emissions from heavy duty trucks are regulated in the EU at present.

Ammonia emissions can be a significant issue for CNG vehicles. Testing of a Euro 6b CNG van by the European Commission's Joint Research Centre during real world driving (RDE) recorded ammonia emissions of up to 66mg/km[76], potentially resulting in the formation of 66mg/km of secondary particles. The current particle mass (PM) emission limit for vans is 4.5 mg/km meaning that this limit would effectively be exceeded over 14 times by secondary particles formed from ammonia alone. Another study measuring on road ammonia emissions from 3 Euro 6 CNG cars recorded ammonia emissions of between 10-20 mg/km, with the highest emission recorded during urban driving.The same study recorded ammonia emission of between 13-24 mg/km during laboratory based tests[77].

These studies indicate that ammonia emissions, which contribute to particle pollution, can be high from CNG vehicles. However, as the emissions of ammonia and the secondary particles that it forms are currently completely unregulated for passenger cars, these high ammonia emissions are not considered illegal. A limit for ammonia emissions must be implemented for cars and vans as is already the case for heavy duty trucks and buses. The implementation of such a limit will help to reduce the effect that ammonia emissions can have on air quality.

6. Conclusions and Policy Recommendations

The emerging evidence regarding the high emissions of both particles and ammonia, a precursor of secondary particles, clearly excludes CNG vehicles from being a solution to Europe's air pollution crisis. Policies to promote the use of this fuel in order to improve air quality are counterproductive and the only way to truly reduce air pollution from transport and achieve the 'zero pollution ambition' of the European Green Deal is to move away from vehicles with an internal combustion engine and fully embrace zero emission technology. In order to achieve this and to limit the environmental and health impacts of CNG vehicles, T&E proposes the following policy recommendations:

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[75] JRC. Suarez-Bertoa, R. (2019) Current non-regulated emissions in the EU, Integer Emissions Summit & AdBlue Conference Europe 2019. Munich.

[76] Suarez-Bertoa, R. et. al.. (2019) On-road emissions of passenger cars beyond the boundary conditions of the real-driving emissions test. *Environmental Research*.

[77] Kontses, A. et.al.. (2019) Particle number (PN) emissions from gasoline, diesel, LPG, CNG and hybrid-electric light-duty vehicles under real-world driving conditions. *Atmospheric Environment.*

EU funding frameworks and policy strategies should not classify CNG as a clean vehicle technology or sustainable transport fuel. A number of EU policy instruments including the Alternative Fuel Infrastructure Directive (AFID), Connecting Europe Facility (CEF) and Clean Vehicles Directive (CVD) allow gas technologies, including CNG, to be labeled as clean and therefore benefit from policy and financial support. This is not in line with the EU Green Deal and is not supported by evidence which shows CNG vehicles emit dangerous pollutants and are therefore decisively not clean. In the future - eg. the Next Generation EU Fund and EU Budget 2021-2027 - only zero emissions technology and infrastructure should be eligible. No binding targets for gas infrastructure or support for local authorities to purchase CNG light or heavy duty vehicles should be allowed.

CNG vehicles should not be counted, labelled or marketed as a 'cleaner, low emission' option for Low-Emission Zones, tolls, taxes or public procurement policies across Europe. The research summarised above shows CNG is not a low polluting option when all pollution from CNG vehicles is taken into account. As such, these vehicles should not be treated as low emission (e.g. when it comes to tolls for commercial vehicles or Low-Emission Zones) where other conventionally fuelled vehicles are banned. Public procurement should not include the purchase of CNG vehicles especially buses as this will fail to improve air quality in towns and cities. Only truly zero or low emission capable technologies (e.g. battery and fuel cell) should be classified as clean given they do not produce tailpipe emissions.

A particle number emission limit must be introduced for light duty CNG vehicles in the future post-Euro 6 emission standards. This limit must be set at a low enough level to ensure particle filters are mandatory for all CNG vehicles, as filters are rarely if ever fitted on CNG vehicles at present. Given that particle filters are already fitted to direct-injection petrol,diesel cars and trucks and will be fitted to gas trucks from 2023, swift adaptation of this technology for CNG cars and vans should be possible.

Vehicle emissions testing should include all particles. Particle number measurement during official tests[78] must go beyond the current 23nm size threshold. Accurate measurement down to 10nm is already possible on the road and in the laboratory. Further improvements to the measurement equipment should be made to allow for the measurement of particles as small as 2.5 nm in the laboratory during type-approval, even if in practice this might require accepting a lower measurement accuracy for these particles. This would ensure that all particles released from vehicle exhausts are regulated which is of great importance given their harm to human health and the environment.

The implementation date of the on-road particle number limit for heavy duty (HD) CNG vehicles (part of EURO VI Step E)[79] should be brought forward and aligned with the

[78] Laboratory (World Harmonised Light Vehicle Test Procedure (WLTP)) and road (Real Driving Emissions (RDE) based type-approval and in-service conformity testing for cars and vans. Laboratory (World Harmonised Stationary cycle (WHSC) and World Harmonised Transient Cycle (WHTC) and on road emission testing using a Portable Emissions Measurement System (PEMS) for type-approval and in-service conformity testing for buses and trucks.

[79] C(2019) 7884 final amending Regulation (EU) No 582/2011.

implementation date for diesel heavy duty vehicles. The current provisions give CNG HD vehicles an unfair regulatory advantage by giving CNG an additional 2 years to comply, compared to diesel vehicles.

An ammonia emission limit needs to be introduced for all light duty passenger cars and vans. An ammonia emission limit already exists for heavy duty trucks, however an ammonia emission limit should also be implemented for cars and vans to ensure that ammonia emissions from all vehicles are reduced.

While switching away from fossil gas to biogas or biomethane is one proposed solution for making gas-powered vehicles cleaner and enabling reductions in CO_2 emissions, T&E has analysed this possibility and has come to the conclusion that it is not a viable solution neither for air quality nor for decarbonising road transport[80]. Firstly, as the chemical composition of fossil gas and biomethane does not vary significantly, switching to biomethane is not expected to result in a significant decrease or elimination of particle emissions or other pollutants such as NOx (nitrogen oxides)[81] As such, even when powered with biomethane, gas vehicles will continue to contribute to air pollution. Secondly, there is not enough sustainable biogas/biomethane feedstocks (wastes, residues) in the EU to meet the energy demand of EU transport. Even if sustainable feedstocks are exploited to their maximum potential, biomethane could only cover 6.2-9.5% of transport's energy needs.[82] Thirdly, it is impossible to ensure that gas vehicles actually run on biogas or biomethane as the two fuels are essentially interchangeable, there is no monitoring of use or compliance mechanism in place and it is highly unlikely that an effective mechanism could be introduced in the future.

The upcoming post-Euro 6 emissions legislation that the European Commission has now started working on is the perfect opportunity to implement the new limits for particle and ammonia emissions described above. But strengthening emission limits and test procedures is not enough. The future Euro standards must also deliver zero emission mobility as outlined in the European Green Deal by mapping out a clear pathway towards only zero emission new vehicle sales. All new cars and vans must emit zero pollution as well as zero CO_2 emission (via EU CO_2 standards) by 2035 at the latest, and all new heavy duty vehicles by 2040. Cars, vans, buses and trucks powered by Compressed Natural Gas do not fulfil these requirements.

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[80] T&E. (2018) CNG and LNG for vehicles and ships - the facts.
[81] Lim, C. (2015) Performance and emission characteristics of a vehicle fueled with enriched biogas and natural gases. *Applied Energy*.
[82] T&E. (2018) CNG and LNG for vehicles and ships- the facts.

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