A review of well-to-tank GHG emission values and pathways for natural gas, biofuels and hydrogen.

Prepared by Gloria Esposito

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Table of Contents

1. Introduction

Well-to-Tank CO_2e emissions are an integral part of determining, and assessing, the Well-to-Wheel CO_2e emission performance of different vehicle powertrains and fuels. This entails a life cycle CO_2e emission assessment across a fuel supply chain. Currently the Ultra Low Emission Bus Scheme and Renewable Transport Fuel Obligation (RTFO) are the only Government policy areas that take into account the WTW CO_2e emissions of different road transport fuels. With the increasing uptake of Electric vehicles the importance of the WTT emissions increases significantly (since all the emissions of a pure electric or fuel cell vehicle are WTT)

The Government's CO_2e emission conversion factors are produced each year by BEIS primarily for company GHG reporting. These cover Well-to-Tank (Scope 2 and 3) and Tank-to-Wheel (Scope 1) CO_2e emissions[1]. This paper presents a critique of the BEIS 2019 Well-to-Tank CO_2e conversion factors for CNG, LNG, liquid and gaseous biofuels. Where alternative figures are available in the public domain these have been presented and discussed for comparative purposes. BEIS do not report a WTT CO_2e emission factor for hydrogen used in transport. A range of CO_2e figures for hydrogen production are presented in this paper. In addition, LowCVP has calculated an initial set of UK specific WTT CO_2e emission values for hydrogen use in transport.

Recommendations are made for revising the BEIS CO_2e conversion factors and identifying where further work is required. This is to achieve both higher calibre, and representative vehicle fuel production CO_2e figures for the UK. This is particularly important for informing policy direction with regards to different low carbon fuel, energy vector and technology pathways in the future.

1.1 Methodology

This desk-top study outlines WTT pathways for CNG, LNG, biofuels and hydrogen, factors influencing CO_2e emissions and published WTT CO_2e values. A list of the studies and reports used for undertaking this critique shown in Appendix 1.

Various Government data sets are used to generate the BEIS CO_2e conversion factors, some of which cover different time periods. For example for the 2019 BEIS figures the following statistics have been used - Biofuels - RTFO Quarterly Report Year 10, accounting for April 2017-April 2018, electricity and natural gas - DUKES 2018, accounting for the period 2017.

One of the challenges with this review has been the heterogeneity in reported upstream CO_2e emissions for certain fuels. This is due to a multitude of factors – differences in the Well-To-Tank 'boundary' and assumptions behind GHG calculations, carbon intensity of heat and electricity, choice of global warming potential for methane, different functional units. This is most evident for hydrogen production. Where possible these differences have been accounted for in the paper and calculations.

[1] In terms of Company GHG reporting only Scope 1 and 2 emissions are mandatory.

2. CNG and LNG WTT CO2e Emission Pathways and Values

Figures 1 and 2 present CNG and LNG Well-to-Tank pathways for the UK. Table 1 identifies the BEIS 2019 CO_2e emission factors for natural, CNG and LNG, in combination with figures from the past two years derived from studies and reports specifically related to the use of natural gas in vehicles. Listed below are the key parameters that influence GHG emissions for each element of the fuel production pathway.

Figure 1: CNG fuel production pathway for the UK

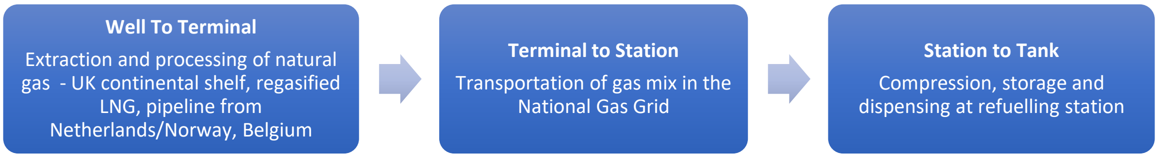


Figure 2: LNG fuel production pathway for the UK

Table 1: CNG and LNG WTT CO_2e emission factors (CO_2e/MJ)

	BEIS 2019 (2017 NG stats)	Element Energy 2018 (2016 NG stats)	ETI 2017 (2015 NG stats)	DfT 2018 (2016 NG stats)
CNG	11.8	6.3	5.2	12.1
LNG	19.5	13.1	12.3	14.6

NG stats - natural gas statistics period associated with DUKES.

