

CNG and LNG for vehicles and ships - the facts

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Further Information

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Executive Summary

The EU has agreed to cut its greenhouse gas (GHG) emissions by at least 80-95% by 2050 and was the driving force behind the Paris Agreement which requires net zero emissions by the middle of the century. Climate policy will require a shift away from petroleum which currently provides nearly all of transport's energy needs. Apart from a transition towards zero emission technologies such as battery electric or hydrogen, regulators and governments across Europe are considering what role gas could play in decarbonising transport. The EU and several national governments support the use of methane in transport through regulations, tax breaks and subsidies. The gas industry - which is faced with stagnating or declining demand in other sectors in Europe - sees transport as a major growth market.

This report compiles the latest evidence on the environmental impacts of using gas as a transport fuel. The report is based on the most up to date literature, test results and data. It builds on a previous report by AEA-Ricardo but analyses in more detail issues such as the role of renewable methane (biomethane and power-to-methane) or the impact of tax policy.

Climate impacts

Gas vehicles and vessels have similar performance to other fossil fueled vehicles and vessels. Based on the latest available evidence fossil gas used in transport has no meaningful - and when including methane leakage and upstream effects in almost all cases no - climate benefits compared to petroleum based fossil fuels.

The overall (well to wheels/WTW) GHG performance identified in this study (with the medium upstream emissions) range from -12% to +9%, depending on the mode of transport. In cars, the GHG savings range from -7% to +6% compared to diesel. In heavy duty, the range is -2% to +5% compared to best in class diesel trucks and depending on the fuel and engine technology. In shipping, the figures are -12% to +9% compared to marine gas oil (MGO) but these figures are highly dependent on methane slip.

We did not find any evidence supporting the theoretical savings of gas vehicles, which are based on the lower carbon content of the fuel. In reality poor gas engine efficiency often offsets the benefit of the fuel already at tailpipe level. This points to the need for policies based on measured performance (through the EU's official tests), not the type of fuel. Uncertainties also exist regarding methane leakage at the vehicle level and the impact of boil-off and venting is not well documented but could have a significant negative impact on gas vehicle's environmental performance.

Methane is a very powerful greenhouse gas. Over a period of 100 years it is 28 times more potent than CO₂. In 2010 methane accounted for 20% of global GHG emissions. These (550 Mt) emissions are growing annually by 25 Mt, with 17Mt of the growth linked to fossil fuel extraction.

Methane leakage - i.e. unburnt methane leaking into the atmosphere - occurs throughout the supply chain (extraction, transport, refueling) and has a large and negative impact on fossil gas' climate impact. Currently the average fugitive methane emissions in the supply chain of fossil gas are 2.2% of fossil gas produced, ranging from 0.2% to 10%.

Recent evidence suggests that upstream methane emissions have been significantly underestimated - by up to 60%, making it likely that CNG/LNG upstream emissions and subsequently well-to-wheel or wake GHG emissions are worse than the abovementioned numbers (which are based on 'central' upstream emissions data). Given that methane is a very potent short term greenhouse gas any benefits from gas vehicles would only materialise several decades into

the future, well after the EU economy would need to be fully decarbonised.

Air quality impacts

There are only limited air quality benefits from using fossil gas in road transport. Gas vehicles perform similarly to petrol cars and only marginally better than diesel cars complying with the new RDE limits. The European Commission is working on a Euro 7 limit which will further decrease or entirely eliminate any benefit gas has over diesel cars. Far greater air quality improvements could be achieved by switching to zero emission cars.

For trucks, CNG and LNG offer no meaningful benefits (NO_x, PM) compared to vehicles complying with the Euro VI standard. HPDI (high pressure direct injection) truck technology has slightly higher NO_x emissions. Particle number emissions are also higher in methane powered transport, compared to diesel. For ships LNG has a clear benefit compared to heavy fuel oil although similar emissions performance can also be achieved by fitting ships with after treatment systems such as SCR and DPF and using low Sulphur marine gas oil.

Renewable methane

Biomethane and power-to-methane can have (significantly) lower GHG emissions than fossil gas. However, sustainable feedstocks for biomethane (wastes, residues) are very limited and cannot be sustainably scaled. Even if we assume the maximum sustainable potential is produced and all of it is allocated to transport - this is very unlikely to happen - biomethane could only cover 6.2-9.5% of transport's energy needs. Currently, only around 4% of gas consumed in the EU is renewable, and this is mainly produced from crops such as maize. The gas grid has just a 0.5% share of renewables, compared to almost 30% of renewables in electricity generation. Less than 1% of biogas produced is currently used in transport.

Crop-based biogas (e.g. from maize) is associated with significant indirect land use change emissions. These impacts eliminate most of the GHG benefits compared to fossil gas. In addition there are issues relating to biodiversity and competition with food. This is why crop-based biogas is capped for transport purposes under the renewable energy directive.

Electricity based methane (power-to-methane) is inefficient and expensive (at least 5 times dearer) to produce and would greatly increase demand for renewable electricity. Renewable electricity is turned first into hydrogen and then into methane. The process efficiency is now roughly 40%, potentially increasing to 60% in a future best case, and requires considerable additional renewable electricity, which is currently not going to be available at the scale required.

This means the contribution of renewable methane will be limited. What potential exists might be better used to help decarbonise sectors that currently depend on methane (residential, industry, power) and where no new infrastructure and engines are needed. Biomethane in transport can play a niche role in local projects, with vehicles running on 100% biomethane, refueling at local biomethane production sites. A wider shift to methane will almost certainly lead to a transport sector powered by fossil gas, not renewable methane.

The economics and politics of fossil gas in transport

The business case for fossil gas in transport depends almost entirely on (fuel) tax breaks, subsidies and public support for infrastructure. CNG and LNG enjoy tax rates below the EU minimum in many EU countries, and well below the equivalent tax rates for diesel (on average for EU countries 9.51€/GJ or 76% lower than diesel and 16.21€/GJ or 85% lower than petrol). The uptake of fossil gas in transport is especially high in countries with the lowest tax rates. For instance, Italy

consumes 60% of the methane used in European transport and accounts for 68% of CNG car sales. In Italy, the price of fossil gas at the pump is about half the price of diesel due to a CNG tax rate of 0.5% of the diesel tax rate. Without this tax benefit, the market for CNG cars would be much smaller. Similarly, if LNG would be taxed at similar levels to diesel the business case for LNG trucks would be negative.

A shift to methane use in transport would require the build-up of new infrastructure, a transition in the manufacturing sector and continued fiscal support, in particular through subsidies and tax breaks. EU domestic fossil gas production is declining (rapidly in the case of the Netherlands) and the EU is increasingly dependent on imports in particular from Russia. Creating a new market for fossil gas in transport will increase the EU's dependence on energy imports.

Based on the available evidence the role of fossil but also renewable methane in decarbonising transport will be extremely limited and continued support for the expansion of methane as a transport fuel does not appear to be justified.

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List of abbreviations

bcm – billion cubic metres
BP - British Petroleum
CARB - California Air Resources Board
CAR - Climate Action Regulation
CEF - Connecting Europe Facility
CH₄ - Methane
CHP - Combined Heat and Power
CIEL - Centre for International Law
CNG - Compressed Natural Gas
CO₂ - Carbon Dioxide
CO₂ eq. - Carbon Dioxide Equivalent
DPF - Diesel Particulate Filter
ECA - Emission Control Areas
EC - European Commission
EDF - Environmental Defense Fund (US)
EEA - European Environmental Agency
EGR - Exhaust Gas Recirculation
EPA - Environmental Protection Agency
ESR - Effort Sharing Regulation
ETS - Emissions Trading Scheme
EU - European Union
EV - Electric Vehicle
GE - General Electric
GHG - Greenhouse gas
GJ - Gigajoule
GWP - Global Warming Potential
HDV - Heavy Duty Vehicles
HFO - Heavy Fuel Oil
HPDI - High Pressure Direct Injection
ICCT - International Council on Clean Transportation
ILUC - Indirect Land Use Change
IMO - International Maritime Organisation
IPCC - Intergovernmental Panel on Climate Change
IPCC AR5 - Intergovernmental Panel on Climate Change 5th Assessment Report
IWW - Inland waterways
JEC - Joint Research Centre-EUCAR-CONCAWE collaboration
JRC - Joint Research Centre
LCFS - Low Carbon Fuels Standard
LNG - Liquefied Natural Gas
MFF - Multiannual Financial Framework
MGO - Marine Gas Oil
MJ HHV – Mega Joule Higher Heating Value
Mt - Million tonnes
Mtoe - Million tonnes of Oil Equivalent
N₂O - Nitrous Oxide
NASA - The National Aeronautics and Space Administration
NEx - Non-Exhaust Emissions
NEDC - New European Driving Cycle

NGVA - The Natural Gas Vehicle Association
NOx - Nitrogen Oxides
OEM - Original Equipment Manufacturer
PCI - Projects of Common Interest
PM - Particulate Matter
PN - Particle Numbers
Ptg - Power-to-Gas
Ptl - Power-to-liquid
PtX - Power-to-X
RED - Renewable Energy Directive
SO₂ - Sulfur Dioxide
SCR - Selective catalytic reduction
SI - Spark ignition
TAP - Trans-Adriatic pipeline
TEN-T - Trans-European Transport Network
TfL - Transport for London
TNO - Netherlands Organisation for Applied Scientific Research
TTW - Tank-to-Wheel for road transport, Tank-to-wake for shipping
ULSFO - Ultra-low Sulphur fuel oil
UNFCCC - United Nations Framework Convention on Climate Change
VECTO - Vehicle Energy Consumption Calculation Tool
VW - Volkswagen
WTT - Well-to-tank (emissions)
WTW - Well-to-wheels for road transport, Well-to-wake for shipping

Terminology used in the report

Methane (CH₄) - Chemical compound of carbon and hydrogen (CH₄). General term for fossil gas and renewable methane

Fossil gas - Natural gas, composed primarily of methane and varying amounts of other higher alkanes, carbon dioxide, nitrogen, hydrogen sulfide, or helium

Syngas - Output of gasification (a thermal reaction without combustion) which contains carbon monoxide, hydrogen and carbon dioxide

Biogas - Output of anaerobic digestion (a biological fermentation process) which contains methane, carbon dioxide, nitrogen and hydrogen

Biomethane (CH₄) - Upgraded biogas and syngas

Power-to-methane (CH₄) - Methane produced from renewable electricity and CO₂

Renewable gas - Renewable methane and renewable hydrogen

Renewable methane - Biomethane and Power-to-methane

CNG - Compressed natural gas (methane stored at high pressure, typically 20-25 MPa). Typically used for cars, vans, busses and short distance trucks.

LNG - Liquefied natural gas (methane cooled down to liquid form at least -162°C). Typically used for long-distance transport (shipping and trucks), as volumetric energy density is ca. 2.5-3 times that of CNG

1. Introduction

To meet its climate objectives, the EU needs to almost entirely decarbonise its transport sector¹ by 2050. This requires a transition to zero emission mobility. Reducing emissions from both vehicles and ships is essential and can be done in three key complementary ways: drastically improving the efficiency of the vehicle and the transport system, thereby reducing the amount of fuel used by vehicles or ships; by decarbonising the fuel vehicles and ships use; and reducing demand for mobility.

Transport emissions have increased by almost a quarter since 1990.² This means the transition to zero emissions will need to be swift and the importance of radical improvement through fuel switching is growing. In this context there is an ongoing discussion about the role of methane in transport. Some stakeholders - often representing the fossil gas industry - claim the use of methane would contribute to decarbonising transport³. In 2016, T&E published a study⁴ by Ricardo Energy & Environment that analysed the role of methane in transport. The study found using fossil gas has no meaningful climate benefits compared to petroleum based fuels, whilst biomethane cannot be produced in sufficient volumes to make a meaningful contribution.

Since then, a number of new studies have been published. The debate on the role of methane in meeting the EU's climate and environmental targets has also intensified both at EU and national level. The Commission is currently developing a long term decarbonisation strategy which will be published by the end of the year and discussed by EU leaders in 2019 and possibly 2020. One key question is the role methane could play in the full decarbonisation of the EU economy.

This report collates the new evidence, assesses a number of issues that weren't covered by the 2016 report (such as power-to-methane, taxation and more details on upstream emissions, pollutants, and biomethane), and updates Transport & Environment's overall assessment of the possible role of methane in transport.

The report focuses on the role of methane powered vehicles in decarbonising transport and its other environmental impacts. In this report "methane" refers to both fossil methane and renewable methane in the context of an energy carrier. Methane-powered vehicles can be fueled by fossil gas, biomethane or power-to-methane (methane produced from renewable electricity). Hydrogen powered transport is excluded from the scope of this report.

2. Political context

There are multiple EU and international policies which impact the use of methane in transport. This section looks into the existing policy and upcoming European policy initiatives.

2.1. Commission white paper and low emission mobility strategy

The European Commission transport white⁵ paper (2011) set a target of 60% lower GHG emissions by 2050 compared to 1990 - or -70% compared to 2008 - with the aim to be “firmly on the path towards zero”. The white paper still underpins the Commission regulatory work (e.g. the 2016, 2017, 2018 mobility packages).

The low emission mobility strategy highlights the need to optimise the transport system, improve its efficiency, scale up the use of low-emission alternative energy for transport and move towards zero-emission vehicles.⁶

The strategy expects fossil gas to be used as an alternative fuel in heavy duty road transport and maritime transport sectors and also highlights that its potential can be increased significantly with the use of renewable methane (biomethane and power-to-methane). There are also references to the build-up of CNG (compressed natural gas) and LNG (liquefied natural gas) refueling infrastructure, as defined in the alternative fuels infrastructure directive. For passenger cars, the strategy focuses on zero-emission vehicles.

2.2. Climate Action Regulation (Effort Sharing)

The Effort Sharing Regulation (ESR), now called the Climate Action Regulation (CAR), was proposed by the European Commission in July 2016⁷, and the text was finalised in December 2017⁸. The CAR sets a 2030 GHG reduction target for non-ETS sectors, namely transport, agriculture, housing, small industry and waste. The regulation sets an EU-wide 30% GHG emissions reduction compared to 2005 levels. The EU wide reduction targets are allocated as binding national targets to member states ranging from 0% to 40%. As a consequence of the regulation, member states need to develop policies to meet the binding GHG reduction targets.

As transport accounts for the largest share (36%) of the non-ETS sectors, it is expected it will need to do its fair share in reducing non-ETS emissions.⁹ In many member states, transport is expected to make a proportionally larger contribution, due to limited reduction possibilities or political difficulty to reduce emissions in the other sectors, and better cost-effectiveness in transport. Finland¹⁰ for example plans to cut transport emissions in half by 2030, to meet its 39% CAR target, and Germany¹¹ has an objective to cut transport emissions between 40% and 42%. The reduction in transport can be achieved through several policies including shifting to the use of lower carbon alternative fuels in transport. As fossil gas can have slightly lower tank-to-wheel (TTW) emissions, and has lower pollutant emissions compared to diesel cars, a small number of member states are promoting a shift to fossil gas, notably Italy, the Czech Republic, Hungary, and Belgium.

2.3. The Paris Agreement

In the longer term, the EU is committed to meeting the Paris Agreement, for which the ESR sectors needs to decarbonise almost completely by 2050. For this goal, the 2050 ambition of the transport white (-60% compared to 1990) paper is insufficient. Öko Institute identified in a study that transport needs to cut emissions by 76-94% to meet the overall EU target of 80-95% overall GHG reductions, a target set before signing the Paris Agreement.¹² T&E supports the higher end reductions, as keeping global warming below 2 degrees is more likely with this ambition. There is still uncertainty at what levels of global warming will tipping pointsⁱ be reached, with some tipping reactions starting with warming between 1-3 degrees. The EU commission is now working on a 2050 roadmap which would be compliant with the Paris Agreement, and

ⁱ When the be earth's own natural climate systems will trigger further warming reached

deeper emission cuts might be necessary. A key question is to what extent, if at all, methane can help meet the needed GHG reductions? 2050 is now only 32 years away, and cars and trucks have typically a lifetime of 15 years and ships 30 years. Long infrastructure payback periods necessitate that investments only flow into those solutions that are ultimately compatible with the 2050 GHG reduction targetⁱⁱ. For new cars and ships this requires a shift to decarbonised solutions by 2035 and 2020 respectively.

2.4. Directive on the deployment of alternative fuels infrastructure

The alternative fuels infrastructure directive¹³, adopted in 2014, sets requirements on alternative fuels infrastructure deployment in member states, including CNG and LNG for transport. The directive requires that an appropriate number of CNG refueling stations are built by the end of 2020 to ensure “motor vehicles can circulate in urban/suburban agglomerations and other densely populated areas, and, where appropriate, within networks determined by the Member States”. By the end of 2025, the requirement is extended to the core TEN-T network.

Most of the member states have submitted their plans to the EC for review, and only three countries (Italy, Hungary and Czech Republic) prioritise fossil gas as an alternative fuel, over electric vehicle infrastructure¹⁴.

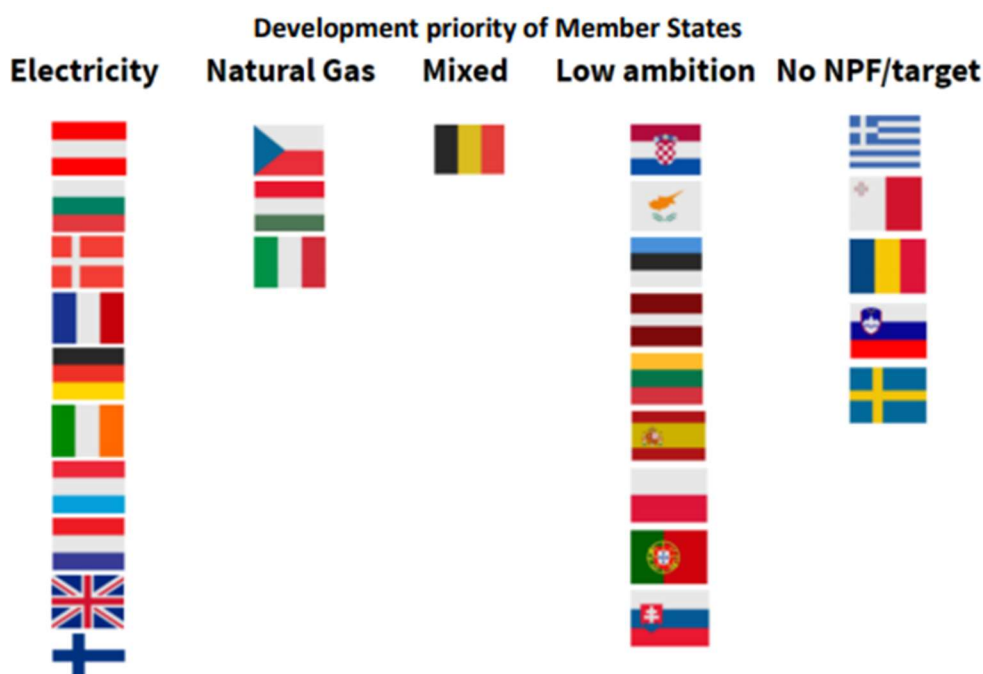


Figure 1. Evaluation of Member state priorities in National policy frameworks linked to alternatives fuels infrastructure directive ¹⁵

In the national plans, only six countries have a target for CNG vehicles, twenty one have targets for CNG infrastructure while seven countries do not plan on complying with the TEN-T network requirement. There are clear geographic disparities, as by 2020 Italy would account for 2/3 of the EU CNG fleet growth and 1/5 of the refueling infrastructure growth. The infrastructure plans for electric vehicles are generally more elaborate, which suggests more effort is put into supporting the uptake of electric vehicles.

LNG infrastructure for heavy duty transport needs to be deployed by the end of 2025 at least on the TEN-T Core Network, to allow circulation throughout the EU. There is however flexibility in the requirement based on demand and on cost. The indicative average distance between LNG refueling points for heavy duty is 400 km. Based on the national plans submitted¹⁶ to the EC, the number of refueling stations will increase to

ⁱⁱ By 2050 transport needs to be close to zero emissions, and not just new vehicle sales, but the full fleet in use needs to be close to zero emissions.

431 by 2025, with the vehicle fleet expected to grow from 1600 to 12000. The estimated infrastructure cost is up to €257 million, or around €200 thousand per vehicleⁱⁱⁱ. The fleet growth is mainly located in Poland and Hungary, whose plans see large development for LNG trucks. The planned infrastructure appears to be in line with the EU requirements in most EU countries. The exceptions are Italy, Portugal, Croatia and Bulgaria, where the plans include limited infrastructure development. However the planned infrastructure development and vehicle sales remain aspirational, as they lack the policies to reach the infrastructure and fleet targets.

The requirement for LNG infrastructure in maritime transport^{iv} is to have sufficient infrastructure for LNG refueling in inland waterways and for ocean-going vessels, to enable the circulation of LNG ships throughout the TEN-T Core Network, by 31 December 2030. These come at an estimated cost of up to €945 million in the TEN-T Core Network Corridor seaports by 2025 and up to €1 billion in the TEN-T Core Network Corridor inland ports by 2030.¹⁷ Actual market needs should be considered when designing the national policy frameworks. National plans vary from high ambition to no consideration of LNG for shipping.¹⁸

Table 1. Refueling infrastructure for methane powered transport in EU

		Number of refueling stations (2017)	Number of vehicles (2016)
CNG	Cars	3 351 ¹⁹	1 194 882
	Buses		14 610
	Light commercial vehicles		119 985
	Trucks		5 461
LNG	Trucks	107 ²⁰	1 598
	Maritime	50 ²¹	117 globally ²² (EU na.)

2.5. CO₂ standards for cars, vans and trucks

The existing regulation on CO₂ standards²³ for passenger cars sets a limit on the average emissions of new cars sold by a manufacturer. The 2016 level is 118 g CO₂/km, and the target for 2021 is 95 g CO₂/km. A similar regulation is in place for vans, which need to cut emissions to 147 g CO₂/km in 2020, with the emissions in 2017 at 156 g CO₂/km.²⁴ The commission's proposal for the post 2020 vehicle CO₂ standard file was presented in November 2017, requiring a further reduction in emissions of cars and vans by 15% by 2025 and 30% by 2030.²⁵ The standard could influence the uptake of methane powered vehicles as they have lower tailpipe emissions than petrol and diesel vehicles. However, CO₂ standards were first agreed in 2008/9 and none of the OEMs has chosen CNG as a compliance pathway so far, so it remains to be seen whether the 2025-2030 standards will change this.

In May 2018 the European Commission made a proposal for the first ever European truck CO₂ standard. This proposal will only regulate trucks that fall within the VECTO²⁶ categories 4, 5, 9 and 10²⁷ which account for 65-70% of HDV CO₂ emissions.²⁸

ⁱⁱⁱ Achieved GHG reduction are discussed in chapter 4.3

^{iv} Maritime transport includes inland waterways in the context of this report.

The Commission proposed that new vehicles put on the market decrease their CO₂ emissions by 15% by 2025 and by 30% in 2030 compared to 2019 reference VECTO data. Truck CO₂ emissions will be measured using the VECTO simulation tool. As for cars, trucks emissions are measured at tailpipe level²⁹. As the unit measured is CO₂, not CO₂ equivalent, the reduction does not take into account methane emissions (tailpipe or venting) or other GHGs. Tailpipe methane is however measured to verify compliance with the EURO VI standards. For methane powered trucks, VECTO has only one category for methane carbon content and calorific values: CNG. This means LNG can be certified by VECTO, but all methane trucks will be treated as CNG trucks under VECTO. Thus, VECTO needs to be developed in order to more accurately reflect LNG, which is currently being amended³⁰.

Given that on a TTW level methane trucks can have lower emissions than diesel trucks, shifting to methane could be one possible compliance pathway for truck makers and according to the Commission impact assessment LNG trucks will account for roughly 20% of new truck sales in 2030.³¹ However, whether CNG and LNG trucks are an attractive compliance pathway will depend on whether they can achieve engine efficiencies comparable to diesel. As discussed below, current generation CNG and LNG vehicles mostly have poor engine efficiency which eliminates most of the CO₂ benefits even at tailpipe level.

In addition, the EU is currently discussing the review of the Eurovignette Directive which sets common rules for truck tolls or roach charges. In the Commission proposal, trucks would also be charged based on their CO₂ emissions. Therefore, trucks with lower TTW CO₂ - as certified by VECTO - emissions could become eligible for lower tolls.

2.6. IMO GHG strategy and global Sulphur cap

In April 2018 IMO agreed to cut absolute annual ship GHG emissions by 50% by 2050 over 2008 levels³². To achieve these levels of reduction, shipping will need to switch to alternative fuels/propulsion technologies in the short to mid-term.

In addition, with the new 2020 global marine Sulphur cap (0.5%) and the establishment of Emission Control Areas (ECA) for marine Sulphur and nitrogen oxide emissions, more attention is being given to a shift to LNG in the maritime sector. The stricter ECA areas which require 0.1% low Sulphur fuels, started the shift to LNG as it has significantly lower Sulphur emissions than heavy fuel oil. It was estimated by TNO³³ that in 2020, 28% of European maritime fuel will be used inside the established ECAs. However, LNG is not the only option to meet the global and ECA Sulphur limits, as switching to cleaner distillate fuels (MGO or 0.5% compliant ULSFO) can be used to meet the requirements.

2.7. EU funding

The EU budget is financing the development of gas infrastructure throughout the EU. The Connecting Europe Facility (CEF) spent €1.3 billion³⁴ on fossil gas infrastructure projects such as LNG terminals and the Trans Adriatic Pipeline (TAP). The same amount was spent on electricity although this was meant to “make the major part of the [CEF] financial assistance available to those projects over the period 2014-2020”, according to the Connecting Europe Facility Regulation.³⁵ These infrastructure developments are justified mainly by energy security concerns - mainly diversification of supply and better integration of the EU gas market. “Projects that are built under the sponsorship of the EU, they are typically being built because there’s no commercial rationale for building them”, the president of Eurogas, Klaus Schäfer stated in an interview in Politico³⁶, continuing that there are already sufficient LNG terminals and new ones are not a commercial topic.

In addition, a recent estimate showed that EU has already spent a quarter of a billion USD on LNG bunkering infrastructure for ships and might be spending USD 22 billion up to 2050 in order to create significant market for LNG ships.³⁷

There have also been a number of transport specific infrastructure projects in the current EU’s Multiannual Financial Framework (MFF)³⁸. Of the current €1 trillion budget running from 2014 to 2020, almost €100 billion is earmarked for investment in the transport sector. Out of the ten largest projects, four are for LNG use in the maritime transport sector and there is a fifth project on the development of LNG and CNG infrastructure for road transport in Hungary. An overall figure is hard to come by, but based on a presentation from a European Commission representative (see Figure 2), the use of methane in transport received 62% of alternative fuels project funding under the TEN-T and CEF programs in 2010-2017, split between road and maritime rather equally.³⁹ This is mainly due to “alternative fuels neutrality” principle used in funding.

The Commission presented a proposal for the post-2020 MFF in May 2018. The MFF includes several legislative files relevant to transport investment. The Commission’s proposal to review the European Regional Development Fund and the Cohesion Fund included a commitment to stop investing in projects that relate to the production, processing, distribution, storage or combustion of fossil fuels. However, this commitment is followed by an exception for investment relating to the clean vehicles directive. This allows for EU Member States to still use EU money for the deployment of natural gas trucks and buses.

The Commission’s proposal to review the Connecting Europe Facility committed to 60% of CEF being spent on projects contributing to climate objectives. Projects that deploy gas that enables the increased use of hydrogen or bio-methane will be considered 40% climate spending. However, it is not outlined how the EU can judge whether a project solely enables bio-methane as same infrastructure can be used for fossil gas. What’s more opaque is that “alternative fuels” (as defined by Dir. 2014/94/EU) would be considered 100% climate spending with natural gas being one such “alternative”.

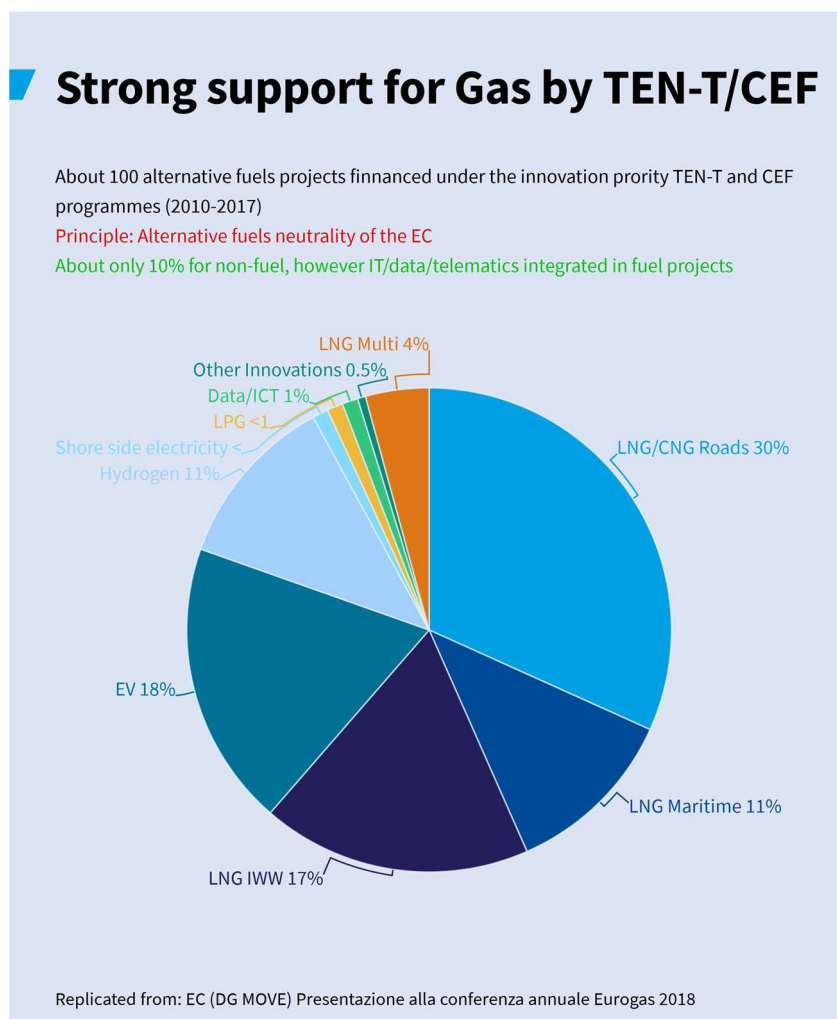


Figure 2. EU support for gas in transport. (IWW=Inland waterways)⁴⁰

3. The role of gas in EU decarbonisation trajectory

The EU has agreed to reduce emissions by 80-95%⁴¹ compared to 1990 levels, but subsequently committed to the Paris climate goals of “keeping a global temperature rise this century well below 2 degrees Celsius”⁴² An 80% reduction may not be sufficient to meet the Paris agreement and is now being re-evaluated. The EU also has a goal of reducing GHG emissions by 40% by 2030. To meet the 2050 targets, the electricity grid will need to be practically zero emissions and housing and industry would need to cut emissions by respectively 90% and 80%⁴³ by 2050.

The image below shows how fossil gas is used in the EU. Currently the largest use of fossil gas in EU is residential and commercial use where it is used for heating and cooking. Industry and power comes second and third; transport accounts for just 0.4% of EU inland gas consumption⁴⁴.

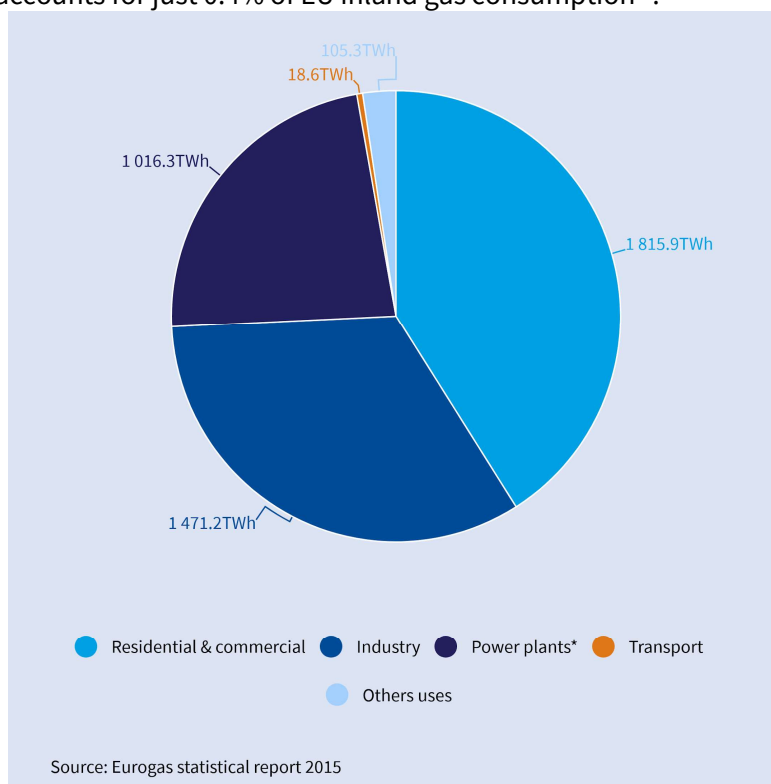


Figure 3. EU gas use by sector in 2014

Fossil gas is often mentioned as a transition or bridge fuel to a cleaner energy system (e.g. to replace coal on the path to zero emissions). The length of this transition period is controversial and debated with climate scientists suggesting a period of 6-9 years⁴⁵ to stay keep within the 2 degrees carbon budget.

By 2050 however the EU will need to completely transition away from coal, gas and oil. As shown in Figure 3, fossil gas is currently used for heating, industry and power generation. Demand for fossil gas in these sectors can be reduced by increasing efficiency, by shifting to renewables but there will likely continue to be a need for methane in these sectors (e.g. as flexible back up or to cover cold spells in winter). Infrastructure exists for the large scale use of fossil gas in the residential, power and industry sectors but not in the transport sector. This means the meager available renewable methane - more on this in chapter 6 - could be deployed more easily and at lower cost in power generation, industry and heating rather than in newly created markets

3.1. Upstream Methane emissions

The upstream emissions from the production and transport of fossil gas have a major impact on the climate performance of this fuel. Fossil gas originating from different regions with different supply routes and

technologies will perform differently as the energy consumption of getting the fossil gas to the market and the leakage rates in production and transport vary.

Methane leakage

The leakage of unburnt methane is a significant source of upstream emissions. The global warming potential (GWP^v) of methane is considerably higher than that of CO₂. The most up to date GWP100 value for methane (CH₄) in general is 28 (from 2013) but the GWP100 value for fossil methane is 30^{vi}. These values reflect the most recent scientific understanding. This means methane in general traps 28 times more - and fossil gas 30 times more - heat in the atmosphere than CO₂. If the climate carbon-feedbacks are included, meaning including the biological and abiological processes on land and the ocean carbon sinks, GWP100 increases to 34 for methane. Methane has an atmospheric lifetime of 12.4 years, before it breaks down to water vapour and CO₂. With GWP100, these emissions from 12.4 years are spread over a 100 year period, and with GWP 20 over a 20 year period. GWP 20 for methane is 84 and for fossil methane 85. GWP20 reflects more accurately the short term climate impact of methane, but the most commonly used metric currently is GWP 100 and is used in most of the studies cited in this report.

Table 2. Global warming values as identified in the IPCC 5th assessment report.⁴⁶

	GWP100	GWP20
Methane	28	84
Methane with climate-carbon feedbacks	34	86
Fossil methane	30	85
Fossil methane (with climate-carbon feedbacks)	36	87

As the lifetime of methane is relatively short, action to decrease methane emissions will quickly benefit the fight against global warming and given the urgent need to cut GHG emissions, reducing methane emissions should be a priority. A recent study, in which fossil gas industry professionals were interviewed, showed that industry players are not fully aware of the methane leakage reduction potential they have in their supply chains, and how cost effective reducing leakage is.⁴⁷ Reducing methane leakage lowers the negative climate impact of fossil gas and would improve the climate performance of the fuel. 40-50% of current methane emissions could be avoided with no net cost, as the previously leaking gas could be sold.⁴⁸

Supply chain emissions

Fossil gas coming from different regions has different upstream emissions. The production emissions are relatively similar in most sources, but transport emissions have a significant impact. Global supply chain GHG emissions for fossil gas in a meta study from 2015 ranged between 2–42 g CO₂ eq./MJ HHV with a central estimate of 13.4 g CO₂ eq./MJ HHV.⁴⁹ The estimated methane emissions (i.e. leakage) in the supply chain were 0.2% to 10% of produced methane with a mean of 2.2% and median of 1.6%. The range in CO₂ equivalent is 1 to 58 g CO₂ eq./MJ HHV. The Economist has quoted the industry average of methane leakage to be over 2%.⁵⁰ Fracked gas represent the higher end of these emissions, with remote sensing data showing methane emissions of 10.1% ± 7.3% and 9.1% ± 6.2% for the Bakken and Eagle Ford fields which are two of the fastest growing US gas production areas.⁵¹ Based on the JEC WTT data on supply chain emissions, the

^v GWP100 is the value used by the United Nations Framework Convention on Climate Change (UNFCCC) as the default metric. For Kyoto protocol reporting, IPCC (AR2) values are used. The values have been updated upwards for methane with each of the latest assessment reports.

^{vi} The higher GWP is due to the fact that some of the methane in the atmosphere, upper stratosphere and that consumed by soils is oxidized, resulting in additional releases of CO₂. Boucher et al. (2009) The indirect global warming potential and global temperature change potential due to methane oxidation. Environ. Res. Lett. 4 044007 <http://iopscience.iop.org/article/10.1088/1748-9326/4/4/044007/pdf>

EU's largest fossil gas supplier Russia has also the highest supply chain emissions, mainly due to transportation emissions, including methane leakages of 0.05-4% and energy consumption at compression stations every 80 to 160 km⁵², which use fossil gas as fuel. The JEC has relatively low methane emissions (0.7-1.5% based on studies from late 1990's/early 2000's) compared to more recent meta-studies (1.6% median, 2.2% average). Thus an update would be necessary, as the WTT figures presented are optimistic.

Table 3. Supply chain emissions of EU fossil gas supply (g CO₂ eq./MJ fuel) vs. diesel and petrol (JEC)⁵³

	Fuel	Total (g CO ₂ eq./MJ fuel)	Production & conditioning at source	Transformation	Transportation to market	Conditioning & distribution	% of total emissions associated to methane	Methane emissions in supply chain (% v/v)	JEC pathway code
EU gas consumption mix (2500 km pipeline)	CNG	13.0	4.0	na	5.1	3.9	34%	0.9%	GMCG1
Gas 7000 km pipeline (Russia)	CNG	22.6	4.4	na	14.3	3.9	33%	1.5%	GPCG1a
Gas 4500 km pipeline (Middle east)	CNG	16.1	4.1	na	8.1	3.9	32%	1.1%	GPCG1b
LNG ^{vii} to gas grid	CNG	21.1	4.1	6.3	4.9	5.7	17%	0.7%	GRCG1
LNG used as LNG	LNG	19.4	4.0	6.2	4.8	4.4	30%	1.1%	GRLG1
Diesel		15.4	4.7	1.0	8.6	1.1	5%	0.1%	COD1
Petrol		13.8	4.6	1.0	7.0	1.2	5%	0.1%	COG1

The supply chain emissions of LNG can be higher or lower than piped fossil gas, with the distance of gas pipe being a major contributing factor. As identified in the table above, fossil gas imports from Russia have higher supply chain emission than LNG, but fossil gas transported a shorter distance via pipelines would have lower supply chain emissions than LNG. In the case of Qatar, the largest supplier of LNG to the EU, more than 50% of the LNG emissions are associated with liquefaction, LNG transport and evaporation of LNG along the supply chain⁵⁴. Tagliaferi (2017) identified the LNG upstream emissions to be 17.4 g CO₂eq./MJ (without distribution of the gas) and previous studies they analysed have central values in the range of 16-18 g CO₂eq./MJ. For transport, conditioning & distribution emissions need to be incorporated, which equate to 5.7 g CO₂eq./MJ for CNG and 4.4 g CO₂eq./MJ for LNG, totaling to higher values for LNG and CNG than in the table above. The study assumed new tankering facilities and ships, and in most analysed cases 8.8% fossil gas consumption in the liquefaction process. Balcombe et al (2017) identified in a meta study that the emissions specifically associated with LNG (liquefaction, transport and regasification) supply

^{vii} The imported LNG figure apply for “conventional natural gas” not fracked natural gas.

chains add 4-15.9 g CO₂ eq./MJ with a central estimate of 8.9 g CO₂ eq./MJ.⁵⁵ Of the central estimate, 44% was methane emissions. For transport use, Ricardo (2016) identified that the supply chain emissions of LNG for transport are in the range of 19.6-43.4 g CO₂ eq./MJ, thus significantly higher than for CNG.

Exergia (2015)⁵⁶ projected the 2030 gas mix and related upstream emissions for the EU, different regions and also for most of the members (member state level data is presented in annex 2). From this data it is clear that the upstream emissions of CNG will increase when going from current estimates to 2030, as the energy consumption during the production and transport of fossil gas changes and sourcing regions change. The supply chain emissions are also different in different regions of the EU, as the origin and transport distances of the gas is different (see annex 2). According to the Exergia data, the upstream emissions of CNG are higher for CNG compared to petrol or diesel.

Table 4. Supply chain emissions of EU fossil gas supply (g CO₂ eq./MJ fuel) vs. diesel and petrol (Exergia 2015)

	Year	Fuel dispensing	Gas distribution, transmission and storage	Feed-stock transportation (pipeline, LNG)	Fuel production and recovery	CO ₂ , H ₂ S removed from NG (gas processing)	Total (g CO ₂ eq./MJ fuel)	Methane emissions in supply chain (% v/v)
CNG	2015	3.8	3.0	6.6	5.4	0.4	19.2	1.1%
	2030 reference scenario	3.8	3.0	8.0	6.7	0.4	22.0	1.7%
Petrol	2015						18.2	
Diesel	2015						17.4	

These two transport specific WTT studies (JEC and Exergia 2015) show that there is still variation in the upstream emissions between studies and thus using a range of WTT figures is relevant, as depicted in the following image. Further it is important to emphasise that supply chain emissions of fossil gas are likely to be significantly underestimated. Atmospheric methane concentrations have risen very sharply since 2006 according to NASA⁵⁷, much faster than expected. The current annual methane emissions are 550 Mt and they are growing by 25 Mt annually, of which 17 Mt is associated to upstream fossil fuel emissions. The upstream emissions from the production of natural gas have long been underestimated, by up to 50% (Dalsoren 2018⁵⁸) or around 60% (Alvarez 2018)⁵⁹. This is crucial because current estimates find that 53%⁶⁰ of upstream emissions are methane.

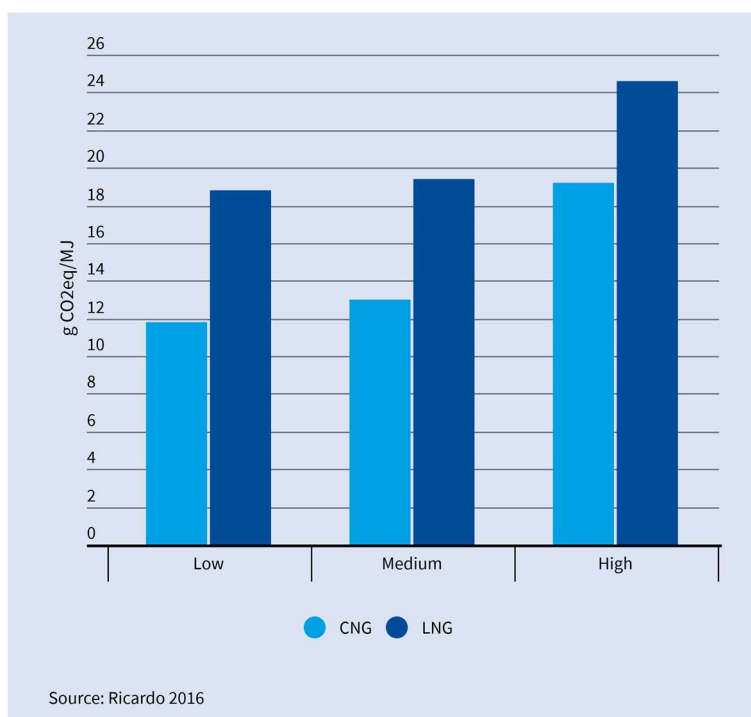


Figure 4. WTT emissions of CNG and LNG

In addition, the fossil gas mix (i.e. where fossil gas is coming from) in the EU is changing with domestic production decreasing and imports increasing. This will increase the overall upstream emissions of the EU's gas mix in the years to come.

3.2. Fossil gas imports to the EU

Of EU fossil gas consumption only 31% is covered by domestic supplies in the EU, coming mainly from the Netherlands and the UK, with 69% of fossil gas imported⁶¹. Energy independence is therefore not significantly better than for oil (88% imported⁶²). The domestic production of fossil gas is decreasing. For example, the Dutch cabinets decided to start limiting production at the Groningen gas field and terminate fossil gas extraction by 2030 due to safety concerns linked to earthquakes in the region.⁶³ The main import regions can be seen from the image below, but it is clear Russia (37%) and Norway (32.5%) dominate. Most of the fossil gas coming from Russia, Norway and Algeria comes through pipelines, while fossil gas from Qatar and Trinidad & Tobago arrives as LNG. As European fossil gas production decreases (also the case for supplies from Norway), the volume of Russian fossil gas imports and LNG imports would double according to the BP energy outlook baseline ('Evolving Transition') scenario⁶⁴. This also means that the fossil gas consumed in the EU will come with higher upstream emissions, roughly 15% higher based on Exergis 2015 projections, with CNG upstream emissions increasing from 19.2 g CO₂eq./MJ to 22 g CO₂eq./MJ⁶⁵. Thus, it is important to also consider in the WTW analysis that future fossil gas consumed in Europe will probably have higher WTT emissions than today.

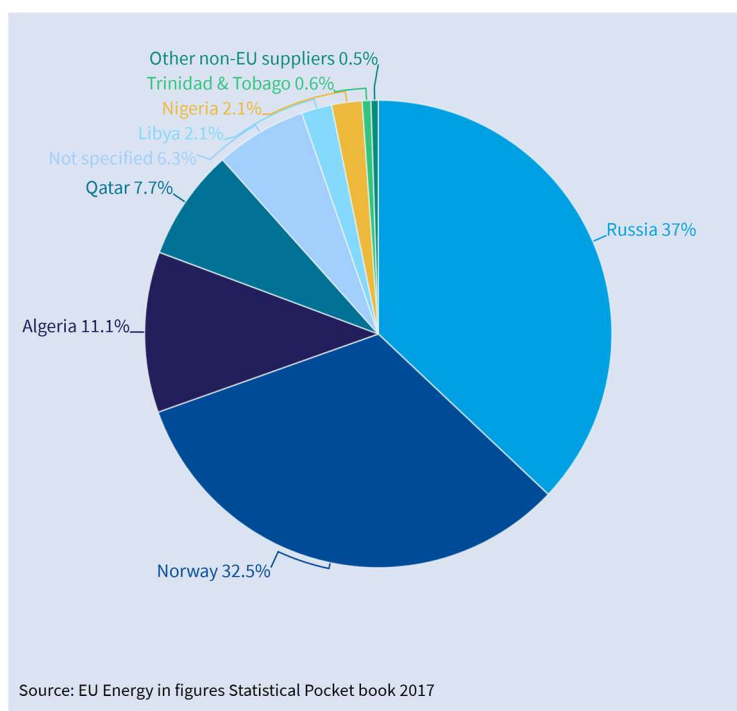


Figure 5. Countries where the EU imports its fossil gas (2015), 69% of total consumption

The crises in Georgia and, in particular, Ukraine revealed the EU's dependence on Russian gas pipelines. As part of its energy union strategy, the EU and its member states started building LNG terminals and increasing LNG imports to increase energy security. In the third quarter of 2017 LNG accounted for 16% of EU fossil gas imports, 22% more than a year earlier. Qatar is the largest supplier of LNG to the EU (44%) followed by Algeria (16%), Nigeria (16%), Norway (9%) and USA (5%).⁶⁶ The current LNG terminals are utilised with only 25% of regasification capacity used. That means there is significant potential to increase LNG imports from current rates and diversify import regions without further investment into import terminals.⁶⁷ LNG is currently more expensive than Russian pipe gas and in that sense LNG terminals act more as an insurance policy, to diversify supply and increase competition in the market. As an example Lithuania, whose sole fossil gas supplier was Russia, paid 30% higher gas prices for Russian gas than Germany for the same gas. With the start of operation of a new LNG terminal, they were able to renegotiate their supply deal with Russia, to around 20% lower rate than before.⁶⁸ This was mainly possible due to the possibility of importing LNG at a more competitive price than the previous rate for Russian gas. The current EU gas infrastructure is sufficient to ensure energy security.⁶⁹ Investments into LNG terminals have been financed mainly with public money, and new ones are “not a commercial topic”⁷⁰ (This is further discussed in sections 2.6 and 7.2).