2.1 Factors influencing GHG emissions

- Country of origin for natural gas extraction and processing, proportion of LNG imported, assumptions on flaring and venting, methane leakage in processing and pipeline transportation, inclusion of energy for vaporisation/re-gassing of LNG.
- Compression in the transmission grid, methane leakage at lower pressure tiers.
- LNG transport emissions by road tanker from the terminal to the LNG refuelling station.
- Energy use for gas compression and dispensing at CNG stations. Energy use from LNG station operations, such as pumping energy during tanker unloading and filling. Methane emissions from transport and station operation.
- Dominant factor across all the stages above is the carbon intensity of electricity, and how transport and distribution losses have been accounted for.

2.3 GHG emission values

For the first time BEIS Conversion Factors in 2019 include a new figure for natural gas with a very low blend of biogas (0.32%). This accounts for biomethane injected in the gas grid (Typically as a result of RHI support). BEIS highlight in their methodology report that the biomethane blend has been incorporated into the CNG figure. Interestingly they do not report separate CNG figures for 100% mineral and a blend of biomethane (unlike diesel and petrol).

A review of BEIS GHG conversion factors for natural gas over the last four years show theWTT GHG emission factor for CNG has ranged from 10-11 gCO_2e/MJ, and LNG from 19-21 gCO_2/MJ.

In the case of CNG and LNG, a comparison of the BEIS 2019 figures has been made with WTT figures presented in reports prepared by Element Energy (2018) Energy Technologies Institute (2017) and DfT's Transport Emissions Model (2018). As can be seen in Table 1 the BEIS 2019 figures are higher than values reported by Element Energy and Energy Technologies Institute This is predominantly due to several differences in the assumptions behind the calculation of fuel production GHG emissions. A summary explanation is given below.

Compressed Natural Gas

- *Well-to-Terminal Emissions*: Element Energy and Energy Technologies Institute propose their lower CO_2e figures for natural gas are due to a drop in the proportion of re-gasified LNG entering the gas grid in 2017. The percentage of re-gasified LNG has reduced over the past two years from 13% in 2016 to 8% in 2017. BEIS 2019 methodology suggests the reduction in imported LNG has been accounted for in their calculations.

- *Terminal to Station Emissions*: Element Energy and Energy Technologies Institute modelling is based on a larger proportion of natural gas being transmitted via the high pressure National Transmission System (NTS) as opposed to Local lower pressure (IP or LP) Gas Transport Network. This results in lower energy requirements for compression (fewer compression stages) and considerably lower methane losses, giving rise to lower station CO_2e emissions. Conventionally CNG refuelling stations have been to connected to the low and medium pressure tier that require more energy for compression to refuel vehicles. Connecting to the NTS reduces station CO_2e emissions by approximately 79% compared to the medium pressure tier. Element Energy is also using a more recent carbon intensity factor for grid electricity than BEIS, consequently lowering the carbon intensity of compression.

- *Station to Tank Emissions*: BEIS assumes a methane leakage rate of 0.34%. Element Energy's study applies a much lower leakage rate of 0.01%. Real world data has been derived from CNG Fuels' Leyland refuelling station.

Liquified Natural Gas

- *Well-to-Terminal Emissions*: For the last few years the dominant source of LNG imports in the UK has been Qatar. Element Energy and Energy Technologies Institute appear to associate imports for LNG from Qatar with lower methane leakage emissions, although their assumptions have not been explained.

- *Station to Tank Emissions*: BEIS modelling takes into account fugitive emissions arising from liquid nitrogen cooling at LNG refuelling station. Element Energy propose that once an LNG station passes its initial ramp up phase liquid nitrogen for LNG cooling is no longer needed; this subsequently lowers CO_2e emissions. This is supported by Energy Technologies Institute who also assume LNG stations undertake best practice in methane leakage control.