From a broader energy security perspective, diversifying away from oil in transport could be argued to reduce the dependence of the transport sector on imports and increase its resilience to oil price shocks. However, it is associated with an increased dependence on fossil gas which also requires imports. For instance, importing LNG from Qatar is not very different than importing oil from one of its neighbours. Given that the EU is becoming increasingly dependent on gas imports, there would be limited benefit (gas prices are currently a bit more stable) in increasing its gas consumption. From an energy security and resilience point of view, the EU should focus on low carbon transport fuels that can be produced in Europe sustainably, such as renewable electricity.

3.3. Technology developments lowering the demand for fossil gas

The need for fossil gas is decreasing as technology is developing and other options which bring greater emission reductions are more readily available. The PRIMES modelling sees for instance a 1.5% per annum decrease in fossil gas consumption in 2010 to 2020 and progressing to a -1.9% per annum from 2020 to

2030.⁷¹ The cost of installing new renewable capacity (especially solar and wind) is coming down very fast, in many cases already beating electricity production costs from fossil fuels. By 2019-2020 the costs are expected to be below the cost for new fossil fuel generation (coal or gas), making them cost competitive and reducing future demand for fossil gas.⁷²

Higher EU targets for renewables (power) or improving energy efficiency (residential) could further slash demand for fossil gas. According to an analysis by energy consultancy Artelys, power generation from fossil gas in the EU could be cut in half by 2030 (from 514 TWh today to 259 TWh) even in combination with a coal phase out⁷³. Grids will become smarter and flexible demand (also from EVs) will provide system balancing at a lower cost. Thus the role of fossil gas in the power sector transition will further decrease. On the contrary, the phase-out of nuclear in some countries (e.g. Germany, France, and Belgium) is expected to increase the use of gas in power generation, potentially increasing gas demand in the short term in those countries.⁷⁴ The developments in batteries are questioning the grid balancing role of fossil gas and starting to eat into this market, hence lowering the long term need for fossil gas.⁷⁵ As an example this is happening in Germany (48 MW)⁷⁶ and Australia⁷⁷ where Tesla built a 100 MW facility.

These developments will reduce the demand for fossil gas in Europe.⁷⁸ This explains why the gas industry is now looking for new sectors where they can sell their product. The gas industry (Eurogas) sees transport as an opportunity for growing demand, and sees growth potential from 2 bcm now to 29 bcm in 2030, a fifteen fold increase.⁷⁹

As identified earlier, renewable electricity is becoming cheaper as technology develops and economies of scale are achieved in production. Similar price decreases for renewable methane are unlikely. Owing to the relative sparsity of feedstocks and the numerous locations required to collect them, the potential to decrease the price of biomethane is limited. Although power-to-methane would benefit from cheaper renewable electricity, as electricity accounts for a significant share of the production cost, it would still be at least twice the cost of electricity due to the efficiency loss (see chapter 6.4). While EVs become cheaper, the case for CNG cars will get worse.

The French ADEME has evaluated the costs of a 100% renewable gas grid and 100% renewable electricity grid in 2050. From these two studies it is clear that the generation of renewable electricity is cheaper than renewable gas, renewable electricity being on average around one third of the renewable gas price.⁸⁰ Moreover, there are concerns about the assumptions in the 100% renewable gas scenario concerning the availability being significantly overestimated, as the costs become too high.⁸¹ This would also mean that the fuel cost of a renewable methane powered vehicle is higher than for electric vehicles running on renewable electricity, and as the engine efficiency is lower, the fuel consumption is around 2.5 times higher.

4. Impacts on GHG emissions of deploying fossil gas in the transport sector

Using fossil gas in transport does not contribute to reducing greenhouse gas emissions and hinders transport decarbonisation. Better alternatives have been developed in both the light and heavy duty road sector. In shipping, better and more cost effective solutions are emerging. It is relevant to compare the emissions of new vehicles and alternatives now coming to the market, as this should be a decisive factor for policy support. The WTW GHG performance for fossil gas identified in this study is within -12% to +12%, depending on the mode of transport. Industry studies show slightly higher savings. In cars the GHG savings are the lowest, with a range of -7%^{viii} to +13% compared to diesel.⁸² In heavy duty the range is -3% to +12% compared to best in class diesel trucks. In shipping the figures are -12%⁸³ to +9%⁸⁴ compared to marine gas oil (MGO) and highly dependent on methane slip. The origin of fossil gas and the supply chain emissions play a significant role in the WTW performance, as well as the choice of the metric. CO₂ values and CO₂ equivalent values are different because considering only CO₂ does not take into account any methane emissions.

4.1. Cars

The WTW (well-to-wheel) performance in cars are dependent on the supply chain emissions (well-to-tank) of the CNG and the emissions of the vehicle (tank-to-wheel). The range of CNG WTT emissions are 7.8-22.6 g CO₂eq./MJ with LNG and Russian gas at the high end and EU supplies at the lower end. EU average fossil gas mix has WTT emissions of 13 g CO₂eq./MJ of fuel according to JEC and 19.2 g CO₂eq./MJ according to Exergia (2015) (see chapter 3.1). The JEC values for diesel and petrol are respectively, 15.4 g/CO₂eq./MJ and 13.8 g/CO₂eq./MJ.⁸⁵ Looking at 2030, Exergia (2015) estimates that the upstream emissions of CNG are 15% higher than in 2015, at 22 g CO₂eq./MJ. There is also wide variation in the sources of fossil gas in the EU, and thus the different member states' CNG WTT emissions are in the range 6.8-44.3 g CO₂eq./MJ in 2030 (see Annex 2). Thus CNG can have lower or higher WTT emissions compared to diesel and petrol, depending on the fossil gas mix of the refueling location and the data used.

On a TTW level (real world) and WTT level the GHG performance of CNG cars is different, as can be seen in Table 5. CNG has a GHG benefit over petrol, but not diesel. With the projected 2030 WTT emissions by Exergia for fossil gas (and all else remains equal), the WTW emissions increase for CNG, decreasing the benefit compared to petrol to -9% while diesel would have 19% lower emissions compared than CNG. In many countries the situation would be worse, as 17 countries would have higher WTT emissions for fossil gas than the EU average.

^{viii} See comparison of VW golf in section 4.1

Table 5. GHG performance of CNG cars compared to petrol and diesel (adapted from Ricardo 2016)

	TTW	WTW			
		Low WTT emissions	Medium WTT emissions	High WTT emissions	WTT projected to 2030
Emissions factors (g CO ₂ eq./MJ)		11.8	13.0 (JEC EU 2015 gas mix)	19.2 (Exergias EU 2015 gas mix)	22.0 (Exergias EU 2015 gas mix) ^{ix}
Compared to petrol	-21%	-18%	-18%	-15%	-9%
Compared to diesel	+5%	+6%	+6%	+13%	+19%

The JEC WTW study looked at different pathways for the production of CNG and the WTW GHG impacts. Looking at the projections for 2020, the study estimated that new diesel cars would reach an average of 106 g CO₂eq./km without hybridisation, or 79 g CO₂eq./km with hybridisation and petrol hybrids would reach an average of 83 g CO₂ eq./km based on the NEDC (New European Driving Cycle) lab tests. The CNG pathways range from 94 g CO₂eq./km for EU shale gas to 122 g CO₂eq./km for gas imported from outside the EU and transported 7000 km via pipelines (e.g. from Russia). The potential difference in WTW GHG emissions between diesel and different CNG pathways is in the range of -11% to +17%. Assuming the average EU fossil gas mix, CNG car emissions are 1 % higher compared to diesel and 14% lower compared to petrol. Diesel or petrol hybrids perform better than CNG, with respectably 26% and 24% lower WTW emissions than CNG vehicles.⁸⁶ CNG vehicles could be also manufactured as electricity hybrids, but such vehicles are not currently on the market and would be disproportionately expensive.

The Natural Gas Vehicle Association (NGVA), the gas vehicle industry lobby, commissioned a study from Thinkstep on the GHG emissions of gas in transport. They use a supply chain emission of 12.5 g CO₂eq./MJ, of which 3.4 g CO₂eq./MJ originates from methane leakage emissions. The study concludes that fossil gas decreases GHG emissions by 7% compared to diesel or 23% compared to petrol, proving that even with optimistic assumptions, CNG doesn't offer significant GHG benefits compared to diesel. These GHG savings are higher than in the studies described above which haven't been financed by industry.⁸⁷

Analysing the CO₂ performance of each fuel alongside a specific car model clearly indicates that there are little benefits in promoting CNG fueled cars. The Volkswagen Golf was the bestselling CNG vehicle in 2017 and was chosen for the comparison as it has a full range of powertrains. The table below includes the CO₂ emissions declared by the manufacturer as TTW and WTT was calculated based on declared fuel consumptions. These were combined to have an idea of the WTW GHG emissions performance. Looking at the table, the CNG vehicle has only 6% better WTW GHG emissions performance when running on CNG than the equivalent petrol car and is 7% better than the equivalent diesel car; the electric version of the Golf using average EU electricity emits less than a third of the CO₂ compared to CNG. If we use Russian gas WTT emissions (22.3g CO₂eq./MJ), the WTW performance of the CNG vehicle becomes 141 g/km, higher than for the equivalent petrol or diesel cars.

^{ix} No change in TTW emissions were considered or WTT emissions for liquid fuels.

Table 6 Comparison of emissions for the most sold CNG vehicle in the EU in 2017 (Volkswagen Golf VII) to equivalent models (g CO₂eq./km)⁸⁸

Energy type	Engine	Version	TTW *	WTT	WTW
CNG	1.4 TGI 81 kW	All trim levels, Manual 6	97 (CNG)	26 (CNG – EU mix) 44 (CNG – Russia)	123 (CNG – EU mix) 141 (CNG – Russia)
			125 (petrol)	24 (petrol)	149 (petrol)
Petrol	1.0 TSI 85 kW	Comfortline 5 door, Manual 6	109	21	130
Diesel	1.6 TDI 85 kW	Comfortline 5 door, Manual 5	109	23	132
Petrol plug-in hybrid	GTE 150 kW (1.4 TSI 110 kW)	GTE 5 door, Automatic	38	8 (petrol)	78
				32 (electricity)	
Battery electric	e-Golf 100 kW	e-Golf 5 door	0	36	36

Transport & Environment looked at fleet level GHG reductions with an in-house EUTRM model⁸⁹ and found similar results. T&E compared a scenario featuring an increase in the penetration of CNG vehicle to the baseline case and assumed sales ramping up from 1% in 2015, to 5% in 2020, to 10% in 2025 and to 20% in 2030, with equal increases per year. Given these sales volumes, CNG cars would reduce the WTW GHG emission of passenger cars by just 1.5% by 2030 compared to the baseline.

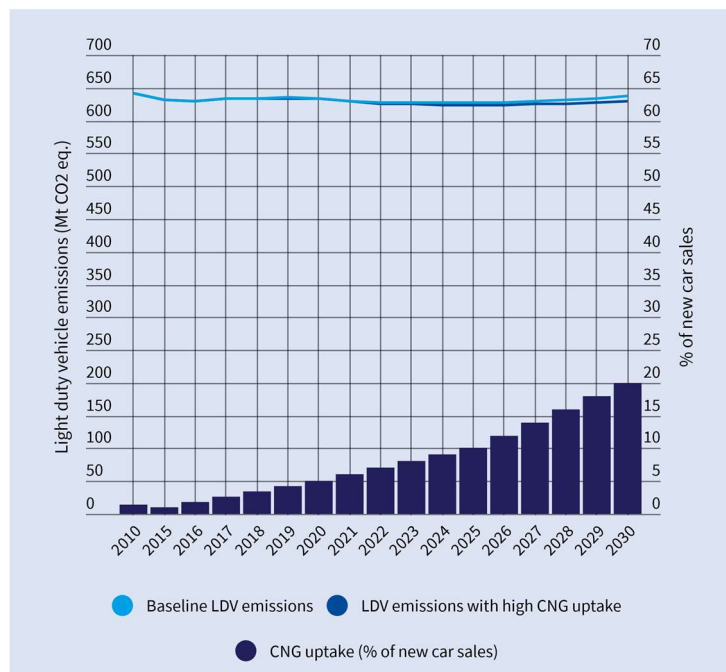


Figure 6. CNG cars impact on WTW emissions.

From a Life Cycle Assessment (LCA) level, comparing the different technologies for passenger cars gives a similar conclusion to the WTW analysis: there is almost no benefit to shift to fossil methane powered CNG vehicles - as can be seen from the image below.

* TTW is CO₂, while WTT is CO₂ equivalent

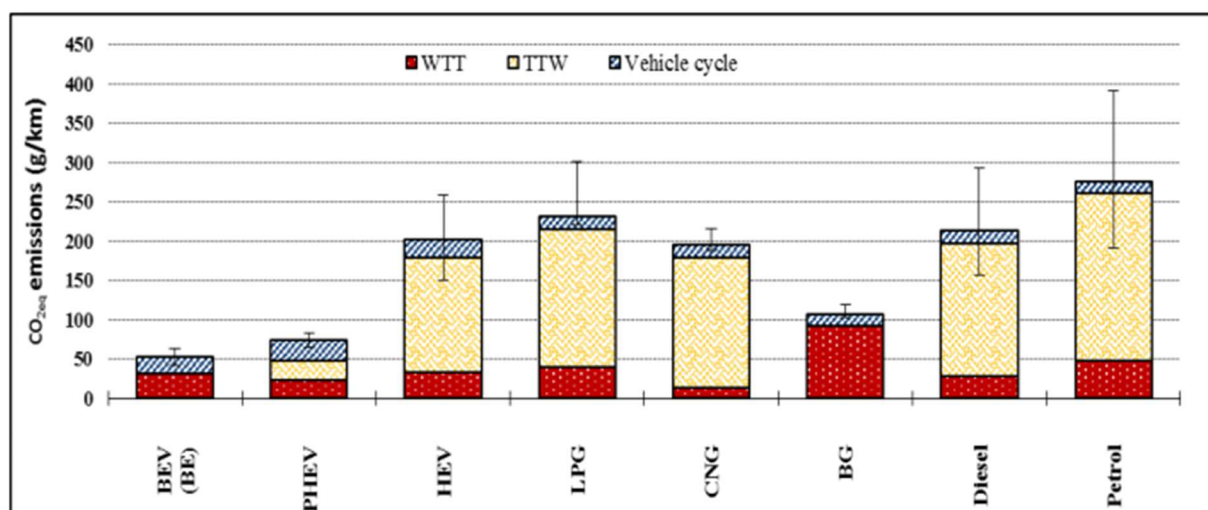


Figure 7. LCA emissions of different power trains (Battery electric vehicle with Belgian electricity mix, Plug in Hybrid, Hybrid electric vehicles, Liquefied petroleum gas, fossil CNG, Bio-CNG, Diesel and Petrol)⁹⁰

The WTW (or LCA) GHG savings of CNG compared to diesel vehicles are marginal with average EU gas upstream emissions, while compared to petrol the savings are slightly higher. The WTW savings are highly dependent on the source of the gas supply, and if average LNG or Russian gas (the fastest growing sources of EU gas consumption) is used by the vehicle, the small WTW GHG savings disappear and CNG vehicles are higher emitters than conventional petrol or diesel vehicles. This would be the case in many member states reliant on high upstream emission fossil gas supply such as LNG or Russian gas. Given that fossil gas only slightly impacts GHG performance of vehicles on a WTW basis, the much lower tax level of the fuel is not justified (this will be further discussed in section 7.1)^{xi}. Hybrids and battery electric vehicles are now on the market, and have significantly lower GHG emissions compared to CNG.

4.2. Trucks

The heavy duty sector is often mentioned as a prime candidate for switching to CNG/LNG - see for example the Commission's low emission mobility strategy. This reasoning is based on the assumption that there are no other viable alternatives, with the exception of biofuels, for long haul diesel trucks. However, the evidence shows that there are no significant climate benefits in shifting from diesel to fossil gas and cleaner alternatives are emerging more quickly than expected.

Tank-to-wheel

On a tank-to-wheel basis methane trucks could in theory have significantly lower tailpipe CO₂ emission because fossil gas has a lower carbon content than diesel. However, the tailpipe result depends on the efficiency of the gas engine powering the trucks. None of the studies or real world tests available show that methane powered trucks have significantly lower tailpipe CO₂ emissions in real driving conditions. Rather, the observed CO₂ emissions are in the range of +10 to -10% compared to diesel.⁹¹

The UK department for transport analysed the GHG impacts of existing dual fuel and mono fuel LNG trucks, under real conditions between 2012 and 2016.⁹² The dedicated methane trucks showed 4% higher TTW emissions, due to a 24% lower engine efficiency. The report concluded that "current generation (Euro VI) dedicated gas vehicles, running on fossil gas (rather than bio-methane), are likely to have broadly similar GHG impacts compared to Euro VI diesel equivalents, to within +/- 10%." The testing showed "no appreciable" methane slip (unburnt methane released during fuel combustion in the engine) emissions in the dedicated methane trucks, but in converted trucks (dual fuel) the methane slip made the vehicles GHG performance 10-35% worse compared to before the conversion.

^{xi} The fuel tax level impacts the fuel price and lowers the total cost of ownership, which explains why people buy CNG vehicles.

In the Netherlands TNO tested two Euro VI LNG trucks (with spark ignition engines) in real world conditions. According to these tests, on a TTW basis the selected vehicles perform 3-6% better than comparable diesel vehicles in terms of tailpipe emissions. However, particle emissions were higher and NOx emissions higher or comparable depending on the operating conditions.⁹³ Exhaust methane emissions were relatively low, contributing only minimally to the overall TTW GHG impact of the LNG vehicles. However, they were not able to properly quantify other methane slip emissions such as fuel tank boil-off gas (BOG), crankcase venting and blow-off. The importance of quantifying the non-exhaust methane emissions is shown by a study from the United States, where tailpipe methane emissions accounted for 30.6% of the pump-to-wheels methane leakages. This means there could still be significant methane slippage at vehicle level and more research should be done to quantify this.⁹⁴

CARB (California Air Resources Board) identified for their LCFS (Low-carbon fuels standard) that compared to diesel trucks, LNG truck GHG emissions are 6% lower and CNG trucks 14% lower on a WTW basis.⁹⁵ The EPA in their own analysis found that CNG and LNG trucks emit -12% and +3% (WTW) compared to diesel, assuming 5% lower engine efficiency.

The engine efficiency gap can theoretically be overcome although this is a moving target since diesel engines also improve. So-called High Pressure Direct Injection (HPDI) technology can deliver engine efficiency for LNG trucks similar to diesel. HPDI trucks use a small (5-10%⁹⁶) amount of diesel to ignite the methane in the cylinders. However, HPDI engines are more expensive, currently only offered in Europe by one manufacturer (Volvo) and the higher GHG performance comes at a cost in local pollutants, with NOx emissions higher than for diesel models.⁹⁷ There is also some unburnt methane slippage lowering the TTW GHG performance. The real performance of HPDI methane trucks still needs to be assessed - both by the EU's new test procedure VECTO and in real world operations. Tests are ongoing in the UK and the Netherlands, with results expected by the end of 2018 for both. The key question is whether more expensive HPDI trucks will deliver significantly lower CO₂ emissions than best in class diesel trucks. For example, a study for NGVA - based on data provided by truck makers - finds that HPDI methane trucks have 16% lower WTW CO₂ emissions than diesel trucks⁹⁸. But they compare the HPDI trucks - which is state of the art, best in class technology - to an average EU truck (31.5l/100km) rather than to a best in class diesel truck (29.9l/100km) which inflates the estimated savings.⁹⁹ Comparing an HPDI truck to a best in class diesel truck (29.9l/100km) reduces the WTW benefit to 2% with medium WTT emissions of 19.4 g CO₂ eq./MJ.

Volvo recently announced an HPDI-style methane truck advertised as having 20% lower tailpipe CO₂ emissions, although Volvo acknowledges the WTW CO₂ eq. saving is lower, 11% because of higher WTT emission for LNG than diesel and methane slippage.¹⁰⁰

Well-to-wheel

As with passenger cars the WTT emissions play a significant role. For LNG, the boil off (evaporation of LNG during storage in tanks), and any venting and blow-off need to be included. The range of WTT emissions in different scenarios are 18.8 g CO₂ eq./MJ for low, 19.4g CO₂ eq./MJ for the central and 24.6 g CO₂ eq./MJ for high. Based on these figures, Ricardo¹⁰¹ estimates additional GHG emissions of +1%, +2%, and +5% accordingly, on a WTW level for SI (spark ignition) LNG articulated trucks weighing more than 32 t compared to Euro VI diesel trucks. A comparison to best in class diesel trucks brings gives even less promise to methane powered trucks, as can be seen in the following tables. A HPDI methane truck which has still 9% lower energy efficiency than the best in class diesel trucks would have 10% lower TTW GHG emissions compared to best in class diesel trucks, and 2% lower WTW GHG emissions based on T&E calculations. From the table below (Table 7) it is clear also that the engine technology has a large impact on the WTW GHG performance of fossil gas powered trucks, as does the fuel used (CNG vs LNG). A comparison of methane trucks to average diesel trucks (Table 8) shows higher savings because average diesel trucks have 5.6% higher WTW emissions than best in class diesel trucks.

Table 7. WTW performance of methane powered trucks compared to best in class diesel truck^{xii}

	Low upstream emissions	Medium upstream emissions	High upstream emissions
Best in class diesel truck (29.9l/100km)	948 g CO ₂ eq./km		
HPDI LNG truck ^{xiii}	-2.7%	-2.0%	+4.4%
Spark ignition LNG truck ^{xiv}	+4.4%	+5.1%	+11.5%
Spark ignition CNG truck ^{xv}	-2.4%	-0.7%	+7.9%

Table 8. WTW performance of methane powered trucks compared to average diesel truck^{xvi}

	Low upstream emissions	Medium upstream emissions	High upstream emissions
Average diesel Truck (31.5l/100km ¹⁰²)	1001 g CO ₂ eq./km		
HPDI LNG truck ^{xvii}	-7.9%	-7.2%	-1.1%
Spark ignition LNG truck ¹⁰³	-1.1%	-0.4%	+5.6%
Spark ignition CNG truck ¹⁰⁴	-7.5%	-6.0%	+2.2%

Whilst in dedicated modern methane trucks, methane slip in combustion is under control, methane emissions (boil-off, venting etc.) still remain on the WTT and TTW level. There is limited to no information available for the quantification of these emissions at TTW level for European trucks in real world conditions.

^{xii} Upstream emissions for CNG: low 11.8, medium 13.0 and high 19.2 g CO₂ eq./MJ for CNG. Upstream emissions for LNG low 18.8, medium 19.4 and high 24.6 g CO₂ eq./MJ. Emissions factors for CH₄ is 56.2 g CO₂ eq./MJ (EU mix gas) and diesel 73.2 g CO₂ eq./MJ from JEC 2015. GWP100 was used fossil CH₄ = 30 and N₂O = 298 from IPCC CH₄ emissions 0.133%wt, N₂O 0.019 g/km. Energy content of diesel is 35.8 MJ/l and fossil gas 45.1 MJ/kg (EU mix from JEC).

^{xiii} Data from NGVA: Energy consumption of 11.7 MJ/km: CH₄ emissions 0.155%wt, N₂O emissions 0.032 g/km. Assuming 94% CH₄ and 6% diesel based on personal communications with VOLVO.

^{xiv} Data from NGVA: Energy consumption of 13.2 MJ/km: CH₄ emissions 0.133%wt, N₂O emissions 0.019 g/km.

^{xv} Data from NGVA: Energy consumption of 13.2 MJ/km: CH₄ emissions 0.133%wt, N₂O emissions 0.019 g/km.

^{xvi} Upstream emissions for CNG: low 11.8, medium 13.0 and high 19.2 g CO₂ eq./MJ for CNG. Upstream emissions for LNG low 18.8, medium 19.4 and high 24.6 g CO₂ eq./MJ. Emissions factors for CH₄ is 56.2 g CO₂ eq./MJ (EU mix gas) and diesel 73.2 g CO₂ eq./MJ from JEC 2015. GWP100 was used fossil CH₄ = 30 and N₂O = 298 from IPCC CH₄ emissions 0.133%wt, N₂O 0.019 g/km. Energy content of diesel is 35.8 MJ/l and fossil gas 45.1 MJ/kg (EU mix from JEC).

^{xvii} Data from NGVA: Energy consumption of 11.7 MJ/km: CH₄ emissions 0.155%wt, N₂O emissions 0.032 g/km. Assuming 94% CH₄ and 6% diesel based on personal communications with VOLVO.

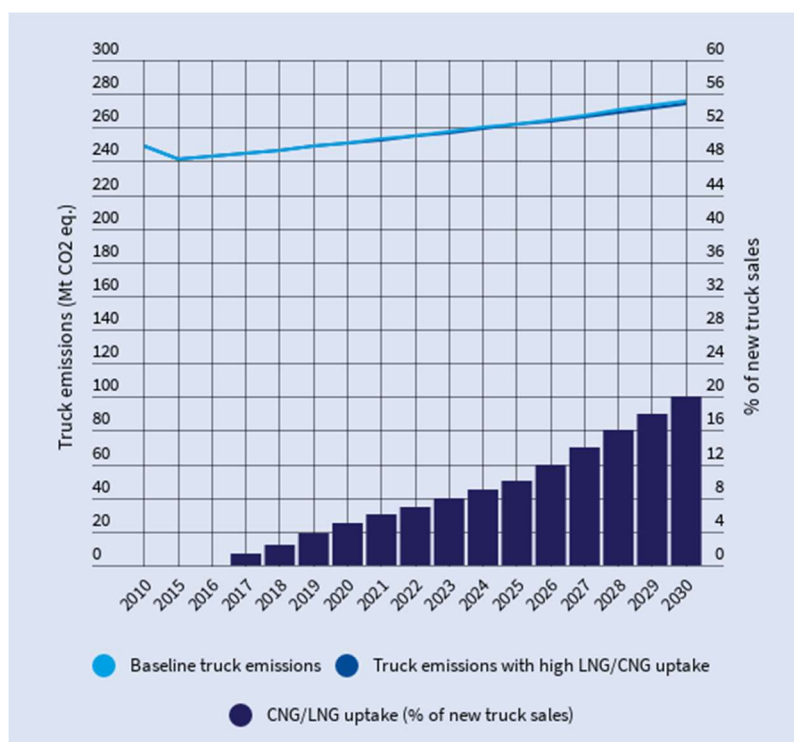


Figure 8. LNG trucks impact on WTW emissions^{xviii}

A transition from diesel to fossil gas, be it CNG or LNG would have very limited benefits at best as can be seen from the image above. Even using the favourable tailpipe metric (TTW), savings from methane trucks are in the range of -10% to +10%.¹⁰⁵ Incentives for low carbon trucks should therefore be based on measured performance, not fuel type. This would avoid subsidising vehicles that in reality perform similar or worse than diesel and will incentivise innovation in methane truck technology to lower and eliminate the engine efficiency gap.

On a well-to-wheel basis, any benefit of at the tailpipe is largely negated. As shown in tTable 7 spark ignited LNG trucks have higher WTW emissions whilst HPDI technology could deliver savings of around 2%. It is important to emphasise that such savings are based on a methane global warming potential over 100 years. In reality, the short term effects will be negative and what GHG benefits exist, will only materialise after 50 years in the best case scenario due to the strong immediate warming effect of methane emissions.¹⁰⁶ This analysis was done using a technology warming potential (TWP) approach, meaning calculating the actual radiative emissions caused as a function of time, putting stronger emphasis on the emissions associated to methane. Whilst methane trucks should therefore be allowed to compete with diesel technology in the market, as well as for the tailpipe based CO₂ standards, there is no justification for any additional support mechanism such as purchase subsidies, fuel tax exemptions or toll discounts.

Other options in heavy duty transport have higher decarbonisation potential. Battery electric trucks for example have 54% GHG reductions on WTW level, with the current EU electricity mix.¹⁰⁷ Section 6 will look at the availability of renewable methane for transport.

4.3. Ships

LNG use is growing in maritime applications, as it is seen by some as the future low carbon, low pollutant (SO_x, NO_x, PM) fuel to help decarbonise the sector and reduce air pollution. What is different from the other

^{xviii} Modelled using T&E EUTRM model. Assuming lower efficiency of 9% for HGV (>16t) HPDI LNG trucks and 5% for HGV (<16t) CNG trucks. WTT emission of 19.4 g CO₂ eq./MJ for LNG and 13 g CO₂ eq./MJ for CNG. Methane truck sales are the same percentages in both truck categories.

transport modes is the level of methane slip being significantly higher, thus impacting the TTW (tank-to-wake) GHG performance significantly. With a methane slip of 1.8% the TTW benefit compared to heavy fuel oil (HFO) is 19% and compared to marine gas oil (MGO) 12%.¹⁰⁸ With double the methane slip (3.5%) the benefit compared to HFO is lowered to 7% and compared to MGO, emissions increase by 1%. Sintef, the largest independent research organisation in Scandinavia, identified methane emission factors in real world conditions in 2017, with an average factor of 31 g/kg or (3.1%) and engine technology specific factors of 23.2 g/kg (2.3%) for Lean Burn Spark Ignited engines (LBSI) and 40.9 g/kg (4.1%) for Low Pressure Dual Fuel engines (LPDF).¹⁰⁹ The split of the 120 LNG ships in operation is around 40-60% between these two technologies, respectively. There are also High Pressure Dual Fuel (HPDF) marine engines, which use liquid diesel for ignition and ostensibly provide complete combustion of methane, but they result in higher NOx that requires additional after-treatment systems, like SCR, in order to comply with the IMO Tier III standard.¹¹⁰ For this reason, HPDF engines are not popular because the GHG benefits (from lower methane emissions) come at the expense of high NOx emissions, which LNG also purports to resolve. Thus in shipping, the engine technology needs consideration to assess climate performance with a holistic approach to other emissions.

Well-to-wake

From the perspective of WTW (Well-to-wake) CO₂ equivalent emissions, the change for better or worse compared to existing marine fuels depends on the level of methane leakage. The GHG performance at low methane leakage (1.8%) is in the range of -0.9% to -10.4% for individual ships powered by LNG compared to marine diesel, but with a doubled rate of methane leakage (3.5%) the savings are nullified, in the range of -0.6% to +9.3%.¹¹¹

The savings are also dependent on which fuel is assumed to be replaced, as a shift from MGO to LNG brings lower annual savings than the shift from HFO if accompanied by a scrubber (which comes with a fuel consumption penalty). As can be seen from the table below, the WTW emissions of LNG used in shipping are also highly dependent on the supply chain emissions (WTT) of LNG, which depends not only on the upstream methane leakage but also the type (pipeline gas liquefied vs. LNG) and the distance of upstream transportation. The WTW savings for LNG compared to MGO range from a 3.7% reduction in the best case scenario to a 9.3% increase at the worst case scenario.¹¹²

Table 9. WTW GHG savings of moving from HFO/MGO to LNG for individual ships under low/central/high WTT supply chain and different methane leakage/slip scenarios¹¹³

	Low supply chain emissions (18.8 g CO ₂ eq./MJ)		Central supply chain emissions (19.4 g CO ₂ eq./MJ)		High supply chain emissions (24.6 g CO ₂ eq./MJ)	
	1.8%	3.5%	1.8%	3.5%	1.8%	3.5%
Methane slip	1.8%	3.5%	1.8%	3.5%	1.8%	3.5%
WTW difference to HFO + scrubber	-9.6%	+0.3%	-10.4%	-0.6%	-7.9%	+1.5%
WTW difference to MGO	-3.7%	+6.8%	-4.7%	+5.7%	-0.9%	+9.3%

The figures above are extracted from Ricardo and are in line with other studies on the topic. The ICCT¹¹⁴ concluded that any GHG savings are inextricably linked to methane emissions reduction in both the supply

chain and the ship.^{xix} A TNO study concludes that the range of GHG savings is highly dependent on the levels of methane slip and that data availability on methane slip is limited. They estimate that the range of WTW GHG emissions is similar to diesel powered ships in ocean going ships, and -12% compared to ships fueled with HFO/MGO, assuming¹¹⁵ low methane slip (0.03 g/MJ fuel or 0.2%).¹¹⁶ This low level of methane slip is not supported by other studies, such as the real world study by Sintef¹¹⁷. However, in short sea shipping TNO assumed a methane slip value of 0.56 g/MJ fuel (or 3.6%) and 0.7 g/MJ fuel (or 4.5%) was assumed for inland shipping, making these equal to or worse than existing fuels on a WTW level. At the global fleet level, UMAS estimates that switching 60% of the global fleet to LNG would deliver only <5% total GHG savings compared to MGO/HFO¹¹⁸

The NGVA in its study identified an 11-21% GHG saving compared to HFO without scrubbers. The 11% figure assumes a dual-fuel four-stroke engine while the 21% saving assumes a two-stroke natural gas engine with high-pressure injection. This is despite the expectation that most LNG vessels will be powered using dual fuel low pressure 2-stroke and 4-stroke engines, as these meet IMO Tier III requirements but have a significant sensitivity to methane slip lowering their climate performance.¹¹⁹ Therefore, it appears that NGVA assumptions are inconsistent with marine engine trends in the market.

The maximum theoretical GHG savings from using LNG in shipping is 20% compared to HFO (NGVA study¹²⁰), also identified as higher end future reductions by TNO. Reaching 15-20% WTW GHG savings can be done by 2030-2035 according to TNO, “provided the market develops in such a way that substantial investments in technology developments can be justified.” But this comes with drawbacks: firstly, best engine technology for methane comes at the expense of high NOx emissions, which LNG was argued to resolve. Secondly, if the shipping industry is to take the Paris Agreement seriously, even the theoretical maximum reduction potential of LNG is not enough. If zero emission shipping is to be achieved by 2050, all new ships should be zero emission from approximately 2030 onwards.¹²¹ Even to meet the recent IMO goals of -50% shipping emissions by 2050 “pursuing efforts towards phasing them out entirely” the maximum 20% GHG is not sufficient. This also means that existing fleet will have to be retrofitted with zero emission fuels/propulsion technologies. If LNG is favoured, the fleet will have to be retrofitted twice or large volumes of renewable LNG will be needed for a fuel switch.

There are other options available to decarbonise shipping. In short sea shipping, batteries can be implemented in the immediate future; for ocean going vessels renewable hydrogen could be an option. Both battery electric and hydrogen require shore-side infrastructure, which offer better investment opportunities for the EU and Member States than LNG bunkering facilities. With the maximum deployment of technologies that are currently known, it could be possible to reach “almost full decarbonisation by 2035” according to the International Transport Forum.¹²² Their scenarios are heavily dependant on hydrogen and ammonia to fuel ships.

^{xix} This applies to all use of fossil gas uses

5. Non-GHG emissions (air quality)

In relation to climate change mitigation, benefits of fossil gas vary between transport modes, but are either nonexistent or very limited in the best case scenario. For a fair comparison methane powered vehicles need to be compared to new petrol, diesel, electric, or hybrid models. With new tests and emission limits, new Euro 6 models are cleaner than in the past, making the air pollution benefits of methane much smaller than if compared to petrol or diesel engines in the past. The tailpipe emissions from methane vehicles are much poorer than from electricity, hydrogen and plug-in hybrids. The non-GHG emissions (air pollutants) are the same for renewable methane and fossil methane, thus methane powered transport is not zero emission transport, even if the fuel is renewable.

5.1. Cars

With respect to local air pollutants, CNG powered vehicles are better than diesel cars (see table below), and similar to petrol cars regarding NOx emissions. Sulphur dioxide (SO₂) emissions are mainly related to the Sulphur content of the fuel, and hence CNG cars perform better though the levels in road transport are negligible to start with. However with policy support in mind, one should compare to best vehicle technologies currently on the market or coming in the near future when we are considering any support for new technologies. It is clear that battery electric or hydrogen vehicles are the best fix with no tailpipe emissions of NOx, SO₂ or PM. In real world driving conditions in China a bi-fuel (CNG/petrol) car was found to have “slightly higher” NOx emissions¹²³. Given that the conformity factor for diesel vehicles is going down, and the adoption of the Euro 6d/temp, the NOx emissions of new diesels should decrease. There is a lack of recent and reliable data on PN, PM and NOx for CNG cars. Ecoscore.be gives some figures on NOx and PM, but the information sources are not clear and the results are based on type approval data which is a poor proxy for real world emissions performance.

Table 10. Real-world tailpipe emissions of Euro 6 vehicles¹²⁴

	NOx (mg/km)	PM _{2.5} (mg/km)
Petrol	56	1.6
Hybrid petrol	13	Data not available
Diesel	170	1.5
CNG	56	1.1
Battery electric vehicle	0	0

Data is scarce when examining particulate number emissions (PN) for passenger cars. In 2009, Ford presented PM and PN emissions for different engine technologies (Figure 9).¹²⁵ The data shows that the two CNG cars considered were amongst the lowest with respect to particle mass and particle numbers. More recent real world data is needed to have a better understanding of the current situation in passenger cars. In truck engines, a CNG engine produced 2-8 times higher PN emissions than diesel engines equipped with a diesel particulate filter.¹²⁶

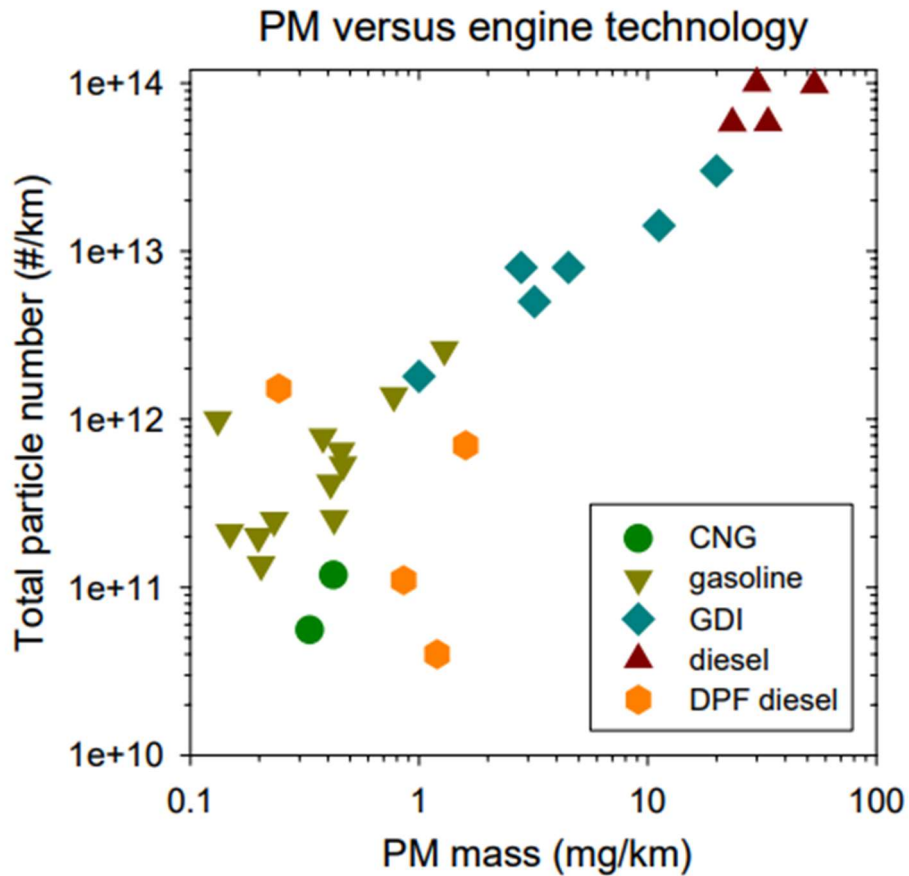


Figure 9. Particle number (PN) emissions versus particle mass (PM) emissions for different engine technologies in 2009¹²⁷

When considering the non-exhaust emissions, electric vehicles emit less PM than diesel or petrol vehicles.¹²⁸ Non-exhaust PM emissions from CNG cars can be considered similar to the petrol or diesel cars, making CNG cars with lower PM emissions from combustion still worse than EVs.

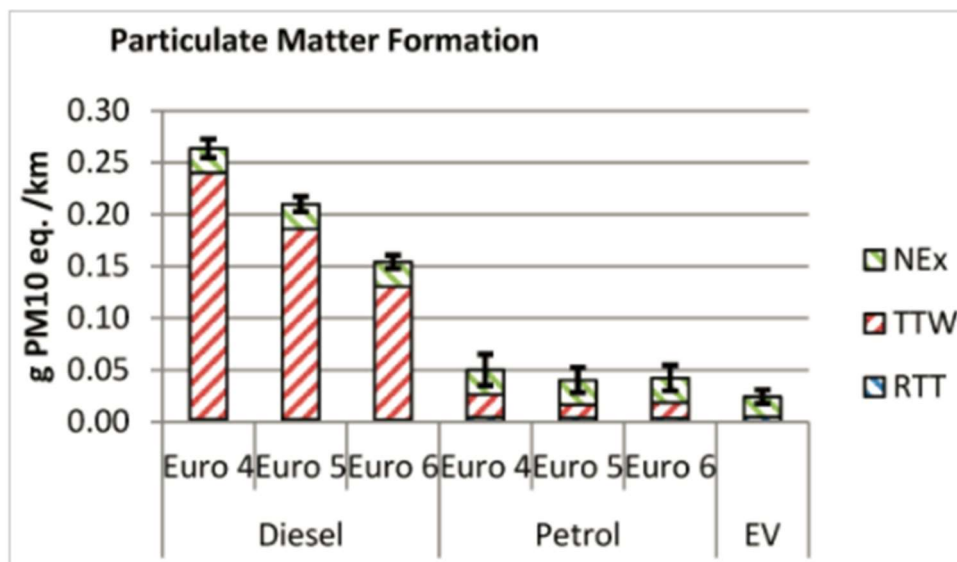


Figure 10. PM emissions including non-exhaust emissions (NEx)¹²⁹

5.2. Trucks and buses

Current Euro VI heavy duty vehicles are relatively clean, having reduced NOx emissions by 80% and PM by half compared to Euro V limits.¹³⁰ Thus, the NOx emissions from heavy duty vehicles are now very similar for diesel and methane vehicles.

Data from the UK and the Netherlands support the fact that there is no significant difference in NOx emissions between diesel and methane. In lab and track testing for the UK Department for Transport NOx emissions from dedicated spark ignition methane powered trucks were on average 135 mg/km under test cycle conditions, while the Euro VI diesel comparator vehicles emitted NOx at a rate of about 230 mg/km.¹³¹ The aftermarket conversion of a Euro VI diesel truck in the same study resulted in higher NOx emissions in dual-fuel mode (540 mg/km on average) than with the same vehicle operating in diesel-only mode (170 mg/km). TNO tested two LNG (spark ignition) trucks in real world conditions in the Netherlands. On average, one truck had similar NOx emissions than the average of tested diesel trucks but the other had NOx emissions on par with the highest emitting diesel trucks. In urban driving conditions, the NOx emissions of both LNG trucks were higher than average diesel trucks.¹³² In 2016, Ricardo considered the NOx emissions between methane powered and modern Euro VI diesel trucks to be equal, as limited data was available and based on buses they were the same.¹³³

If there is a move to LNG trucks using high pressure direct injection (HPDI), a more diesel like technology, instead of spark technology, NOx levels may increase. For example, Volvo’s new LNG truck emits on average 744 mg NOx/km, 11% more than their similar diesel engine.¹³⁴

Based on the available evidence, the performance of methane and diesel HDVs appears to be similar. Unfortunately there are no comparative real world emission tests for Euro VI diesel and methane trucks using different engine technologies. These would be necessary to evaluate actual benefits of methane trucks compared to diesel trucks, especially as the European Commission’s Joint Research Centre (JRC) identified from a real driving test on a Euro VI diesel truck that 85% of the NOx emission were outside of the specified boundaries in the legislation.¹³⁵ Zero emission technologies are available for inner-city use, and soon also for intercity heavy duty vehicles and so policy support should be given to technologies with higher emission reductions.

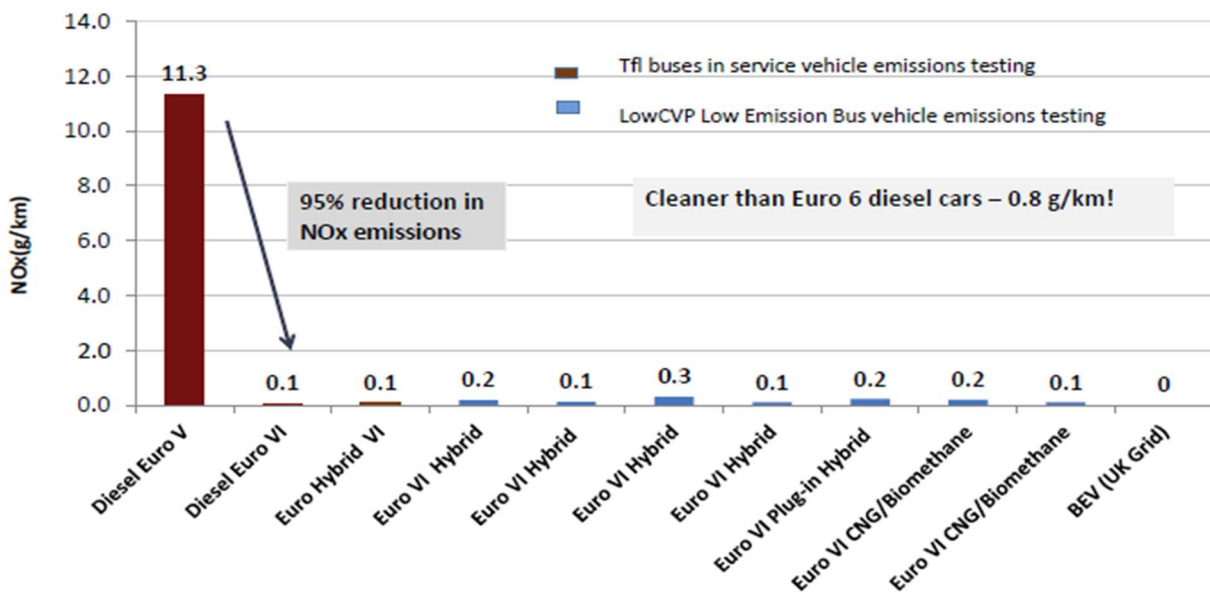


Figure 11. NOx emissions of different bus technologies based on LowCVP emissions testing (lab testing).¹³⁶ xx

xx TfL = Transport for London

For buses, air pollutant emissions are comparable between Euro VI diesel and Euro VI CNG buses, with diesel performing better with respect to CO₂ emissions.¹³⁷ As can be seen from the image above, there is a marginal difference between the NO_x emissions of Euro VI diesel buses compared to other alternative fuel vehicles.

PM emissions are generally lower for methane trucks, however the number of particles (PN - particle number) is higher compared to Euro VI diesels based on road and laboratory tests carried out by the JRC.¹³⁸ PM measures the mass of the particulate emissions giving more emphasis on heavier particles, while PN measures the number of particles, giving more emphasis on smaller particles, which are more harmful for health¹³⁹. This difference in methane trucks compared to diesel occurs because DPFs (diesel particulate filters) have been efficient at cutting diesel particulate emissions significantly reducing emissions compared to older Euro standards. In the JRC report, the CNG bus test had higher SPM emissions compared to the Euro VI diesel bus with a diesel particulate filter. CNG or LNG trucks generally emit less PM (particulate matter)¹⁴⁰ or black soot than non-DPF equipped diesel vehicles but, this is not necessarily true anymore for PM¹⁴¹, if they are compared to DPF equipped diesel vehicles. The results from the UK department for transport gas vehicle study¹⁴² which included lab tests and track tests did not measure for PM, but based on data from the manufacturers, gas vehicles emitted 1 - 3 mg/kWh and diesel 2 – 6 mg/kWh. TNO also found that “...spark ignition gas engines and diesel engines with wall flow particulates filters often have quite similar particulates emissions, both in mass and in number.”¹⁴³ The difference in PM emissions between diesel and methane-powered vehicles is lower than it was in previous Euro standards. The literature gives differing views when comparing to modern Euro VI diesel trucks with DPFs, as the different engine technologies for methane vehicles have different performance.¹⁴⁴ ¹⁴⁵ However, the solid particle number (PN) is higher for CNG trucks compared to diesel trucks, and this result will likely also apply to LNG trucks.