BEIS calculate upstream GHG emissions for CNG and LNG based on the proportion of natural gas from different origins – domestic and imported, notably UK continental shelf, imports from Norway, Netherland, Belgium and LNG predominantly from the Middle East. The proportion of re-gasified LNG in the natural gas mix is taken into account. This is covered each year in the DUKES report, all be it two years before the publication date of the latest BEIS report. BEIS weight GHG emissions according to the origin of natural gas imported using data from a study carried out by Exergia (2015). It is difficult to determine the figures BEIS have used to derive their WTT GHG factor for CNG and LNG from the Exergia report. It would be useful if BEIS could disclosure CO_2e emissions for each element of the WTT pathway for CNG and LNG. It is important to highlight that the Exergia report is based on a variety of measured data going back to 2012. A review of GHG emission data from the different emission pathways should be considered in light of more recent and accurate data sets.

A detailed literature review of GHG emissions from natural gas supply chains, both CNG and LNG, has been undertaken by the Sustainable Gas Institute (2015). The study reveals high variance in GHG emissions data for the natural gas supply chain. SGI identifies incomplete and unrepresentative data sets for a number of key emission sources. The authors highlight a lack of transparency in data and a lack of accounting for methane emissions across all of the LNG stages. They advocate work is undertaken in this area to strengthen understanding and availability of more representative data.

2.4 Recommendations

a) In order to gain clarity on the BEIS 2019 CNG and LNG WTT CO_2e values it would be beneficial if the department could provide a breakdown of life cycle CO_2e emission for each element of the fuel production pathways. This would enable a better understanding of the inputs and assumptions for calculating Well to Terminal, Terminal to Station and Station to Tank CO_2e emissions.

b) BEIS to undertake a detailed review of WTT CO_2e emission factors for CNG and LNG, taking account of emission sources for CO_2, CH_4 and N_2O; with a view to adopt more representative figures and make use of real world data where available. Consideration should be given to recent UK studies that have explored and assessed natural gas WTT CO_2e emissions. It is recommended the work undertaken by Element Energy, Energy Technologies Institute and Sustainable Gas Institute should be submitted as primary evidence. In particular BEIS should review:

- CO_2e emissions from natural gas extraction, processing and transportation with particular attention to methane emissions from LNG supply chains.

- Station to tank assumptions on fugitive methane emission arising from LNG stations further to Element Energy and ETi engagement with industry.

- Assumptions related CNG refuelling station leakage, taking into account real world data. BEIS to ensure up to date WTT electricity factors are adopted, in particular for calculating CO_2e emissions associated with different compression rates in the transmission grid.

c) BEIS to present three CNG figures to account for refuelling stations connected to different tiers of gas network e.g low pressure, medium pressure and high pressure mains.

d) BEIS to insert an annotation with the CNG CO_2e emission figures to highlight that this includes a small percentage of biomethane.

3. Biofuel WTT CO_2e Emission Pathways and Values

Biofuels have a prescribed life cycle methodology in the UK and European Regulations - RTFO and RED. Biofuel producers can use actual or default values to calculate the life cycle CO_2e emissions of their biofuel supply chain. Example pathways are presented below for biodiesel and biomethane. Listed below are examples of the main parameters that influence life cycle CO_2e emissions for different biofuels.

Figure 3: WTT pathway for biodiesel (high blend)

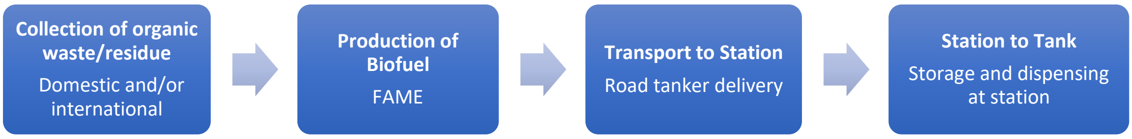
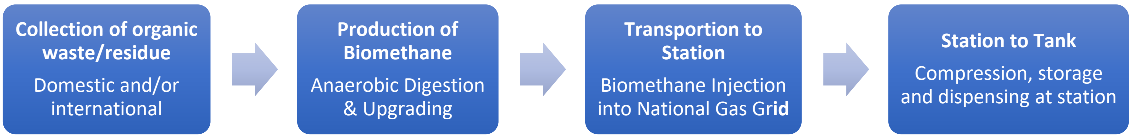


Figure 4: WTT pathway for compressed biomethane



3.1 Factors influencing GHG emissions

- Feedstock type: energy crop or waste/residues. For energy crops -method of cultivation, including use of fertilizer, land use change and indirect land use change. Biomass waste can be associated with a methane credit, notably manure.
- Biofuel production energy requirements, including use of co-products for renewable energy.
- Process fugitive methane emissions (biomethane, HVO).
- Method of transportation and distribution, for biomethane compression energy requirements
- Co-products and economic allocation in life cycle calculation.
- Carbon intensity of heat and power across the biofuel supply chain.