Based on the available evidence, methane trucks and buses do not have a significant benefit compared to equivalent Euro VI diesel trucks in terms of air quality. Different studies give slightly conflicting results, but the differences do not justify a move from diesel trucks to LNG or CNG trucks. Further testing is needed, also comparing the air pollutant emissions performance of spark ignition and pressure (HPDI) methane trucks to the best available current Euro VI diesel trucks, both under laboratory and real driving conditions. The EU is currently preparing Euro VII emission standards for trucks. From a vehicle technology and fleet replacement point of view a shift towards EURO VI and further tightening in EURO VII would likely be a much more effective air pollution control strategy than shifting the fleet to CNG or LNG.

5.3. Ships

The reductions in local air pollutant emissions are large with the use of LNG in ships. Current marine fuels have very high Sulphur content compared to road fuels and LNG offers a promise of a much cleaner fuel from a local air pollution perspective. This is one of the main reasons why LNG in ships is promoted, to meet the requirements of the Emission Control Areas (ECA) and the 0.5% global Sulphur cap coming into force in 2020 (more detail in section 2.5). The local air pollutant reductions associated with using LNG in shipping are well documented in ICCT 2013¹⁴⁶ and Ricardo 2016¹⁴⁷. They estimate NO_x, SO₂ and PM reductions in the range 85-100%, compared to ships powered by HFO.

LNG is not the only way to meet the ECA requirements. Lower Sulphur fuels can be used (MGO), which is generally more expensive than LNG but can deliver very large SO_x and PM reductions. Exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) exhaust after treatment systems also deliver up to 80% NO_x reductions for MGO/HFO ships and are currently the only options used to comply with the North American NO_x ECA.

The local pollutant emissions of shipping are also relevant for global warming, as the PM emissions include black carbon, which absorbs heat in the atmosphere and when landing on ice, causes faster melting. This is important as, according ICCT estimates, black carbon emissions from shipping are responsible for 7-21% of the sector's global climate warming impact.¹⁴⁸ Because of these issues, using LNG can be beneficial in the

short term, especially close to arctic regions with snow cover. However, there are measures which can be taken with existing fuels to eliminate black carbon emissions from ships, such as shifting from HFO to MGO and applying diesel particulate filters which reduces black carbon emissions by >99%¹⁴⁹, a result much more efficient than switching to LNG, as infrastructure is already in place.

Table 11. New infrastructure requirements for different fuel options

	Reduces air pollution (SOx, NOx, PM)	Investment required in ship technology (new build or retrofits)	Investment required in new shore-side bunkering infrastructure
LNG	yes	yes	yes
MGO (0.1% S) + SCR + DPF	yes	yes	no

It is worth noting that there are many other alternatives to lower local pollutant emissions in shipping. Zero-emission shipping is becoming possible, through hydrogen use and batteries for example. Battery ships already exist. Hydrogen ships are not yet on the market, but on their way. The choice of technology will also be dependent on the distance individual ships travel per journey. Renewable ammonia is also the most widely considered zero GHG fuel for deep sea large ships.¹⁵⁰ There are already smaller battery powered ships in operation on regular routes in China¹⁵¹ and a ferry in Norway¹⁵².

6. Renewable methane

Renewable methane is the umbrella term for biomethane and power-to-methane produced with renewable electricity. Power-to-methane is not considered a renewable fuel unless only renewable electricity is used to produce it. Biomethane and power-to-methane are chemically identical to fossil methane (CH₄) and can be used as substitutes. Currently less than 3% of the transport methane consumption is renewable.¹⁵³

Biomethane

Biogas consists of around 50-75% methane, the rest being mainly CO₂. When the CO₂ and other impurities are removed, the final product is biomethane. Biomethane is used in transport, as biogas is not pure enough for vehicle engines. There are two main technologies for the production of biomethane. The first is anaerobic digestion (a bacterial break down process), which is suitable mainly for wetter, less tough materials (e.g. sewage sludge, manure, crops). The second is gasification (a thermal process) which produces syngas^{xxi}. It can be produced from multiple raw materials which are solid (e.g. wood, municipal waste). Both biogas and syngas can be further converted to biomethane. The sustainability of biomethane varies depending on the raw material. Genuine wastes are the most sustainable raw materials, as they deliver the highest GHG savings and have no other uses.

Power-to-methane

Power-to-methane is a synthetic fuel (also known as e-fuel, Power-to-gas, PtG or Renewable Fuels of Non-Biological Origin, RFNBO). The basic principle is that electricity is used to produce a synthetic fuel. The first step is to produce hydrogen and CO₂ is added to the hydrogen in a methanisation process to form synthetic methane. For electrofuels to provide GHG benefits, the electricity needs to be carbon free, renewable and additional (i.e. would not exist without the production of the electrofuel).¹⁵⁴ If renewable electricity is diverted from other end uses, it would easily lead to more electricity produced from fossil fuels, hence increasing emissions in the rest of the electricity grid. Renewable hydrogen, the basic building block of all electrofuels, has many other alternative uses, as it could be used to decarbonise industry, or used as an energy carrier itself. Power-to-methane needs CO₂ as a feedstock, and for the fuel to be fully circular, i.e. the atmospheric concentration of CO₂ remains the same, the CO₂ needs to be captured from the air.¹⁵⁵ This also avoids double counting of CO₂ reductions and prolonging the needed CO₂ reductions in CO₂ emitting industries.

6.1. Climate benefits of renewable methane

Biomethane

The greenhouse gas performance of renewable methane depends on the raw material and the technology used to produce the fuel. The GHG performance of different raw materials and production technologies is presented in the table below. It is clear that both the production technology and the raw material affect significantly the GHG performance of the fuel. The best and worst production technologies are provided to show the range of GHG performance in the table below.

The use of food and feed crops for liquid biofuels is associated with negative environmental and climate impacts due to Indirect Land-Use Change (ILUC). The use of crops to produce biomethane raises the same sustainability concerns, because using land for energy crop production leads to additional land conversion elsewhere, increasing GHG emissions. When ILUC emissions are incorporated, the real GHG savings of CNG from maize remain relatively low (13% to 46% for CNG depending on production technology). In addition, mono-cropping for biogas is associated with other sustainability concerns, including soil compaction, erosion in the field and run-off of fertilisers. Using food crops like maize for biofuels has also proven to push up food prices¹⁵⁶.

^{xxi} Syngas has a different composition than biogas, comprising of CH₄, CO, CO₂ and H₂. The energy content is less than half of fossil gas.

By contrast, manure is the most sustainable feedstock. It is a true waste and the anaerobic digestion acts as a waste treatment (it captures the methane emissions that would have otherwise been emitted if biogas had not been produced). This explains why the GHG savings are higher than 100% (because the GWP for methane is so much higher than for CO₂).

The Renewable Energy Directive (RED) sets minimum GHG savings thresholds for biofuels used in transport, and “biomass fuels”^{xxii} which includes biomethane used in the power and heating sectors. The current requirement is at least 50% GHG savings for biofuels.^{xxiii} The recast of the RED sets new GHG savings requirements for the period 2021 to 2030. For transport, GHG savings need to be at least 65% in plants starting operation after 1 January 2021. Biomethane used in the transport sector needs to comply with these thresholds and sustainability criteria. In other sectors, plants below 2 MW rated thermal input capacity do not need to comply with the requirements, hence they do not need to comply with these GHG savings thresholds or the sustainability criteria set in the RED.^{xxiv}

Table 12. GHG savings of biomethane pathways (as CNG for transport),¹⁵⁷ with Indirect Land-Use Change (ILUC) values for maize¹⁵⁸

Raw material of biogas	Production technology	GHG emissions of fuel (g CO ₂ eq./MJ)	GHG savings compared to the fossil comparator (%)	ILUC emission (based on Globiom modelling) (g CO ₂ eq./MJ)	GHG savings compared to the fossil comparator with ILUC emissions (%)
Wet manure	Open digestate, no-off gas combustion	-16	117%		117%
	Closed Digestate, off-gas combustion	-100	206%		206%
Maize whole plants	Open digestate, no-off gas combustion	61	35%	21	13%
	Close Digestate, off-gas combustion	30	68%	21	46%
Bio-waste	Open digestate, no-off gas combustion	54	43%		43%
	Close Digestate, off-gas combustion	13	86%		86%

The different production technologies of biomethane have an impact on the GHG and methane emissions in production. Various estimates indicate methane emissions at 1% to 3% of produced biogas.¹⁵⁹ The upgrading of biogas to biomethane has also a methane loss of 0.1% to 15% depending on the process used. JRC is using a value of 3%¹⁶⁰ for the total methane emissions but reduces it to zero if the off-gasses are combusted, meaning the off-gas is captured and burnt. The uptake of the off-gas combustion is increasing but at the moment it is unknown at what rate this technology is used.

^{xxii} As defined in the REDII: 'biomass fuels' means gaseous and solid fuels produced from biomass.

^{xxiii} The 50% GHG savings apply to biofuels produced in installations starting operation before 5 October 2015. A 60% threshold applies for biofuels produced in installations starting operation after 5 October 2015.

^{xxiv} As the EU average biogas plant has an installed capacity of 609 kW electricity, so with an electrical efficiency of 35-40% gives the input as around 1.5-1.7 MW input. Assumptions from: Scarlat, Dallemand & Fahl (2018) Biogas: Developments and perspectives in Europe Renewable Energy Volume 129 p.457-472

The storage of the digestate^{xxv} also impacts the GHG performance. Small amounts of methane are present in the digestate^{xxvi} even after it has passed the anaerobic digester. This leads to 1 to 10% methane emissions in case the digestate is not stored in an airtight tank, as the methane would be emitted into the atmosphere. Storing the digestate in an airtight tank decreases the methane emission to zero in JRC calculations. The closed digestate is mandated by law in many EU countries, hence its high uptake (exact level unknown). The uptake may further increase as producers will want to meet the GHG savings requirements. The use of better technology is crucial as moving from open storage of digestate to an air tight tank increases GHG performance by 17% points for maize and municipal waste, and the combustion of off-gasses increases GHG performance by 16% points for all the feedstocks listed above.

Power-to-methane

As power-to-methane is a relatively new fuel, and not yet established, there are no GHG values for this fuel in the Renewable Energy Directive. The recast of the directive for the period 2021-2030 sets a 70% GHG savings threshold for electrofuels used in transport, but the EC still needs to develop a methodology for the GHG accounting. The Commission will also adopt a delegated act regarding the cases when electricity can be credited as fully renewable for the production of electrofuels.

Looking at the GHG performance of power-to-methane with different electricity mixes, it is clear that the electricity needs to be zero carbon to achieve GHG savings, as can be seen in Figure 12. Even a small amount of carbon emissions in the electricity production will reduce the GHG saving potential as the process efficiency for power-to-methane is currently around 40%. Thus any CO₂ emissions from electricity production is at least doubled, as there are also emissions associated with conditioning and distributing the fuel (efficiencies discussed in more detail in section 6.4).¹⁶¹

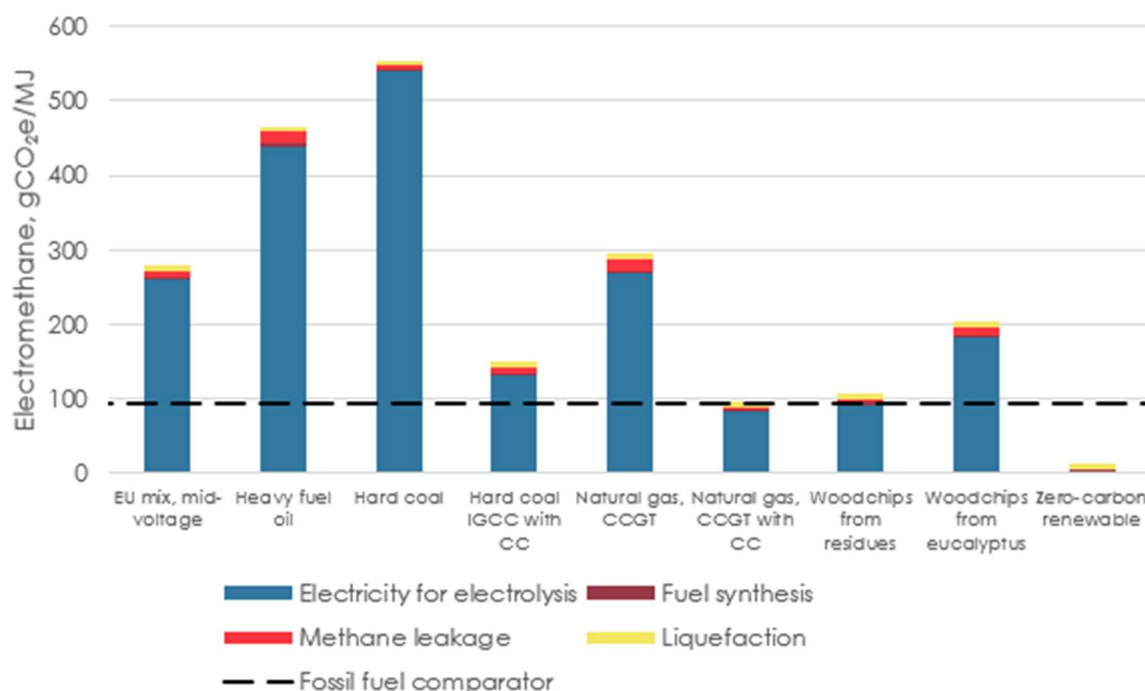


Figure 12. Carbon intensity of Liquefied power-to-methane with different electricity sources assuming point source CO₂. (Malins 2018)

The electricity also needs to be additional, in addition to being renewable.¹⁶² If existing renewable electricity is diverted for electrofuel production (including power-to-methane), then it implies that less renewable

^{xxv} Digestate is the solid/liquid material remaining after the anaerobic digestion of a biodegradable feedstock.

^{xxvi} Solid output of anaerobic digestion

electricity is available to the other grid users and the demand needs to be covered with marginal electricity production, often fossil. To ensure additionality, renewable electricity used for electrofuels (including power-to-methane) needs to be:

1. Generated from new and unsupported production plants or
2. Surplus production which would otherwise have been curtailed.¹⁶³

Power-to-methane production requires CO₂ as a feedstock and the CO₂ is released to the atmosphere during its combustion - the source of CO₂ used is therefore important. There is also a risk of methane emissions in the supply chain and use. Three types of sources of CO₂ can be potentially used as inputs into the process: CO₂ of fossil carbon origin, CO₂ from biogenic origin or CO₂ from the atmosphere. Using CO₂ from a fossil carbon origin, such as the one being emitted in a steel or a power plant, creates the risk of locking-in one sector to decarbonise the other, creating an incentive to keep producing CO₂. There is also a risk of double counting the emission reductions (in other words not counting the emissions at all) first rewarding the industrial facility capturing the CO₂ in the ETS, and treating electrofuels produced from captured fossil carbon as carbon neutral. In a decarbonised economy, as required by the Paris Agreement, this is not acceptable. With the use of fossil CO₂, care is needed to ensure the CO₂ emissions are counted somewhere, either in industry or transport, as the CO₂ is still emitted, but just used twice. The optimal long-term solution is for the CO₂ to be captured from the air, as it ensures the fuel is fully circular. Air capture increases cost and energy consumptions, but with technology still developing prices and energy consumptions are coming down.^{164,165}

Provided the production-electricity is zero carbon, renewable and additional, power-to-methane in transport has high GHG savings, in the range of 74-90% compared to fossil fuels (image below). As with fossil gas, the potential savings are dependent on the methane leakage rates in distribution and operation. The associated emissions come from the liquefaction or compression of the methane to LNG or CNG, any methane leakages in distribution and operation and the CO₂ feedstock. Grid electricity of 141 g CO₂/MJ was assumed for the CO₂ absorption, as it might happen in a different location from where the electrofuel is being produced with a point source assumed in the calculation.¹⁶⁶

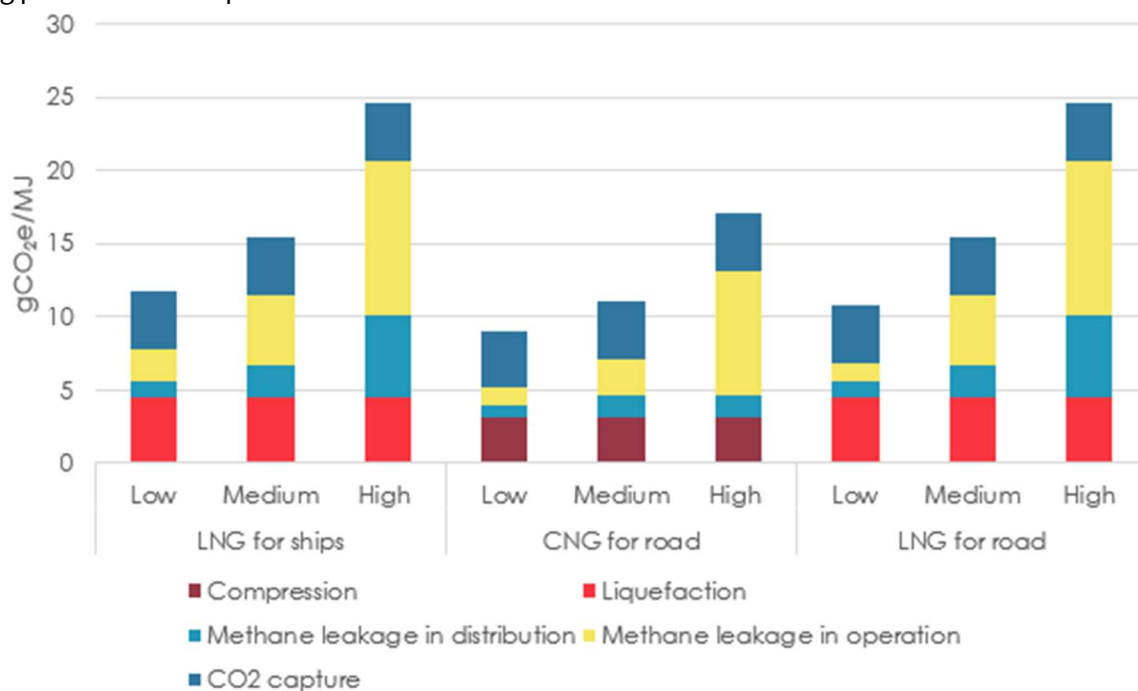


Figure 13 Power-to-methane emissions of CNG and LNG using zero carbon electricity (Malins 2018)

6.2. Current consumption of biomethane

Current production of biogas in the EU is 16.1 Mtoe (or 17.9 bcm or 674 PJ).¹⁶⁷ It is being produced in 17 662 production plants, of which only 497 (11%) upgrade the biogas to biomethane, while the rest is used at the production site, mainly for electricity.¹⁶⁸ To put this into perspective the EU’s fossil gas consumption in 2016 was 383 Mtoe¹⁶⁹. Power-to-methane production is negligible. Renewable methane consumption is hence 4% of EU methane consumption. Only around 0.5% of the gas grid is renewable, as the majority of biogas never gets upgraded to biomethane and injected in the grid but is used on site for electricity production. Only 2.9% of the methane used in transport is renewable EU wide.¹⁷⁰ Over half of the current biogas is produced from energy crops, mainly maize, followed by landfill gas as can be seen in Figure 13. Maize has associated ILUC emissions which reduces considerably its GHG-savings potential compared to fossil gas and has other sustainability concerns (see section 6.1).

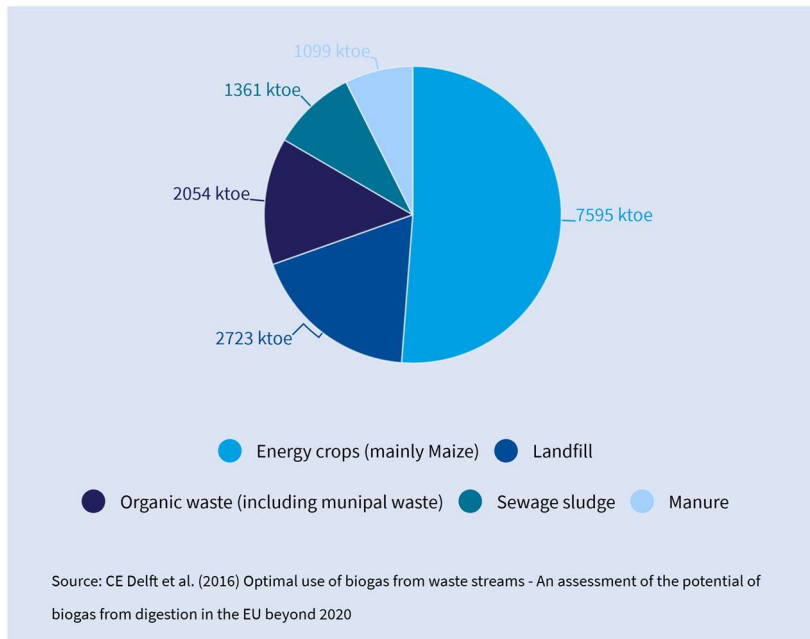


Figure 14. Biogas composition in EU (2014)

Of the current EU biogas production, Germany accounts for 49%, followed by Italy, the UK and Sweden. As can be seen from Figure 15, production is highly concentrated in a few countries with strong policy support and is not developed EU wide.

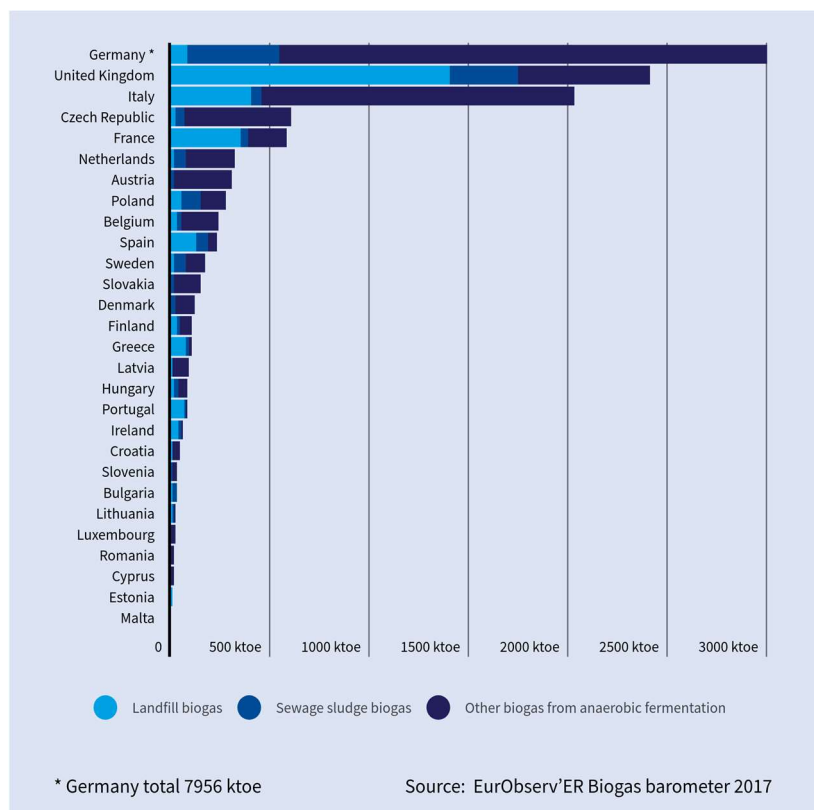


Figure 15. Biogas produced in EU per member state (2016)

6.3. Potential of biomethane

One of the key questions in the gas debate is how much biogas/biomethane can be produced sustainably. The above sections show that the climate benefits of fossil gas in transport are very limited. Whilst gas lobbies continue to claim greater benefits than observed in independent studies, their main argument is that fossil methane will ultimately be replaced by very low carbon renewable methane. The key question is therefore whether large quantities of sustainably produced renewable methane are readily available at acceptable cost, and if so, whether they should be directed to transport rather than to industry, heating and electricity production.