3.2 GHG emission values

Table 2: Biofuel WTT CO_2e emission factors (gCO_2e/MJ)

	BEIS (2019)	RTFO Yr 11 (2019)	RTFO Yr 10 (2018)	RED (2009)
Bioethanol (crop)	30	27		55
Biopetrol (waste)		8		
Biodiesel (RTFO average	11	12		
Biodiesel (UCO)	8	11		14
Biodiesel (tallow)	14	14		N/A
HVO (waste)			7	N/A
Biomethane (waste[2])	13	18		23
BioLPG (crop/waste)		20		

- RED Annex V - Default values
- N/A no default values available for HVO produced from waste and biodiesel from tallow.
- RTFO yr 11 provision data period April – Dec 2018

[2] Biogenic waste feed-stocks for biomethane production in 2019 do not include manure

- BEIS 2019 reports RTFO year 10 stats, these have not been presented again. Only shown for HVO

3.2.1 Biodiesel, HVO, bioethanol, BioLPG

Table 2 presents biofuel WTT CO_2e conversion factors from BEIS 2019, which reports RTFO figures for 2015/16. These are compared to the most recent RTFO statistics report – year 11 (2019), covering the period April – December 2018 (note this data set is provisional). There are subtle differences between the two data sets that are likely to be due to difference in feedstocks between one year and the next. Over the last four years the WTT CO_2e conversion factor for biodiesel has ranged between 11 to 18 gCO2e/MJ. For bioethanol this has ranged for 28 to 32 gCO_2e/MJ (RTFO stats).

BEIS report an average biodiesel RTFO figure, then separate figures for biodiesel produced from UCO and tallow. Based on the latest RTFO statistics six companies produce biodiesel from 100% UCO, other biodiesel suppliers typically produce biodiesel from a range of waste feedstocks which can include UCO. It would be useful for a fleet operator using a high blend biodiesel made from 100% UCO to have a bespoke figure available. However, as there are no biofuel suppliers selling biodiesel produced from 100% tallow, subsequently it is recommended this value is removed.

The BEIS 2019 inventory does not include a WTT CO_2e emission figure for HVO, this is however presented in the Year 10 RTFO report. Given the opportunities for HVO as a high blend drop in renewable fuel for commercial vehicles, it would be beneficial if this renewable fuel were included in the data set. The RTFO report identifies the feedstock for HVO as palm oil mill effluent (POME) and waste pressings from vegetable oil plant. Given the controversy over palm oil as a feedstock for biodiesel in Europe, it is somewhat perverse that palm oil mill effluent is acceptable given its status as a waste material, and considered sustainable, Over the last four years the RTFO statistics reveal the WTT CO2e emissions for HVO has ranged from 7 to 29 CO_2e/MJ. The broad range in values is due to variances in feedstock notable energy crop versus biogenic waste.

For the last three years the RTFO statistics include a carbon intensity figure for biopetrol. The Year 11 RTFO statistic (2019) identifies a carbon intensity value of 8gCO2/MJ for biopetrol, the feedstock is 100% UCO. As biopetrol is a type of renewable petrol, BEIS should report this figure. Given that retail petrol will comprise of bioethanol and biopetrol, consideration could be given to BEIS presenting a renewable petrol value, this being an average of the bioethanol and biopetrol figure.

The BEIS 2019 CO_2e conversion factors do not include a WTT value for bioLPG. This is likely to because no bioLPG suppliers were was not approved under the RTFO scheme over the period 2017 and 2018. The lasts RTFO statistics Year 11, now presents a carbon intensity figure for bioLPG as 20 gCO_2/MJ. Biopropane is a by-product of HVO production and therefore its carbon intensity will be influenced by the feedstock used to manufacturer HVO. Feedstocks can be energy crops (eg crude palm oil) or waste (eg UCO, POME). Interestingly the feedstocks for HVO are different to bioLPG in the RTFO statistics.

RED Annex V default values for biofuels are also presented in Table 2, these are more conservative with regards to calculation of fuel life cycle CO_2e emissions.