There is an array of potential or availability studies for biomass resources, all with different assumptions, especially on the role of crop based biomethane and thus different outputs on how much biomethane can contribute to the energy supply in the future. The image below summarises a few biomethane potential studies identified by the European Biogas Association, comparing the potential with current methane use.¹⁷¹ On the higher end is a European Commission funded study on the new waste biogas potential for the 2030 timeframe, identifying an additional potential of 11-21 Mtoe¹⁷². When including the existing waste biogas production (and excluding crop biogas), waste based biogas/biomethane can contribute in the range of 21.2-32.6 Mtoe. In the 2050 timeframe, a study by ECOFYS for the Gas For Climate consortium concluded that residual waste biomass suitable for anaerobic digestion (wet biomass such as manure and sludge) could amount to 23 bcm or 21.7 Mtoe, which is on the lower end of what CE Delft identified for 2030 (21-32 Mtoe).¹⁷³ The ICCT concluded that the technical biomethane potential is in similar range, but realising the potential requires significant subsidies, 4€/m³ or 20 times the fossil fuel price, and if subsidies are only 0.75 €/m³, a small fraction (ca. 1Mtoe) of the technical potential can be realised.¹⁷⁴

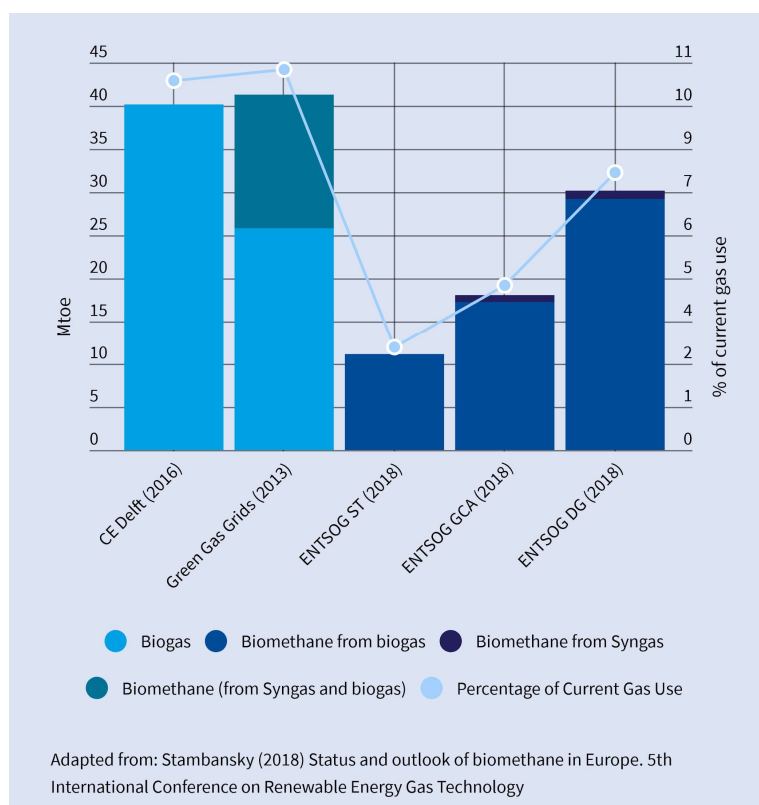


Figure 16. Biomethane potential studies (2030)

The maximum sustainable potential for waste based biomethane could cover only around 6.2% to 9.5% of projected EU transport demand for 2030, in a business as usual scenario and assuming all of it is used for transport.^{xxvii}

The assessment of the potential for future biogas production usually includes fuel produced from crops. However, as explained in section 6.1, crop-based biogas has significant land use impacts and other sustainability concerns due to mono-cropping. To address the ILUC impact of crop biofuels, there is a cap on food and feed based biofuels in the Renewable Energy Directive (RED). Currently, this limit applies to on crop based biofuels (liquid or gaseous) which are used in the transport sector (and crop based bioliquids used in heating and electricity) at 7% of road and rail transport energy in 2020. Crop based biogas used in electricity or heating is excluded from the cap, a flaw in the policy.

After 2020, this limit will be set in member states at the level of national consumption in 2020, with a possibility to only increase its level by one percentage point but also to have a lower limit. The policy support after 2020 shifts towards waste and residue resources, which are considered advanced biofuels under the REDII. Taking this into consideration, the EU policy enables only very limited growth for crop based biomethane in transport to 2020 and theoretically no growth at all after 2020.

For all these reasons, crops are excluded from the sustainable potentials considered in this study. To ensure robust sustainability, biomethane production should be based on wastes while respecting the waste hierarchy. The waste framework directive counts anaerobic digestion of organic waste as recycling, if the solid digestate is used, hence giving strong policy signal for the production of biogas.

The 2018 ECOFYS study looked at the potential from crops but did so on the basis of so-called ‘sequential cropping’ practices. This is an agricultural practice where different crops are used sequentially on

^{xxvii} Comparing the CE delft waste biogas potential to the Reference scenario (REF2016) - 2030 projected transport energy demand.

agricultural land, growing more than one crop in a year on a given land. The basic principle is that a second crop is sown after the main crop (grown during the summer growing season) is harvested in the autumn, so the land is under production also during winter. This practice is promoted by a consortium of Italian farmers, including the Italian biogas association¹⁷⁵, but it is currently not standard practice in many regions of Europe. The evaluation of the potential of this practice is very difficult as the potential is dependent on climate, soil conditions and crops currently grown. The second crop could be often used for animal feed. Sequential cropping would also require the introduction of very detailed sustainability safeguards which would ensure the main crop growing season is not affected negatively, and the soil fertility is not decreased, and displacing existing winter crops should not be allowed. The ECOFYS study assumes 50% of today's EU harvested area of wheat and maize (excluding Nordics, Baltics and Ireland) would transition to sequential cropping and all of the production going to biomethane. This is extremely optimistic, and it is unclear what the basis of the 50% assumption is as there are no real world or regulatory trends indicating this is the direction the market will take.

Gasification of solid biomass is another potential pathway for the production of biomethane. However, of all the possible uses for this solid biomass, the conversion into biomethane through gasification is amongst the most complex and costly and the same feedstocks could be used for drop-in liquid biofuels which would not need new vehicles and infrastructure. Transport & Environment considered solid biomass for liquid biofuels in its assessment for advanced biofuels.¹⁷⁶ This is why we have excluded gasification of solid biomass from this potential assessment.

Figure 17 shows the high end of biogas potential per member state in 2030 in relation to transport energy demand. It depicts a case where all biogas, existing biogas (including also 7.6 Mtoe of crops in the EU total^{xxviii}) and the full high end potential of waste based biogas, is converted to biomethane and consumed in transport. This shows that even with very optimistic estimates of the deployment of biomethane production, and allocating all of it to transport, it would make a maximum contribution of 9.5% of EU transport energy demand. It is however unrealistic that the high end potential is mobilised, and extremely unlikely that the full potential goes to transport, given that currently less than 1% of biomethane is used in transport¹⁷⁷.

These studies identified so far have not properly analysed the cost of supplying the biomethane to transport, which decreases the potential to a fraction, as getting all of the dispersed resource to transport has an excessively high cost. The ICCT analysed the cost of producing biomethane and injecting it to the gas grid and using it in transport as CNG for Spain, Italy and France. They looked only at untapped potential and did not include existing biogas use, as it would be just shifting emission reductions from one sector to another. With a low cost of CNG (2.9€/kg excluding subsidies) they saw no new biomethane potential for transport in France and Spain, and less than a tenth of the technical potential of biogas produced in Italy. With a higher cost (8.1€/kg), a larger share of the technical potential was met: a quarter in France (0.9% of transport energy), half in Italy (0.7% of transport energy) and a fifth in Spain (1.3% of transport energy). This is mainly because the currently unused feedstocks are dispersed, and situated far from the existing gas pipelines, and when the dispersion is modelled and the related transportation costs of the biomethane to the grid, the supply cost increases significantly.¹⁷⁸

Thus it is clear biomethane is not a scalable solution to decarbonise transport. Given the limited availability of sustainable biomethane, the high cost of building gas infrastructure and changing the vehicle fleet as well as the risk of expanding and locking in fossil gas use in transport, the question is whether biomethane should be used at all in the transport sector or should rather be directed to sectors that are currently dependent on fossil gas (see section 6.5).

^{xxviii} The per country data of the study did not specify the feedstocks, hence also crop biogas is included in the image, even though T&E does not consider them as sustainable.

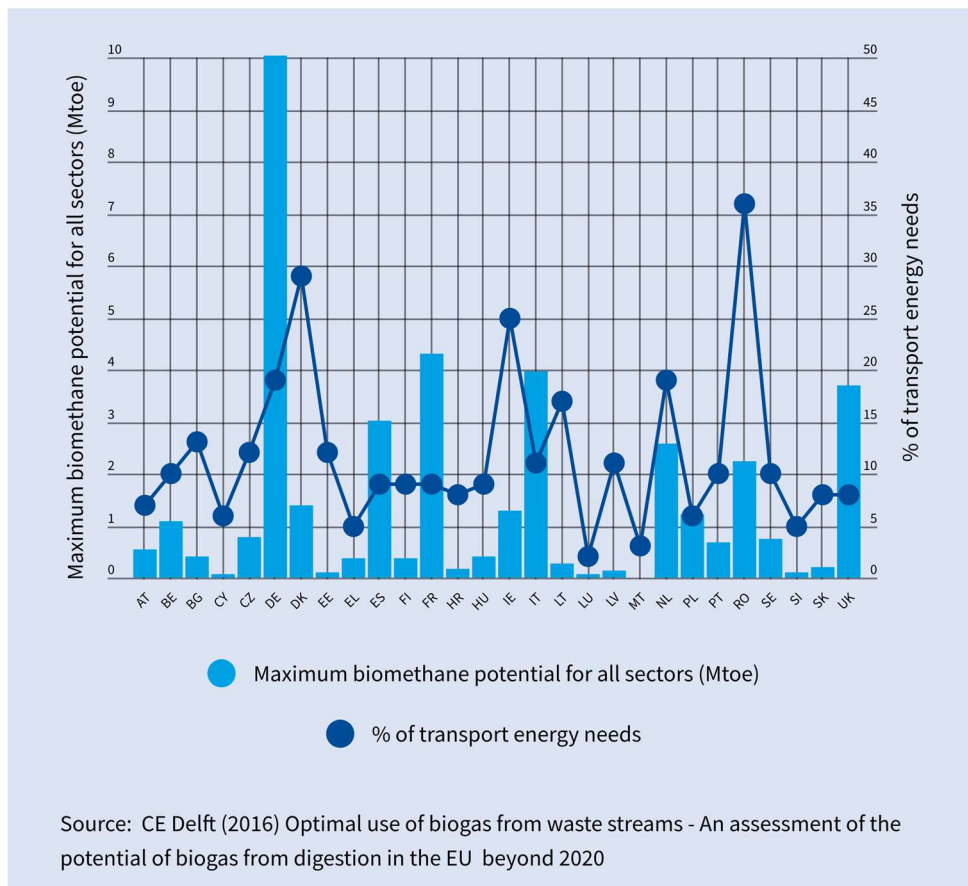


Figure 17. Maximum biomethane potential by member states (2030)

6.4. Potential of Power-to-Methane

Currently, the production and use of power-to-methane is limited to pilot plants in the EU. The future potential can theoretically be considered large, but it is very much dependent on the policy support and the price development and availability of renewable electricity, as the production costs of power-to-methane are very high. The electricity consumption to produce 1 MJ of CNG is 2.58 MJ and 2.59 for LNG, thus large volumes of renewable electricity would be needed.¹⁷⁹ As an example on cost, a study done for the ICCT estimates that a 1.5€/litre subsidy for drop in liquid electrofuels in the 2030 policy framework would deliver around 400 million litres of electrofuels¹⁸⁰ (0.15% of total EU road fuel market in 2030). A similar evaluation identified that power-to-methane in Italy, Spain and France would start being viable with a price of 4€/kg CNG.¹⁸¹ The hydrogen council¹⁸² has estimated that roughly 250-300 TWh of excess renewable electricity could be used for renewable hydrogen production by 2030, resulting in roughly 15-18 Mtoe^{xxix}. If all is used in transport, this could contribute 4.4-5.3% of transport energy need in 2030.

^{xxix} Assuming 70% efficiency of conversion of electricity to hydrogen

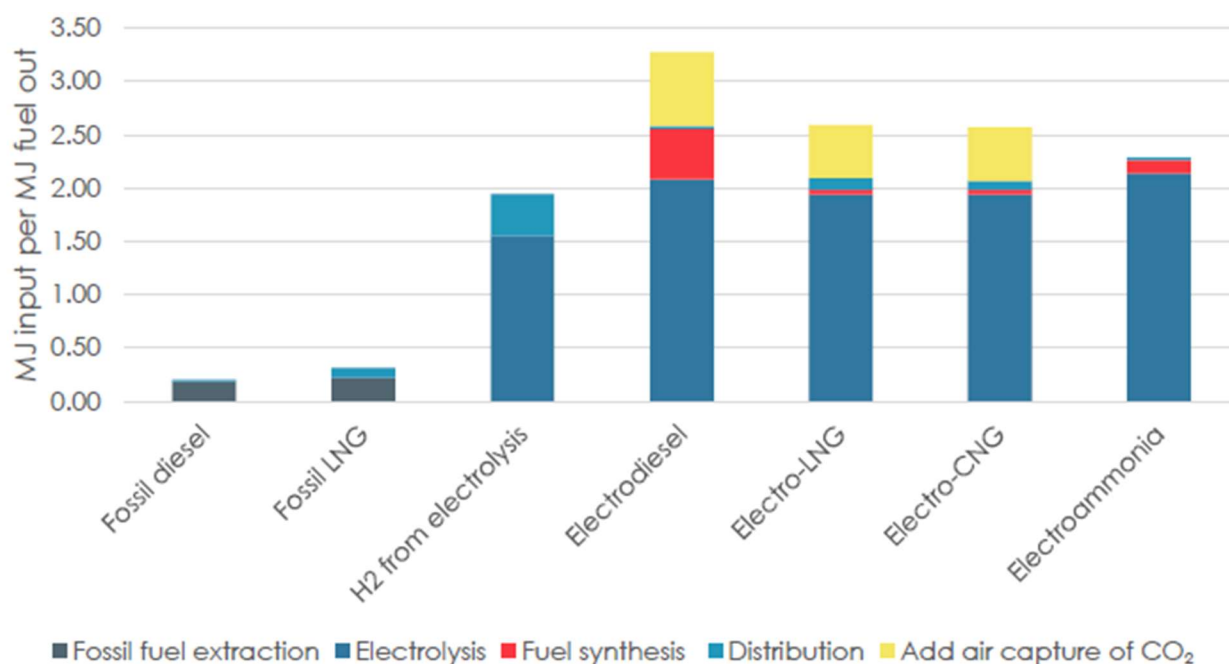


Figure 18. Comparison of energy inputs to different fossil and electrofuel systems. ¹⁸³

Power-to-methane development is more uncertain as there is currently less focus on decarbonising the gas grid. Hydrogen is an alternative energy carrier to methane, which can be blended in the existing gas grids at small shares but larger shares need investment into the adaptation of existing gas infrastructure, which would also mean that methane is not transported in these pipes. Hydrogen has a better energy efficiency in production than power-to-methane, but the energy content of methane is higher. Thus the choice of energy carrier is complex. The Gas for Climate study by Ecofys expect hydrogen to play a more important role and chose power-to-gas to be hydrogen, not methane. Other studies also point out that hydrogen is the more likely power-to-gas technology.¹⁸⁴ Hydrogen is a preferential energy carrier over methane, as its global warming potential (GWP) is much less than for methane, so in case it leaks during production, distribution or use, the climate impact is lower. It is however a costlier technology to use as there is currently limited infrastructure, and the infrastructure development cost needs to be considered.

Power-to-methane is expensive, with a current cost estimate of 1700-7900 €/toe with an electricity cost of 0.05€/Kwh which is at the low end of current renewable electricity auction prices.¹⁸⁵ Biomethane is much cheaper, at about 700-800€/toe¹⁸⁶, but different feedstocks have different cost factors. For instance for manure, the transport of biomethane from farm to transport use is expensive, and decreases potential significantly¹⁸⁷. Given that fossil gas now has an average price of 350€/toe (0.03 €/kWh¹⁸⁸) for medium-sized non-household consumers, even the low end prices of power-to-methane are currently at least five times more expensive than fossil gas, and with little decrease to be seen until 2030 as can be seen in the image below. Even with free electricity, power-to-methane remains significantly more expensive (6 times in a base case 2030¹⁸⁹) than fossil gas. Given the cost of power-to-methane (and power-to-fuels in general) it should be used only in sectors where more efficient alternatives are not available.

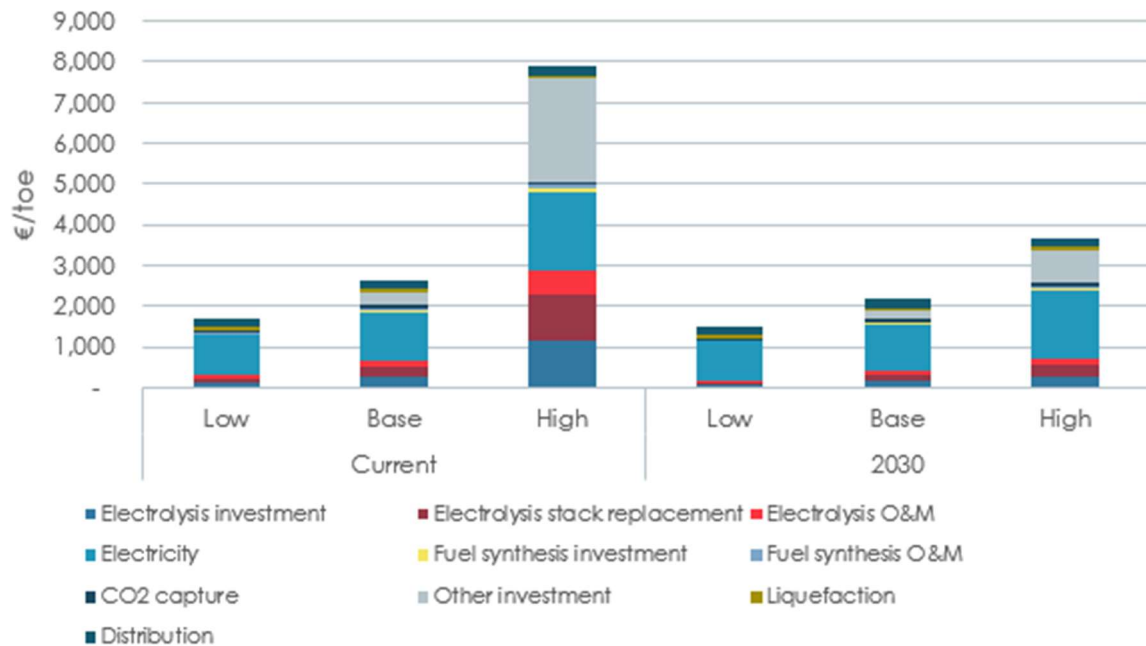


Figure 19 Cost estimates for renewable methane production given a 0.05€/kWh electricity price and point source CO₂ capture. (Malins 2018)¹⁹⁰

The production of electrofuels is inefficient and costly and therefore not a credible or cost-effective solution to decarbonise road transport¹⁹¹. To power the current EU vehicle fleet with electrofuels would require adding 1.5 times the present total EU electricity generation and all of this electricity would have to be renewable and additional. This means sustainable electrofuel production cannot realistically be scaled up to the levels needed to fuel the European fleet and cover other existing fossil gas uses. These fuels will remain significantly more expensive than fossil fuels, and linked to the price of renewable electricity. This is why policy support would be needed, but it should only be granted to projects using only additional renewable electricity and CO₂ captured from the air. Electrofuels should be given further consideration for sectors where few other alternatives exist, meaning the aviation sector and parts of the shipping sector for transport. Other more energy efficient options than power-to-methane are available to decarbonise land transport.

6.5. Where renewable methane should be used?

As there is limited potential of sustainable biomethane and power-to-methane production, it should be used smartly. In 2015, biogas was used mainly in the production of electricity (62%) and heat (27%) which is easier and less costly than use in transportation. Only 11% of the generated biogas was upgraded to biomethane which was injected to the gas grid and used in households for heating and cooking or in transport. Different metrics can be considered for deciding how to use the available renewable methane. Results vary depending on the timeframe and whether the assessment is based on GHG savings, cost-efficiency or other metrics.

It is important to emphasise that allocating biomethane use is mostly superficial. Currently, biogas is mostly used onsite or injected into the grid. In reality cars or trucks driving on biomethane are mostly filling up in stations that are connected to the grid and the share of biomethane will thus be equal to the grid mix (currently 0.5% renewable). To achieve higher blends vehicles would either require to fill up at off-grid filling stations or receive biomethane directly from producers' renewable micro grids - both options are unrealistic at scale. A more realistic approach is to buy biomethane certificates as part of wider clean gas credit scheme, which would mean in practice that the methane used is the grid mix. An important question therefore is whether changing vehicle engines from to CNG or LNG and building up a new refueling network

makes much sense if these vehicles are unlikely to actually consume above grid-average (currently 0.5%) biomethane blends.

In addition, it is also clear that other sectors are likely to require renewable gas to decarbonise. Directing gas away from electricity, industry and heating would make the effort in these sectors much more difficult. Looking at 2030, the **electricity** grid is expected to be around 50% renewable (or more) and the carbon intensity of the grid will have decreased considerably. This also means there will be a higher amount of intermittent renewable electricity in the grid. Going to 2050, the electricity grid will need to be completely renewable and decarbonised. As a result, power supply would be almost entirely based on intermittent renewable sources (wind/solar) supported by different storage options and possibly renewable gas. From a social cost perspective, electricity use of renewable methane is justified as the infrastructure already exists, especially as an alternative to seasonal storage (as renewable methane) and grid balancing.¹⁹²

Heating has limited alternative options. The renovation rate of buildings is low, and new buildings with better energy performance account for a small share of the building stock. District heating networks are rare in Western Europe, where fossil gas is a major fuel used in heating houses. In 2013, five EU countries covered 80% of the blocks residential fossil gas use: UK 24%, Germany 20%, Italy 16%, France 12%, and Netherlands 7%.¹⁹³ There is existing gas distribution infrastructure in many regions, which could be put into use. For instance, the gas distribution grid could be used to distribute renewable methane to households, to complement energy efficiency measures, electricity and geothermal heating¹⁹⁴. The residential gas consumption is expected to decrease in the longer term due to efficiency measures, but the remainder of the heat used will need to come from renewable sources. Renewable methane could be a cost-efficient solution, as the infrastructure and end use appliances already exist in many countries.

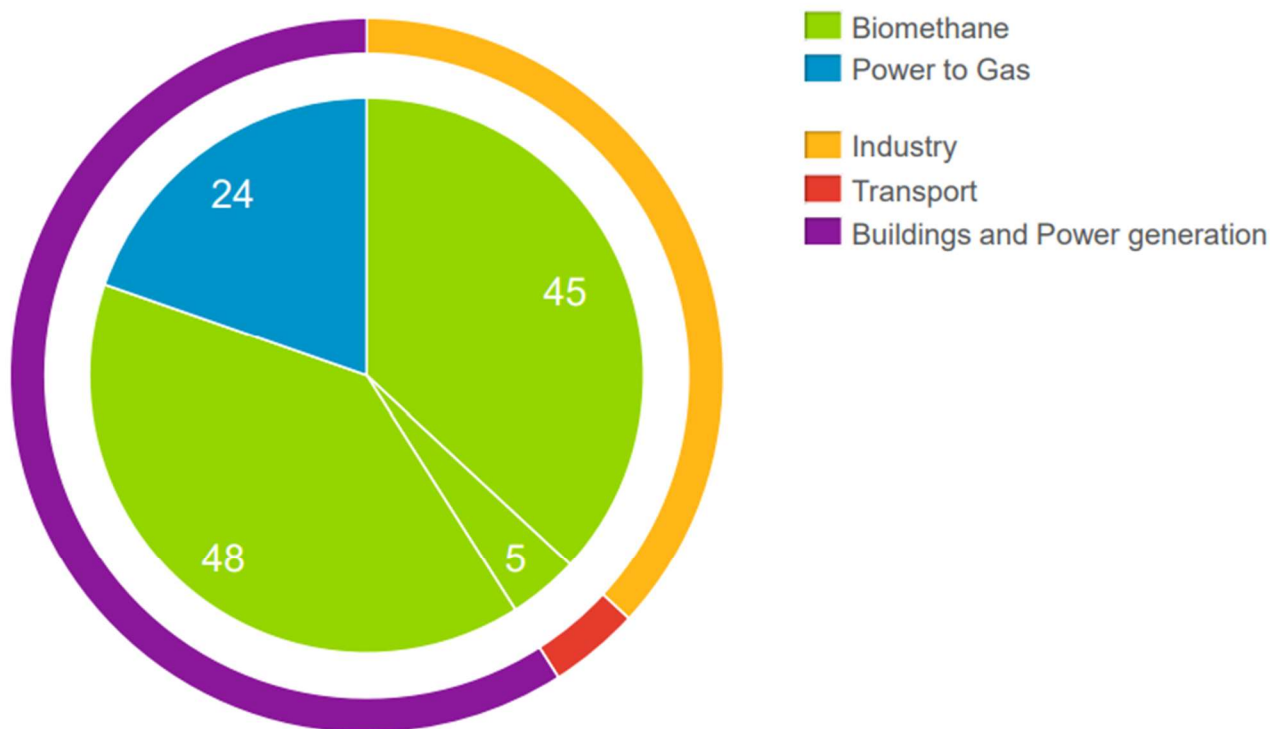
Industry is consuming fossil gas as a heat source (including high degree heat) but also as a platform chemical for other raw products. The industry is already using fossil gas and the infrastructure for use and distribution is in place. Renewable methane can substitute fossil gas and limited (often electrification or renewable hydrogen) or no other options exist to decarbonise, depending on the type of industry.