3.2.2 Biomethane

The WTT GHG emission figure presented for biomethane in the BEIS 2019 inventory (Table 2) specifically relates to compressed biomethane produced from anaerobic digestion (AD). The value is from a single biomethane supplier (CNG Fuels), with feedstocks comprising of food and agricultural waste. The refuelling station dispensing the CBG is situated on the high-pressure LTS, demonstrating best practise in terms of reducing 'station to tank' CO_2e emissions. Element Energy (2018) has used CNG Fuels biomethane production data for their WTT model, also arriving at a value of 13 gCO_2e/MJ. Historically the biomethane CO_2e conversion factor reported in the BEIS inventory has been for LBM produced from landfill gas; this pathway is no longer in existence in the UK. Over the last four years biomethane produced from AD has reported WTT CO_2e emissions ranging from 10 – 13 gCO_2/MJ (RTFO stats).

RED and REDII present three default CO_2e emission figures for biomethane produced from AD based on different feedstock categories – energy crop, biowaste (municipal waste) and manure. The WTT pathway is specifically for compressed biomethane. Under REDII[3] the biomethane default value for manure is associated with a large methane credit 206%; this significantly lowers the carbon intensity of biomethane production -85gCO_2e/MJ. Whilst it would be useful to have biomethane GHG conversion factors by feedstock, it is uncommon for companies supplying biomethane from AD plants to use a homogeneous waste feedstock supply throughout the year. It is likely that an increasing volume of manure will be used as a feedstock for biomethane production over the next few years, which could give rise to a negative WTT value. BEIS should be mindful of this and provide explanatory information in their inventory if this situation arises. It may be necessary to present two biomethane GHG conversion factors, one of biowaste (food/plant based wastes) and a separate figure in cases where a high proportion of manure is used as a feed-stock. The challenge will be for fleet operators to be confident that the biomethane they are being supplied is actually produced from manure, and hence using the appropriate emission factor. This can potentially be resolved through LowCVP forthcoming Low Carbon Fuel Assurance Scheme.

The biomethane figure presented in the BEIS 2019 inventory does not fully align with the WTT pathway for other biomethane supply chains in the UK.

<u>Green Gas Certificate Schemes</u>

Two biomethane certificate schemes exist in the UK – Green Gas Certification Scheme (GGCS) run by REAL, and the Biomethane Certification Scheme (BMCS) run by Green Gas Trading Limited. These schemes track biomethane injected in the gas grid from AD plants supported under the RHI. Both schemes issue certificates showing the volume of biomethane extracted from the gas grid and therefore purchased by a company. However, neither scheme identifies the carbon intensity of biomethane production on their certificates. To date all UK biomethane bus operators and a few freight operators have purchased biomethane from companies that are registered under these schemes. The refuelling stations that serve the majority of biomethane fleet operators are located on the low and medium pressure grid, which will influence the carbon intensity of the biomethane supply. It could be useful to understand the number of CNG stations located on the low, medium and high pressure grid, and those soon to be commissioned.

It is important to highlight that the life cycle boundaries for the RHI are different to the RTFO. The RHI covers biomethane production up to the point of injection into the gas grid, whereas the RTFO extends to biomethane distribution and compression at the refuelling station. To complicate matters further

[3] DfT will transpose REDII into RTFO in 2021

the RHI allocates waste a zero carbon intensity factor. Default values presented in Annex V of the RED could be used instead, these would need to be weighted depending on the blend of feed-stock eg manure, biowaste, crop. This should be taken into account if REAL and Green Gas Trading Ltd decide to show the carbon intensity figure of biomethane on their certificates.

Liquified Biomethane

Two new biomethane suppliers have recently been registered under the RTFO scheme. Their products will be CBG and LBM produced from biogenic waste via AD. It is likely that RTFO team will report an 'average' biomethane figure across suppliers, separate values for CBG and LBM will not be presented. It is important to highlight that these new biomethane suppliers will use a mass balance methodology to approve LBM under the RTFO, using the gas grid as the transport mechanism for biomethane.

LowCVP anticipate biomethane WTT emissions will reduce over the next few years as feedstock changes (higher proportion of manure), an increased number of stations located on the NTS and potentially more AD plant use biogas as renewable energy on site.

3.2 Recommendations

a) BEIS to include new WTT CO_2e emission value for HVO and bioLPG; the value should be sourced from the latest RTFO statistics. The feedstock of the HVO should be identified eg waste or energy crop and waste.

b) BEIS to omit presenting a biodiesel value for tallow.

c) BEIS to present a WTT CO2e emission figure for biopetrol, based on RTFO statistics. Also recommend presenting a new 'renewable petrol' value which is an average of the RTFO bioethanol and biopetrol values. Commentary on the feedstock should be provided.

d) BEIS to provide commentary in their CO_2e emission factor inventory on the feedstock and production process for biomethane. In addition it should be made clear that the biomethane value applies to compressed biomethane, and when relevant, also liquid biomethane.

e) GGCS and BMCS to consider presenting a CO_2e emission savings figure on certificates issued to transport operators. For simplicity, RED default values for biomethane could be adopted these should align with the type of biomass feedstock used for biomethane production

4. Hydrogen WTT CO_2e Emission Pathways and Values

BEIS do not report a CO_2e emission factor for hydrogen production. Given the growing interest in hydrogen fuel cell applications for decarbonising buses in the near term, and trucks long term, the inventory could benefit from inclusion of carbon intensity figures for pathways representative of UK hydrogen production. The two dominant, and mature, hydrogen supply chains in the UK are steam methane reformation and electrolysis[4] of water. Emerging hydrogen production pathways include SMR with carbon capture and storage (CCS), gasification of biomass with and without CCS, and as a by-product from certain industrial processes. Various studies suggest that liquefied hydrogen could be imported into the UK from regions associated with less carbon intensive production. The RTFO's development fuel sub target is likely to galvanise a low carbon hydrogen market, specifically produced from renewable fuels of non-biological origins (RFNBOs). The RTFO is the only Government policy that set a GHG threshold for hydrogen and requires calculation of fuel life cycle GHG emissions.

The WTT pathways for hydrogen are diverse and there is uncertainty as to when various low carbon pathways could offer economic, large-scale supply chains for road transport. This paper focuses on three pathways presented in Figure 5 and 6, with a recommendation that a study is undertaken to map out WTT pathways for hydrogen over the next two decades, and identify associated GHG emissions specific to the UK.

Figure 5: SMR pathway (red) and with CCS (green)

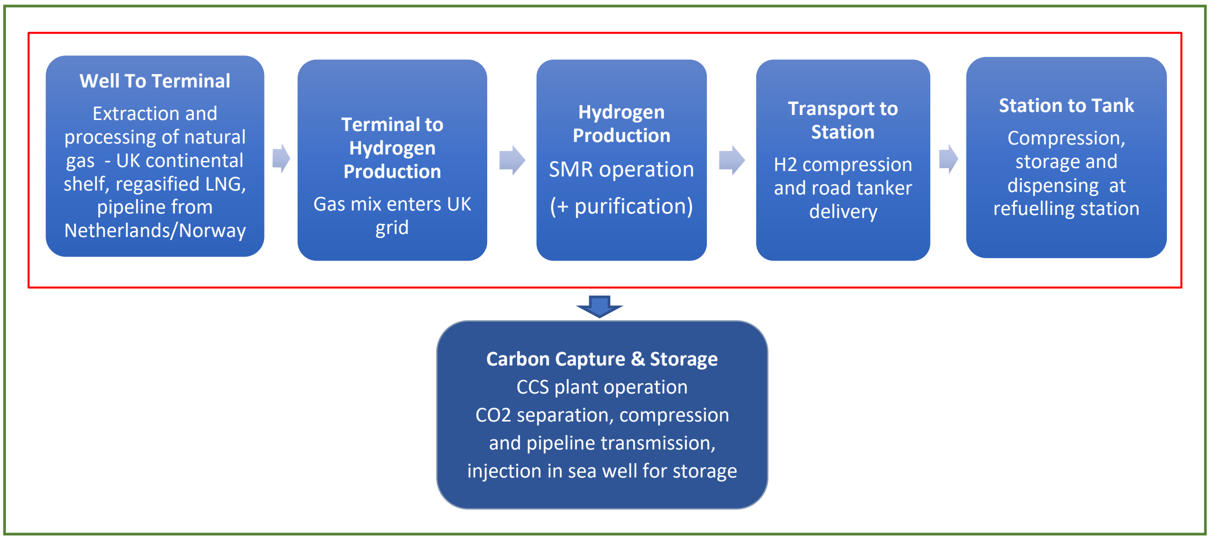


Figure 6: Electrolysis (Grid) pathway[5]