Transport can also consume renewable methane, but the infrastructure or vehicles do not currently exist to any significant extent and requires investments. Only a very small amount of renewable methane is allocated to transport in Ecofys 2018 (using social cost as metric), 5 bcm or 4% of all renewable gas, which would account for around 5% of projected energy use in heavy duty transport in 2050.¹⁹⁵ From a GHG reduction perspective in the 2030 timeframe, CE Delft¹⁹⁶ identified the highest savings in heavy duty transport, essentially giving the result that biomethane should be used where the highest emitting fuels are expected to be used in 2030. The analysis did not take into account which other alternatives might be available or the cost efficiency. The study assumed that in heavy duty transport diesel is replaced, fossil gas is replaced in the gas grid (mainly used in built environment), and in electricity the average electricity (with average carbon intensity) was replaced. With assumptions of higher heat utilisation in Combined Heat and Power (CHP) and replacement of fossil fuels in electricity production the results of the CE Delft study would change. If renewable methane is used indirectly in transport, meaning the methane is combusted for electricity and used in an electric vehicle, the overall energy efficiency is higher than used directly in the transport sector as methane (see section 6.6). This supports the use of renewable methane for electricity over transport.

Given that there are other alternatives for transport, and insufficient existing infrastructure to accommodate renewable methane use in transport, investing in the large scale use of renewable methane would be irresponsible and ill-advised, especially as other sectors, which also need to decarbonise, can more easily accommodate renewable methane. However, transport use of renewable methane may be a suitable option for local applications, if renewable methane is produced locally and there is no local heat demand or gas grid to accommodate the use of the gas. But in the long term, when the grid is reaching close

to 100% renewable electricity, these types of renewable methane production sites could be needed as a dispatchable renewable power source. This suggests biomethane powered vehicles are at best a niche and transitional solution.

The most recent assessment of where renewable gas should be best used was conducted by Ecofys for the Gas for the Climate consortium. As illustrated below, Ecofys finds that renewable gas should be directed in priority to buildings, power and heating, as they provide the best cost-effectiveness. Only 5% of the 2050 potential is allocated to transport. This assessment seems to confirm that biomethane will (and indeed should) remain a niche solution in the transport sector.¹⁹⁷ Comparative GHG savings will diminish when we are moving closer to a fully decarbonised world. Thus, cost efficiency appears like a more valid factor to evaluate where to use renewable gas in the long term.



Allocation of renewable gas over various sectors in billion cubic metres of gas

Figure 20. Allocation of renewable gas to different sectors in 2050 by Ecofys (bcm)

Considering that all sectors need to decarbonise, we should not allocate the renewable methane to only one specific sector, especially if it gets injected into the grid. The grid average is the most appropriate allocation tool for each use, and the same methodology is often used for the calculation of the share of renewable electricity used in transport. It gives a realistic and fair view of how much renewable energy enters the grid and it allocates it equally to all sectors. This renewable share will be grid-specific in an ideal case.

6.6. Energy and system efficiency

Energy efficiency needs to be taken into account when considering the use of methane for transport. Indeed, the cornerstone of climate policy is the decarbonisation of the power sector. This requires a shift from fossil to renewable technology (e.g. solar, wind). Whilst the costs of zero emission electricity generation has decreased enormously over the last years, it remains a significant challenge. Scaling up the use of fuels that rely on renewable electricity - which is the case for power-to-X - also increases the need for renewables. Depending on the volumes required, this could make the power sector decarbonisation more

difficult, although power-to-X fuels can also help balance the system by storing renewables during overcapacity.

The concern around efficiency applies especially to power-to-methane with an efficiency from electricity to final fuel of around 40% (it could reach around 60% by 2050 depending on the technology and learning curves).¹⁹⁸ Looking at the image below, the efficiency of battery electric vehicles is around five times higher than producing power-to-methane and using it in an ICE engine.

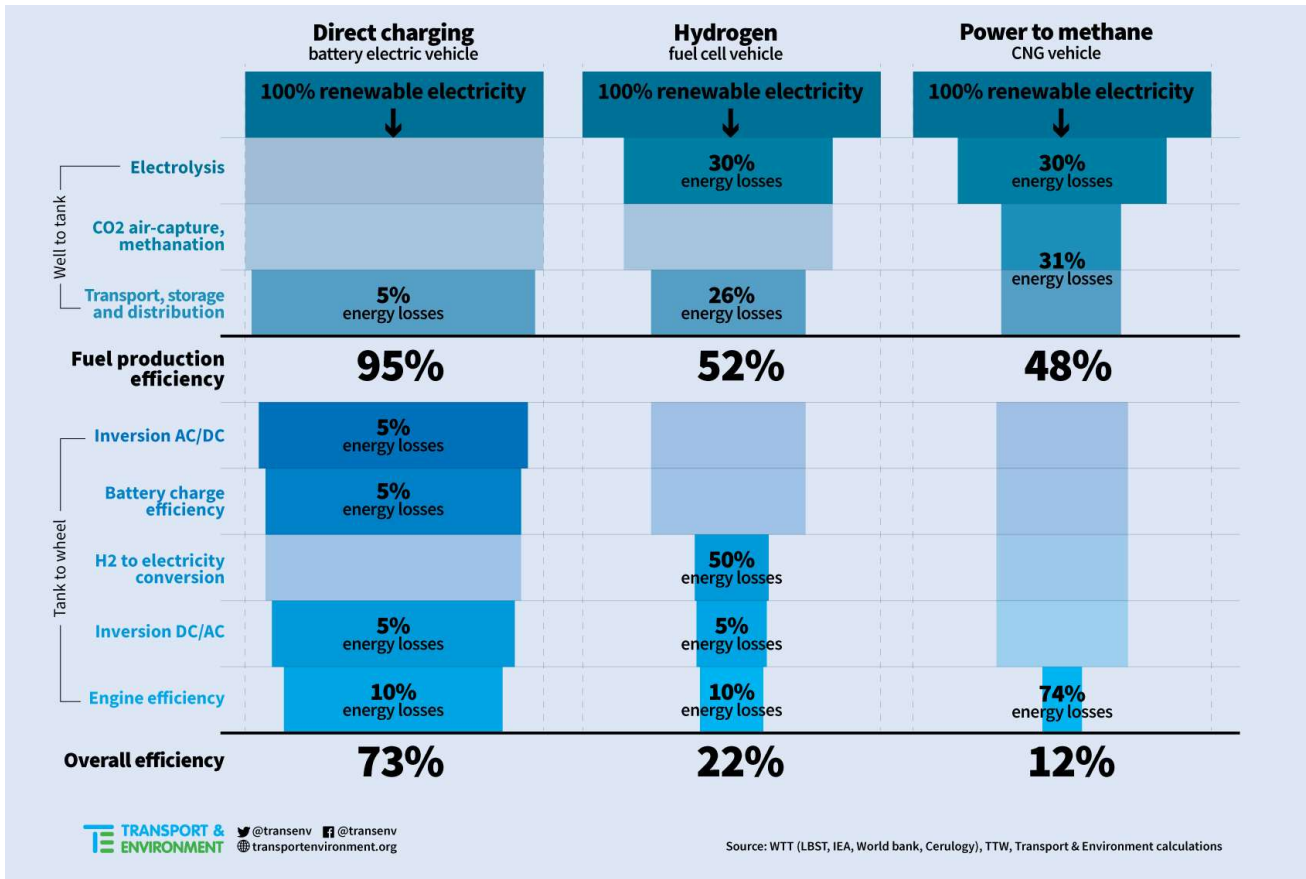


Figure 21. WTW efficiency of different powertrains fueled by electricity based fuels.

To power 50% of the current truck fleet with power-to-methane would require 35%^{xxx} of the EU’s current electricity generation to be exclusively dedicated to producing PtG. All of that electricity would need to be zero emission as well as additional to current zero emission generating capacity. This would be extremely challenging to achieve and should be seen in a context of industry, heating and power generation also requiring a degree of PtG, shipping hydrogen and aviation synthetic liquid fuels. Combined, this adds up to an unrealistic increase in zero emission electricity generation. Thus, where possible electricity should be used as efficiently as possible and PtX should be reserved for modes with no alternatives (e.g. aviation).

Leaving the very low PtX efficiency aside for a moment, it should be considered whether power-to-methane has any meaningful benefits compared to Power-to-liquid drop in fuels. The production pathways and efficiencies for renewable gas and renewable liquid fuels (PtL) are similar, with diesel having an engine efficiency benefit. But the infrastructure and engine technology for liquid transport fuels already exists, whereas a transition to PtG would require the roll out of a new infrastructure and a transformation of the vehicle fleet.

^{xxx} Assuming 40% conversion efficiency and using 2015 data from PRIMES reference scenarios for heavy duty energy demand (78507 ktoe) and gross electricity generation (3 251 309 GWh).

In fact, it would be more efficient to use methane (fossil or renewable) to produce electricity with a high efficiency combined cycle gas turbine (ca. 50%) and use the generated electricity in electric vehicles, rather than using the gas directly in a CNG or LNG vehicle.¹⁹⁹ The efficiency of the gas turbine-EV path could be further increased if the heat produced as a by-product of the electricity generation process is utilised, for instance, in district heating networks. Even in the case of smaller gas engines used at farm level with an electrical efficiency of around 40% the total energy efficiency of the methane-to-electricity-to-EV is higher (27%) than for direct use of methane in a methane fueled vehicle (14-22%). The figure applies mainly for modes where electrification is a possibility. This does not cover the timing of the charging but gas turbines have quick response times so it is relatively comparable, as the energy is stored in gaseous format and can be used when needed.

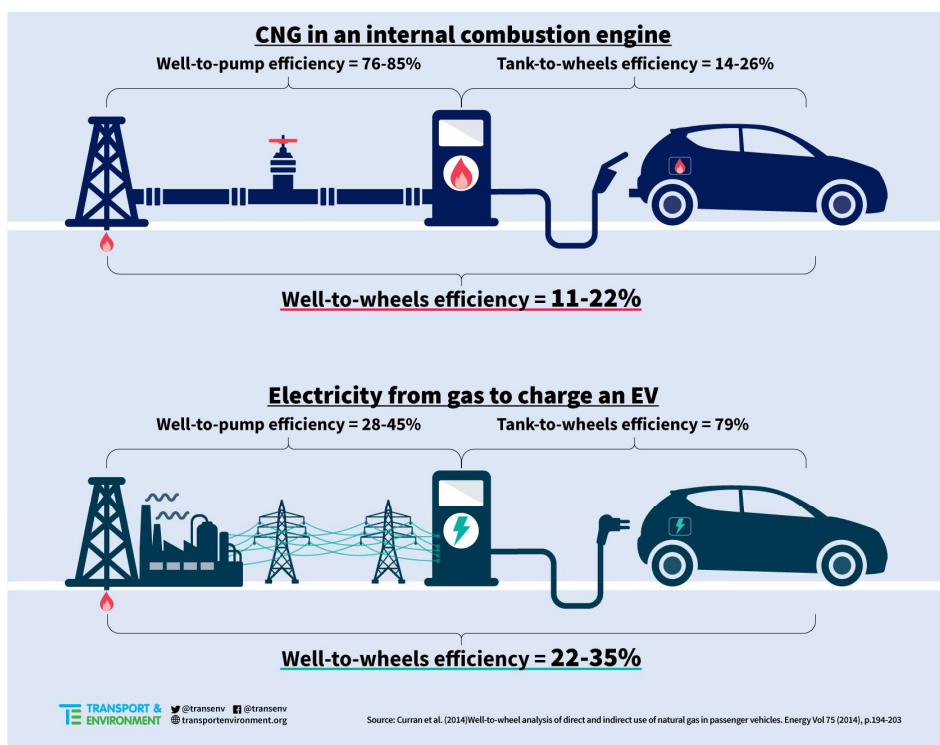


Figure 22. WTW efficiency of CNG vehicle compared battery electric vehicle and electricity produced from gas (Curran et al. 2014).²⁰⁰

6.7. How to use renewable methane in transport

As discussed in the previous chapters, fossil gas cannot play a meaningful role in the decarbonisation of the transport sector. The performance of gas powered vehicles and vessels is at best marginally better but in most cases similar or worse than conventional technology. At first sight the situation for renewable methane is different with waste based or renewable electricity-based methane capable of delivering significant savings compared to fossil. The higher the blends of (sustainable) renewable gas, the higher the savings. Given the necessity to decarbonise, transport blends should reach 100%. However, as discussed in previous chapters, renewable methane will not be available in sufficient volumes and should be prioritised for sectors where methane is currently used. It is therefore not realistic to assume that the transition to fossil gas powered vehicles and vessels will result in transport being powered by renewable methane.

A case in point is the fact that the current (and most likely) business model for LNG refueling is using imported LNG and redistributing it with ships and trucks to refueling stations.²⁰¹ This means also that around 75% of small-scale LNG terminals are in countries with large LNG import terminals²⁰². This business model is not compatible with locally produced renewable methane being liquefied and used by, for instance, trucks or ships. The way LNG infrastructure is currently being developed gives a clear idea of the risk of fossil gas lock-in associated with LNG for our transport use.

A niche market may exist for biomethane powered vehicles. Such vehicles should run on 100% waste-based biomethane. This means refueling stations close to production units mainly next to cities, large farms and food industry, or alternatively fully renewable local gas grids. As examples the local applications can be public transport, municipal heavy duty traffic, or trucks travelling between two logistics centres which both have renewable methane supply. This cannot be expected to be scalable and indeed might be challenging from a commercial point of view.

For example, Lille's (France) gas-powered buses initially filled up directly at the municipal biomethane production site but for administrative and commercial reasons that biomethane is now injected into the gas grid. In reality, Lille's bus fleet only runs partially on biomethane.²⁰³ To reach 100% renewable methane (in theory, not in practice), guarantees of origin could be used to allocate methane use as renewable, based on a mass balance system. A similar approach is currently used in some countries. This means that renewable methane is produced at any given time, injected to the grid and the producer gets a proof of this injection. The end user who wants to buy this renewable share of the grid gas can do so and gets the proof of renewability, while in fact using whatever the gas grid delivers. The use of the gas grid could also lead to a situation with both fossil gas and renewable methane being provided in the same refueling stations^{xxxi}. Fossil gas is likely to be the cheapest, thus the final consumer is likely to choose the fossil fuel. In addition, experience with guarantees of origin for electricity suggests the system may not be sufficiently robust to guarantee that only renewable methane is used in transport from a system point of view.²⁰⁴

In the renewable energy directive for the accounting of renewable electricity used in transport guarantees of origin are not allowed, and to determine the renewability of the electricity used in transport, the grid average as two years before is used. A similar approach for grid injected methane should be applied if it passes through a gas grid, essentially using the grid average renewable methane share.

The fundamental question is whether it makes sense to develop a CNG/LNG fueling infrastructure and promote the transition to gas engines if in reality vehicles and vessels are unlikely to ever run on biomethane blends that are higher than the grid average (currently 0.5%). Certificate schemes are a relatively complex and expensive way to stimulate renewable gas injection into the grid. An alternative and simpler policy - without the associated infrastructure and vehicle costs - would be to require higher rates of renewable methane injection into the grid. This would be similar to the EU's current policy for transport fuels (biofuels) and would thus require robust sustainability safeguards to ensure only sustainable feedstocks are used.

In conclusion, the EU's current policy requires the roll out (and finance) of an EU-wide LNG network for trucks, requires countries to put in place CNG stations and mandate LNG bunkering facilities in ports. Many governments support gas vehicles through tax credits, subsidies and fuel tax exemptions. This may well result in a significant increase in gas powered vehicles and vessels. The result of this would be a transport system that is (mainly) powered by fossil gas instead of petroleum. Renewable gas will not play a meaningful role. If the EU or governments would want to promote biomethane in transport, they should focus on local projects, with vehicles running on 100% biomethane, refueling at local biomethane production sites. Current EU policy is heavily focused on LNG (a long distance fuel) and achieves the opposite of this recommendation.

^{xxxi} This happens in Finland with GASUM operated CNG stations, where biomethane and fossil methane are available side by side. On 22.7.18 the price for fossil CNG was 0.822€/l and 0.929€/l for bio CNG. <https://www.gasum.com/yksityisille/tankkaa-kaasua/tankkausamat/>

7. What drives the (limited) uptake of methane vehicles?

In some markets there is a shift to use methane in transport. The section below explains the drivers behind this shift.

7.1. Tax breaks for fossil gas

When considering the attractiveness of different fuels for the consumer, the price is the key determining factor in particular in commercial operations. The price of fossil gas depends on a number of factors but the key ones are the price paid to the gas producer, the use of the distribution network, and taxes. This explains for example why fossil gas in the US - where there has been a shale gas boom - is very cheap. EU countries pay different rates for fossil gas - this depends on the contract they have with the producer or the exporting country - but in Europe the main differentiator is taxation. This leads to a situation where household gas prices are four times higher in Sweden than in Romania.²⁰⁵

The prices of CNG vary widely across the EU. For instance, in Italy the price is around 0.96 €/kg, and in Sweden 1.87 €/kg²⁰⁶. Given the low CNG price in Italy, equivalent to 0.62 €/diesel equivalent litre^{xxxii} - less than half of the diesel price - there is a clear fuel price advantage for the consumer. However, if the tax rate per energy content (€/GJ fuel) were set on a par with diesel, the price of CNG would double to 1.23€/diesel equivalent litre or 1.91 €/kg CNG.^{xxxiii} Since the purchase price of methane cars is similar to diesel cars the current taxation regime in Italy gives a major advantage to fossil gas over petrol and diesel. In the heavy duty sector, average diesel trucks cost about 40 000€²⁰⁷ less than LNG trucks so the fuel needs to be cheaper or other incentives need to be provided in order for methane use to make economic sense. The benefit due to taxation varies in different EU countries as can be seen from the table in Annex 1.

Figure 23 illustrates the importance of the excise duty rates. Excluding excise duties, LNG trucks are 0.02€/km more expensive to operate due to higher purchase price and maintenance. The excise duty rates of the fuel play a decisive role in shifting the scales to the benefit of one fuel, and there are large variation between EU countries as can be seen in Annex 1. Without fuel related costs, LNG trucks are more expensive to operate. This illustration does not consider the cost of the refueling infrastructure, which needs to be developed if LNG is to become a large scale fuel.

^{xxxii} A normal Diesel price of 1.4€/l gives a per energy cost of 39€/GJ, while the normal CNG price of 0.96€/kg gives a cost of 17€/GJ. Taxation for diesel is 17.15€/GJ and for CNG 0.09€/GJ.

^{xxxiii} Calculations: CNG kg was converted to diesel equivalent. Excise duty free fuel prices were calculated subtracting the excise duty rates from CE Delft 2016. The diesel excise duty rate was added to CNG price without excise duties.

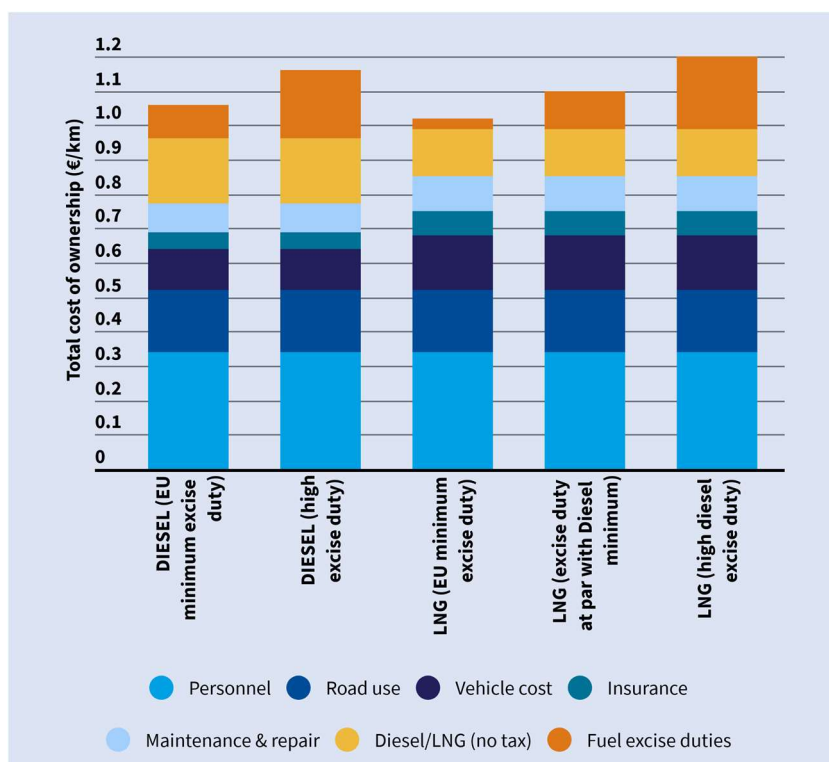


Figure 23. Comparison of LNG (HPDI) trucks and best in class diesel truck operational cost^{xxxiv}

The EU sets minimum taxation levels for transport fuels (see image below). Member states are not allowed to go below the rates for diesel and petrol, but they can do so for fossil gas. This has led to a situation where fossil gas has a significantly lower taxation rate in the EU compared to liquid fossil transport fuels. In a study by CE Delft, the taxation of fossil gas in EU countries was on average 9.51 €/GJ lower than diesel and 16.21 €/GJ lower than petrol²⁰⁸. If we weigh the taxation to consumption by EU countries, the taxation difference is larger, as fossil gas consumption is higher in countries with lower tax rates for fossil gas. Denmark is the only EU country with comparable fossil gas and diesel taxation. In all other member states, the tax rate is much lower for fossil gas use in transport. For example, Italy, the largest fossil gas consumer in transport, has a tax rate of 17.25 €/GJ for diesel and 0.09€/GJ for fossil gas.

^{xxxiv} Main assumptions: 5 years use with 150 000km/year. Comparison of LNG truck to best in class diesel: purchase price is 30 000€ higher, maintenance 15% higher. Diesel fuel consumption from Rodríguez et al (2018) 29.9 l/km, HPDI (from NGVA) LNG 11.7 MJ/km). Diesel price is from Eurostat oil bulletin 4/6/2018 (0.64€/l tax free) and LNG pump price is 0.95€/kg (low end from CNGEurope). Tax free LNG price was calculated subtracting 20% VAT and EU minimum excise duty). Excise duties added as in Annex 1. Insurance is proportional to vehicle purchase price. Road use, depreciation of value and personnel costs are equal. No cost of capital is included.