[4]Three types of electrolysis PEM (most mature), alkaline (demonstration) and solid oxide (emerging)
[5]Pathway would only comprise of 'station to tank' element when 100% renewable energy used

4.1 Factors influencing GHG emissions

Electrolysis	SMR + CCS
Energy requirement of electrolyser Compressor energy requirement Energy requirement for chilling unit Carbon intensity of electricity	Natural gas mix, including % LNG imports GWP of methane SMR energy requirement Energy for H2 compression – transportation and at dispensing station Tube trailer fuel efficiency & volume transported CCS - efficiency and energy requirement Energy for CO_2 transportation and storage Carbon intensity of natural gas and electricity.

4.2 GHG emission values

A number of studies present CO_2e emission values for hydrogen production via electrolysis (on site), SMR with and without CCS, examples are presented in Table 6. In situations where electrolysis entails 100% renewable energy studies report a carbon intensity value of zero; no consideration is given to transmission and distribution losses for electricity which occur regardless of electricity generation source. It is important to highlight that the majority of studies have focused on lifecycle CO_2e emission in relation to hydrogen replacing natural gas for heating. Only two reports have been found that cover WTT pathways for H2 used in transport, CONCAWE (2014) and DfT (2018). The assumptions and system boundaries of the lifecycle methodology across all these reports are inconsistent and not entirely transparent. Commentary is provided in Table 6 explaining the figures presented.

Table 6: Summary of hydrogen production GHG emissions (CO_2e/MJ)

Source	SMR	SMR + CCS	Electrolysis (Grid)	Commentary
CONCAWE 2014	108	43	232	WTT - Extraction/processing of natural gas, EU pipeline to UK, SMR, distribution by road tanker, compression at refuelling station, EU-electricity grid 2014
DfT 2018	100	35	160	WTT - Electrolysis uses 2017 grid factor, SMR based on CONCAWE 2014 data.
E4Tech 2019	61-90	24		SMR/SMR+CCS includes natural gas upstream emissions
CCC 2018	83-99	11-26	80-99	Electrolysis only (based on 2017 grid) SMR includes natural gas upstream emissions
Balcombe et al 2019	80-96	6-41	138	SMR/SMR+CCS includes natural gas upstream emissions. Electrolysis only
CertifHy 2019	90	45	220	SMR/SMR+CCS includes natural gas upstream emissions. Electrolysis only, EU electricity grid 2014
Mahmeti et al (2018)	74-107			SMR + upstream

Hydrogen fuel cells require hydrogen to be at 99.97% purity whereas hydrogen for heat or spark ignition use does not have to be anywhere near this purity. This element of hydrogen production from SMR has limited mention in published data. The purification of hydrogen would take place prior to distribution to the market, using pressure swing absorption. Only Balcombe et al (2019) and Mann et al (2001) make reference to this element of the SMR process. This high level of purity is achievable by electrolysis.

In the case of SMR fitted with CCS, the lifecycle figures have a high level of uncertainty with limited transparency of energy requirements and associated CO_2e emissions for CCS plant and CO_2 transport and storage. Studies in the public domain do not fully account for entire the CO_2 supply chain. This subsequently omits large energy requirements, plus any CO_2 leakage. Specifically, the calculations do not appear to take into account extraction of the CO_2 from the SMR flue gas, drying and high pressure compression of CO_2 to a supercritical fluid for pipeline distribution to shoreline terminals, then offshore pipeline transportation to a sea well for storage. It is also possible for CO_2 to be transported as a supercooled liquid. Even with CCS fitted to SMR, about half the total emissions are from upstream natural gas, highly influenced by how and where the gas is extracted and transported, the carbon intensity of the future UK natural gas supply chain will be important. The adoption of SMR with CCS as a route of hydrogen production could increase natural gas imported into the UK. Balcombe et al (2019) propose that due to the efficiency of SMR being c65% and CCS c90%, natural gas usage could increase between 15% and 66%. A complete picture of life cycle CO2e emissions from SMR fitted with CCS requires urgent attention.