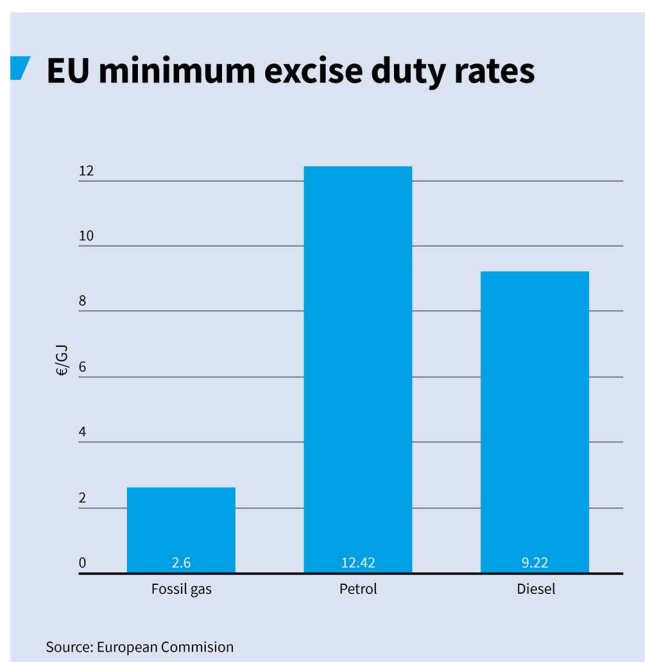


Figure 24. Image on EU minimum tax rates.²⁰⁹

Considering the lower rates for methane compared to diesel, the income loss, or tax subsidy EU wide was estimated at €860 million in 2014, with Italy's share being 72%.²¹⁰ This estimation of loss assumes no rebates on diesel taxation for heavy duty vehicles so in reality the income loss would be smaller but we could not quantify the impact of this. The high share is due to Italy accounting for around 60% of EU's consumption of fossil gas in transport. If fossil gas uptake would reach 5% of road transport energy consumption, the tax subsidy for fossil gas would increase to €5.4 billion.^{xxxv}

Given that fossil gas is a fossil fuel, it should be taxed accordingly, at similar excise duty rates to diesel or petrol. Given that fossil gas saves at maximum 3% on WTW level compared to best in class diesel trucks, the tax rate should be maximum 3% lower than for diesel. A carbon content based taxation would be preferred. As discussed in section 5, the air pollutant emissions are not necessarily better for fossil gas compared to modern diesels (especially in heavy duty), hence it should not be used to justify the significantly lower tax rates. A higher excise duty rate combined with tax exemptions for sustainable renewable methane (biomethane from wastes, or power-to-methane) would also aid the uptake of renewable methane in transport. As with diesel and petrol, member states should not be allowed to set lower rates than the EU minimum level, hence the current practice of allowing exemptions from the minimum EU rate should be discontinued.

7.2. Subsidies and tax breaks for gas vehicles

Growth in sales of methane powered passenger cars has been slow. From 2016 to 2017 there was a 15% decrease in sales and only 49 243 CNG cars were sold.²¹¹ Market analysts expect sales to increase from current 0.5% of new sales to 1% in 2025.²¹² This growth in some markets of the CNG segment is large, with Spain and Germany having a fivefold increase from 2017 to 2018.²¹³ The rate of increased sales at EU level is lower than for EVs and thus the amount of EVs on EU roads is probably going to be larger than CNG cars in 2018, or 2019.

National financial schemes and industry bonuses to reduce the purchase price of methane vehicles contributed to the increased uptake of methane vehicles across the EU. Such support is visible in Italy, Germany, Spain and France, described in more detail below.

^{xxxv} Assuming 5% of EU reference scenario road transport consumption is fossil gas and excise duties remain constant.

Italy introduced preferential measures for boosting methane use in transport. In 2009, a new scheme offered purchase 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 scrapped²¹⁴. After only a year of the programme, CNG vehicles had reached 5.42% of the market share²¹⁵. Since then, subsidies have been reduced and the CNG market share has decreased from 5.32% in 2014 to 2.37% in 2018²¹⁶. But Italy is still the largest methane vehicle market in the EU and accounted for 68% of all new methane vehicle registrations at EU level in 2016²¹⁷. In addition, the government recently adopted new incentives for the purchase of methane trucks with a direct subsidy of 4 000€ for CNG trucks and 20 000€ for LNG²¹⁸.

Germany: methane vehicles benefit from reduced energy taxes on LNG and CNG for motor vehicles, a measure running until 2026 and profit from a slightly reduced vehicle tax due to their lower air pollutant emissions compared to e.g. diesel cars. Despite this, the overall share of CNG vehicles on the market remains very low and never exceeded 0.4% of the market share²¹⁹. But Germany still ranks second in the EU for new methane vehicle registrations as of 2016 (7.5%). In June 2018, the transport ministry announced direct support for companies purchasing CNG and LNG trucks, with a subsidy of 8 000€ for CNG trucks and 12 000€ for LNG (with a ceiling of 500 000€ per company).

Spain: a variety of subsidies and tax breaks are available when purchasing a methane powered vehicle. For example, as part of the €20 million MOVALT-Vehicles plan agreed in 2017, a financial support between 2 500€ and 18 000€ was available for the purchase of a methane vehicle. In addition to this and the 2017 MOVALT-Infrastructure plan, the Government launched in 2017 the €14.26 million MOVEA Plan, to boost the purchase of alternative fuel vehicles, including electric vehicles but also LPG/Autogas and CNG vehicles, as well as the implantation of recharging points in areas of public access. The latest support scheme – the VEA plan – was agreed in July 2018 with a dedicated budget of €66.6 million. Out of these, €50 million are aimed at the purchase, by individuals, of electric vehicles but also LPG, CNG and LNG-powered vehicles. In addition to the above, as of today, methane vehicles with emissions lower than 120 g/km are also exempted in Spain from payment of registration tax. Some regions have put in place further support schemes, such as a bonus of up to 75% on the tax on mechanical traction vehicles in Barcelona and Madrid, discounts on highway tolls in Catalonia or financial help for purchase of new taxis in Madrid. Finally, methane vehicles will be allowed to enter the “Madrid Central” zone, a large area of 480 hectares where traffic will be restricted and pedestrians, bicycles and public transport will be favored.

France: CNG cars do not benefit from the “ecological bonus”²²⁰ but they do benefit from other support. When shifting from a diesel vehicle which was put on the road before 1st January 2006, a person purchasing a methane powered vehicle (with emissions lower than 110 g/km) will benefit from a bonus of 500€ to 1000€²²¹. In 2017, a company investing into CNG or LNG trucks benefited from specific tax breaks, for amortizing its investments. Depending on the French region, there is also a tax exemption on the registration document of up to 100% is applicable for CNG and LNG vehicles.

More recently, the car industry has also played a crucial role in incentivizing the purchase of CNG vehicles. Volkswagen rewarded buyers with a bonus of up to €2,000 when they switched to a CNG vehicle before the end of March 2018²²². This was additional to the “scrapping premium” obtained from exchanging a Euro 1-4 diesel for another car. In the US, oil companies are also entering the game, with Total participating in a scheme to support the switch from diesel to LNG trucks²²³.

As mentioned previously, the market could evolve differently for heavy duty vehicles. According to NGVA, the lobby group representing methane vehicle interests, methane-powered truck sales increased by 15% in 2017. The haulage market is more price sensitive to prices than the passenger car market. Given that many countries have (partially) exempted CNG and LNG from fuel taxation and provide purchase subsidies, a shift

to CNG/LNG for trucking could be economical for hauliers when in particular when oil prices are high. However, as discussed in chapter 7.1, this price difference is artificial and not justifiable.

7.3. Infrastructure development and costs

Major pipelines such as (Nordstream II, TAP, etc.) are being built to transport more fossil gas into the EU. As an example the European Investment Bank has granted a loan of €1.5 billion²²⁴ to the Trans Adriatic Pipeline, extending the Southern Gas Corridor connecting Azerbaijan to Italy. Fossil gas projects have received over €1.3 billion²²⁵ EU money under the Connecting Europe facility (CEF). This is happening while the existing gas infrastructure is estimated to be sufficient for current and future EU gas demand²²⁶. LNG terminals for example are being built to diversify supply, but in reality 44% of LNG is coming from Qatar²²⁷, and the average utilization rate was around 25% in 2016²²⁸. From an EU perspective, these investments are made for energy security and diversification of supply. In some cases this has paid off. In that sense LNG-terminals - which can also be floating, non-permanent terminals - can improve the energy security and bargaining position of EU countries. However, if used as an insurance policy, LNG terminals will continue to be underutilised as in many parts of Europe LNG is not cost-competitive with (fully amortised) pipeline gas because of the transportation and liquefaction costs. In that sense expanding fossil gas demand to improve LNG terminal utilisation is pointless as this will mainly benefit the pipeline exporters.

In the medium to long term fossil gas has no place in the EU's (decarbonised) energy system. This calls into question the wisdom of the development of new gas pipelines being planned and built. It is extremely unlikely that pipeline countries like Russia - which sit on enormous fossil gas reserves - intend or can switch to renewable methane (or renewable hydrogen) any time soon. The World Bank has also recently announced it will cease financing upstream oil and gas projects after 2019, as they are not in line with climate pledges and risk being stranded assets.²²⁹

Currently there is limited distribution and refueling infrastructure for methane use in transport (see section 2.3. and Table 1), but it is sufficient for the current methane powered fleet^{xxxvi}. If methane use is to be further increased in transport, the infrastructure needs to be developed and would require significant investments, starting from practically nothing in most countries. As an indication, a refueling station for CNG costs €200 000 while a LNG refueling station for trucks costs €1 million.²³⁰

There are currently 107 LNG stations operational in Europe serving around 1 600 LNG trucks.^{xxxvii} Assuming there would be 400 000 LNG trucks running in Europe by 2030 (the gas lobby's ambition) the number of LNG stations would need to expand very significantly with considerable associated costs. This cost should not be borne by taxpayers but by gas companies or gas grid operators.

7.4. Lobby push by gas industry

Fossil gas faces a declining market in the medium to long term as electricity production is shifted to more renewables and energy efficiency measures reduce residential gas demand. In the short term fossil gas may benefit in some countries from coal and nuclear phase-out but the industry gas industry is looking for new markets both to sustain production and support its existing assets. As there is limited options for growth in existing markets, with the potential exception of short term growth in power production. In all the cases envisaged by Eurogas, residential gas consumption goes down. Fossil gas use in transport accounts currently for less than 1% of EU fossil gas demand²³¹ and is seen as one possibility to increase demand for fossil gas²³². Methane consumption in most sectors is decreasing, in the long term, therefore transport is a potential growing market for fossil gas suppliers. Eurogas²³³, foresees a fifteen fold growth in demand for methane in the transport sector by 2030, increasing from current 2 Mtoe to 29 Mtoe²³⁴. For the 2050

^{xxxvi} According to the EAFO (European Alternative Fuels Observatory) <http://eafo.eu/>

^{xxxvii} See Table 1. Refueling infrastructure for methane powered transport in EU page 13

timeframe, Ecofys identified a renewable methane potential of 98 bcm, of which they allocated only 5 bcm to transport, when taking cost effectiveness into account.

There is a powerful and well-funded lobby behind the recent efforts to promote methane use in the transport sector. The gas industry in Brussels has around 1000 lobbyists and is spending over €100 million on lobbying every year²³⁵. The Natural Gas Vehicle Association (NGVA) is the main lobby group pushing for methane use in transport. It has a broad membership of national associations, gas & energy companies, and vehicle manufacturers. Around half of the board members^{xxxviii} are traditional energy companies (ENI, TOTAL etc.), around a third are vehicle manufacturers (IVECO, VW etc.) and the remaining members are gas infrastructure companies and renewable gas companies and associations. NGVA receives funding and instructions from powerful members such as Gazprom which supplies close to 40%²³⁶ of Europe's gas needs.²³⁷

7.5. Vehicle manufacturers focus on CNG/LNG?

Different vehicle manufacturers have different strategies to reduce the emissions of their new vehicle fleet. FIAT and IVECO are examples of companies with a focus on CNG/LNG. Volkswagen is a much larger company which invests heavily in battery electric (40 bn in investments announced) but is putting efforts also in promoting CNG. SEAT is strongly pushing for CNG, they plan 5%²³⁸ of this year's sales to be CNG-petrol dual fuel cars (or "hybrids") and increasing to 10% of the sales in 2020. The president of SEAT considers CNG as a "long-term alternative"²³⁹. Looking at 2017 new car sales data from the EEA²⁴⁰, FIAT sold 32% of new CNG vehicles in the EU, the VW group 64% and the rest were sold by Opel (2.5%) and Mercedes (0.5%). Thus the methane vehicle market in the EU is close to a duopoly. However, if FIAT's CNG strategy is designed to help it meet the EU's CO₂ targets, the plan is not working. FIAT is currently on a trajectory to miss its 2021 CO₂ reduction targets (which means it will have to pay fines) while most European car makers are on track.²⁴¹ Fiat has since then adopted a stronger push for electrification, and aims at having less than half of vehicles fully combustion-powered by 2025 "as gas and diesel give way to hybrid, electric and fuel-cell drivetrains"²⁴². Within the VW group, Audi is also promoting the use of power-to-methane in transport. It has started a test plant which can provide energy for 1500 vehicles annually and sees it as a potential way of decarbonising the transport sector.²⁴³ The power-to-methane process is very inefficient as highlighted in section 6.3, and would require vast amounts of new renewable electricity to be installed.

On the heavy duty side, Scania, Volvo, Iveco and Mercedes have LNG vehicles in their model ranges, with an aim to provide a decarbonisation option.²⁴⁴ All four brands are separately owned, showing that the heavy duty sector is looking into LNG. In their view, LNG is a path towards zero emissions, as Volvo states²⁴⁵ on the website introducing its new LNG truck. However, the industry is not looking into decarbonising the fuel itself, but just highlights the possibility of using renewable LNG, a fuel which currently costs around 10 times more than fossil LNG.²⁴⁶

^{xxxviii} List organisations in the Board of NGVA: Audi (GER), Bohlen Doyen (GER), Daimler (GER), DVGW (GER), Enagas (SPA), Energigas Sverige (SWE), Engie (FRA), Eni (ITA), E-on (GER), Erdgas (GER), FCA (ITA/US), FordonsGas/Air Liquide (SWE/FRA), Gas Natural fenosa (SPA), Gas Networks Ireland (IRE), Gasmobil (SUI), Gasrec (UK), Gazprom (RUS), GRDF(FRA) - subsidiary of Engie, GRTgaz (FRA) - subsidiary of Engie, Hexagon Xperion (NOR), IVECO (ITA), The Linde Group (GER), RAG Energy Storage (AUS), Renault (FRA), Scania (SWE), Shell LNG (NED), Swagelok (US), Total (FRA), Uniper (FIN), Volkswagen (GER), Volvo (SWE), Westport (CAN)

8. Conclusions

Climate impacts

The report shows gas vehicles and vessels have similar performance to other fossil fueled vehicles and vessels. Based on the evidence identified in this report, fossil gas used in transport has no meaningful - and when including methane leakage and upstream effects in almost all cases no - climate benefits compared to petroleum based fossil fuels.

The overall (well to wheels) GHG performance identified in this study (with medium upstream emissions) range from -12% to +9%, depending on the mode of transport. In cars, the GHG savings range from -7% to +6% compared to diesel. In heavy duty, the range is -2% to +5% compared to best in class diesel trucks and depending on the fuel and engine technology. In shipping, the figures are -12% to +9% compared to marine gas oil (MGO) and highly dependent on methane slip.

Limited testing of the vehicles in real world conditions or on the official tests is an important issue. We did not find any evidence supporting the theoretical savings of gas vehicles - based on the lower carbon content of the fuel. In reality poor gas engine efficiency often offsets the benefit of the fuel already at tailpipe level. This points to the need for policies based on measured performance, not the type of fuel. Uncertainties also exist regarding methane leakage at the vehicle level and the impact of boil-off and venting is not well documented but could have a significant impact.

Recent evidence suggests that upstream methane emissions have been significantly underestimated, making it likely that CNG/LNG upstream emissions and subsequently well-to-wheel or wake GHG emissions are higher than the abovementioned numbers (which are based on 'central' upstream emissions data), and likely to increase in the future as fossil gas is sourcing evolves. Given that methane is a very potent short term greenhouse gas, any benefits from gas vehicles would only materialise several decades into the future, well after the EU economy would need to be fully decarbonised.

Air quality impacts

There are only limited air quality benefits from using fossil gas in transport. Gas vehicles perform similarly to petrol cars and only marginally better than diesel cars complying with the new RDE limits and not better than the best performing new diesel trucks. The Commission is also working on a Euro 7 limit which will further decrease or entirely eliminate any benefit gas has over diesel. Far greater air quality improvements could be achieved by switching to zero emission cars.

For trucks, CNG and LNG offer no meaningful benefits (NO_x, PM) compared to vehicles complying with the Euro VI standard. HPDI technology has slightly higher NO_x emissions. Particle number emissions are also higher in methane powered transport, compared to diesel. For ships LNG has a clear benefit compared to heavy fuel oil but similar emissions performance can also be achieved by fitting ships with after treatment systems such as SCR and DPF and using low Sulphur marine gas oil.

Renewable methane

Biomethane and power-to-methane can have (significantly) lower GHG emissions than fossil gas. However, sustainable feedstocks for biomethane (wastes, residues) are very limited. Crop-based biogas (e.g. from maize) is associated with significant indirect land use change emissions and is capped for transport purposes under the renewable energy directive. Electricity based methane (power-to-methane) is inefficient and expensive to produce and would greatly increase demand for renewable electricity, making it harder to decarbonise the power sector.

In reality the contribution of renewable methane will necessarily be limited. What potential exists should be used to help decarbonise sectors that currently depend on methane (residential, industry, power). If the

EU or governments would want to promote biomethane in transport, they should focus on local projects, with vehicles running on 100% biomethane, refueling at local biomethane production sites. A wider shift to methane will almost certainly lead to a transport sector powered by fossil gas, not renewable methane.

The economics of gas in transport

The business case for gas in transport depends almost entirely on (fuel) tax breaks, subsidies and public support for infrastructure. Faced with declining demand for its product in other sectors and significant expansion of production over the last years, the gas industry has a strong interest in creating a new market for methane in transport. But without the generous support of governments, that market would not exist. EU domestic fossil gas production is declining (rapidly in the case of the Netherlands) and the EU is increasingly dependent on imports in particular from Russia and Qatar. Creating a new market for fossil gas in transport will increase the EU's energy dependence.

In conclusion, it is hard to see meaningful benefits accruing from a shift to methane that cannot be in most cases better achieved by other technologies. Zero emission (capable) technologies including hydrogen and electric cars, trucks and vessels are already on the market or are soon coming to the market. Improvement in technology and costs are making these technologies increasingly attractive and economical. Based on all of the above elements continued support for the expansion of methane as a transport fuel cannot be justified.

9. Policy recommendations

1. Fossil gas has no meaningful - and when including methane leakage and upstream effects in almost all cases no - climate benefits compared to oil based fossil fuels. As a fossil fuel it has no future in a decarbonised transport system. Hence, there is no reason policymakers should support the use of fossil gas in transport.
2. Gas vehicles and vessels should compete with other fossil fuel technologies such as diesel, petrol and marine fuels on a level playing field.
3. Governments should end fiscal support and in particular fuel tax exemptions for fossil gas in transport. As for other fossil fuels (petrol/diesel) fossil gas should be taxed based on its carbon and energy content.
4. Standards and fiscal measures (including CO₂ standards, toll differentiation, subsidies, tax breaks, and bonus-malus) for vehicles should be based on the measured tailpipe performance, not the fuel type. Methane vehicles can perform better or worse than diesel and petrol equivalents and governments should only support those vehicles that are proven to perform better (as tested on the official EU tests) as otherwise they risk incentivising cheap, poorly-performing technology and disincentivising innovation.
5. No public money should go into developing a pan-European LNG/CNG refueling network since fossil gas has no/limited climate benefits, whilst renewable methane cannot be produced at the required scale and needs to be developed and used locally.
6. The Paris Agreement requires the full decarbonisation of the economy. In that context, renewable methane - biomethane and zero emission power-to-methane - is a scarce and precious fuel which can be deployed in different sectors including the heating, power and industry sector that currently depend on methane. The best available analysis points to heating, industry and power, not transport, being the optimal destination for renewable methane. To expand demand for methane in the transport sector would entail unnecessary costs and could considerably increase the difficulty of decarbonising the industry, heating and power sectors.
7. There is no role for biomethane beyond niche, local operations and renewable methane should be used in captive fleets only, with dedicated (100%) biomethane vehicles, so that a sustainable supply of renewable methane can be guaranteed locally. The volume of renewable methane potentially available is far too small to support pan-European, large scale use.
8. Support for biomethane should be limited to methane produced from sustainable wastes or residues, complying with robust and appropriate sustainability criteria, including the principles of waste hierarchy. No crops grown on productive agricultural land should receive support for the production of biomethane.
9. As with electricity used by electric vehicles the grid average renewable share should be used to evaluate climate performance of methane powered transport. 100% renewable methane can only be counted in case the renewable methane refueling station is not grid connected. Systems based on certificates or guarantees of origins are unlikely to be sufficiently robust and effectively lead to grid injection and consumption of biomethane (currently 0.5%). If policymakers would want to promote the injection of sustainable biomethane into gas grids, there are simpler and more cost effective policy instruments to achieve this (e.g. a blending obligation).

ANNEX 1. Tax rates for transport fuels

2016 Tax rates for transport fuels in EU in €/GJ ^{247 xxxix}

	Diesel (cars)	Diesel (trucks) ^{xl}	Petrol	Fossil gas
European Union (minimum rate)	9.22		11.29	2.60
Austria	11.09		15.16	1.66
Belgium	12.98	10.85	19.47	0.00
Bulgaria	9.23		11.42	0.43
Cyprus	12.57		15.06	2.60
Czech Republic	11.26		14.86	0.70
Germany	13.14		20.58	3.86
Denmark	11.62		19.22	11.46
Estonia	12.51		14.62	0.00
Greece	9.22		21.07	0.00
Spain	9.25	8.49	13.36	1.15
Finland	14.14		21.42	4.84
France	13.91	12.55	20.16	1.05
Croatia	11.19		15.89	0.00
Hungary	9.85	8.85	12.06	2.63
Ireland	13.38	11.84	18.48	2.60
Italy	17.25	11.26	22.91	0.09
Lithuania	9.22		13.66	6.56
Luxembourg	9.36		14.53	0.00
Latvia	9.53		13.71	2.67
Malta	13.20		17.28	0.00
Netherlands	13.53		24.21	4.57
Poland	9.60		12.36	3.18
Portugal	13.03		20.49	3.25
Romania	12.00	10.81	14.49	2.79
Sweden	17.39		21.16	6.66
Slovenia	13.21	9.81	17.22	3.45
Slovakia	10.79		16.75	2.60
United Kingdom	18.83		21.20	6.59

^{xxxix} To adjust to diesel equivalent, a conversion factor of 0.91 can be used for petrol and CNG. This would take into account the lower engine efficiencies of petrol and gas.

^{xl} Assuming 2015 diesel rebates for commercial users from Transport & Environment (2015) Europe's tax deals for diesel

https://www.transportenvironment.org/sites/te/files/publications/2015_10_Europes_tax_deals_for_diesel_FINAL.pdf

Annex 2. Estimated 2030 WTT GHG emissions of CNG per EU country (Exergia 2015)²⁴⁸

Table 8-10 2030 estimated GHG emissions disaggregated by EU country (grCO₂eq/GJ LHV)

EU region	EU Country	Fuel dispensing	Gas distribution, transmission and storage	Feedstock transportati on (pipeline, LNG)	Fuel production and recovery	CO ₂ , H ₂ S removed from NG (gas processing)	CNG total emissions
EU North	DK - Denmark	2991	212	597	2965	20	6785
	IE - Ireland	4972	996	1037	11925	254	19184
	FI - Finland	2669	2989	19660	3808	3	29129
	SE - Sweden	1904	1230	667	4864	109	8774
	UK - United Kingdom	4573	1304	5262	5549	280	16968
EU Central	BE - Belgium	2697	1346	7472	7257	440	19212
	CZ - Czech Republic	3477	2085	17684	3509	35	26790
	DE - Germany	4221	2202	12072	3755	282	22532
	EE - Estonia	2322	3622	23993	4488	26	34451
	LV - Latvia	2356	2249	23794	3938	31	32368
	LT - Lithuania	2984	2820	23506	4066	57	33433
	LU - Luxembourg	2927	967	8885	2685	57	15521
	HU - Hungary	3499	4000	19961	4281	211	31952
	NL - Netherlands	2435	2351	2530	2899	74	10289
	AT - Austria	2472	2475	14831	3976	76	23830
	PL - Poland	5726	8784	4974	6086	34	25604
SK - Slovakia	2718	3102	24438	3818	3	34079	
EU SW	ES - Spain	3679	787	3768	17580	750	26564
	FR - France	2191	887	6024	10005	397	19504
	PT - Portugal	3902	7042	3159	14915	740	29758
EU SE	BG - Bulgaria	4752	8407	19022	3688	23	35892
	EL - Greece	6157	1210	14021	10165	263	31816
	HR - Croatia	3561	12901	23889	3998	3	44352
	IT - Italy	3983	6605	7617	10072	889	29166
	RO - Romania	4189	2403	6348	6028	42	19010
	SI - Slovenia	3489	802	18119	7162	195	29767

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