An interesting subject that should be explored more deeply by Government and academia is the potential impacts of increased hydrogen emissions on atmospheric chemistry due to hydrogen leakage. A recent study undertaken by Derwent (2018), on behalf of BEIS, identifies unintended atmospheric impacts of elevated hydrogen emissions primarily through influencing the behavior of hydroxyl radicals. These are increased production of methane and troposheric ozone contributing to climate change, plus stratospheric ozone layer depletion. Derwent estimates a GWP of 4.3 for hydrogen, over a 100 year time horizon. Whilst a hydrogen leakage rate has yet to be identified it shows a precautionary approach should be taken to avoiding hydrogen leakage from producing, transporting and storing hydrogen in automotive, and heating, applications. Derwent makes recommendations for understanding and assessing the atmospheric effects of increased hydrogen emissions. These include before a hydrogen economy begins establishing atmospheric hydrogen baseline, through ambient air monitoring, obtaining a community based estimate of GWP of hydrogen and for Government to undertake a policy analysis of the global atmospheric impacts of hydrogen.

4.2.1 LowCVP proposal for WTT GHG emissions for current UK H2 pathways

This desk top study has revealed that robust CO_2e emission values for UK hydrogen production pathways for transport specific to the UK is lacking. Given the strong interest in hydrogen as a route for decarbonising heating and heavy-duty vehicles over the next two decades, it is imperative that accurate and representative WTT CO_2e emissions are determined. This should be carried out for current and future hydrogen production pathways and their differing product specifications.

LowCVP Secretariat has engaged with its members involved in the hydrogen industry to source primary data to calculate WTT hydrogen production figures for SMR and electrolysis (UK grid), based on the refuelling stations dispensing hydrogen at 350bar and 700bar. Pathways shown in Figures 5 and 6. For stations dispensing hydrogen at 700bar it has been assumed the equipment includes a chilling unit. BEIS 2019 GHG conversion factors have been adopted for natural gas and electricity usage, taking into account upstream and in-use GHG emissions. It has been assumed SMR is taking place at a large-scale centralised plant, and electrolysis at a refuelling station. Our calculations have not taken into account fugitive methane emissions from the SMR process.

As can be seen in Table 9, our calculation shows hydrogen production by SMR figures to range between 129 and 143 gCO_2e/MJ. Hydrogen production by electrolysis, using current grid electricity, ranges between 164 and 180 gCO_2e/MJ. LowCVP intends to share these figures with the industry and once agreed to adopt these as WTT hydrogen production GHG emission values in our WTW emission assessment work. Obviously, the figures would need to be updated each year as the carbon intensity of natural gas and electricity changes, in addition to any variance in the UK natural gas supply.

Table 9: LowCVP proposed WTT GHG emissions for hydrogen (gCO_2e/MJ)

H2 refuelling station	SMR	Electrolysis (UK Grid)
350 bar	129	164
700 bar	143	180

It is worth highlighting that the RTFO sets a GHG emission threshold of >70% GHG emission saving compared to fossil fuel for RFNBOs as development fuels. One could therefore propose a low carbon hydrogen production pathway should meet this threshold.

4.3 Recommendations

a) BEIS to introduce WTT CO_2e emission factors for hydrogen production pathways relevant to transport, in the first instance these should be SMR and electrolysis. LowCVP's figures could be adopted once refined and agreed by members. The values should clearly be annotated to describe the different pathways.

The RTFO team may publish carbon intensity figures for hydrogen production in their RFTO statistics in the very near future. DfT will not, however, identify the method of hydrogen production. If BEIS adopt these hydrogen production figures they could be incorrectly applied to more carbon intensity production routes.

An interim approach for BEIS could be to present 'fossil' hydrogen pathways eg LowCVP's figures and a 'low carbon' hydrogen value representing the RTFO values, once released. Where possible BEIS should identify the production pathway and ensure the values are stated as hydrogen for transport. In the future it would be prudent for BEIS to have separate values for hydrogen production associated with use in the heating sector.

b) As can be seen in Figure 7 overleaf hydrogen production via SMR and electrolysis, based on UK grid average electricity and natural gas figures, has a much higher carbon intensity than fossil and renewable fuels currently on sale. BEIS and OLEV should consider setting a target for low carbon hydrogen with regards to use in heat and transport. This could be set at the RTFO threshold for RFNBOs of >70% savings compared to fossil fuel and based the RED life cycle methodology.

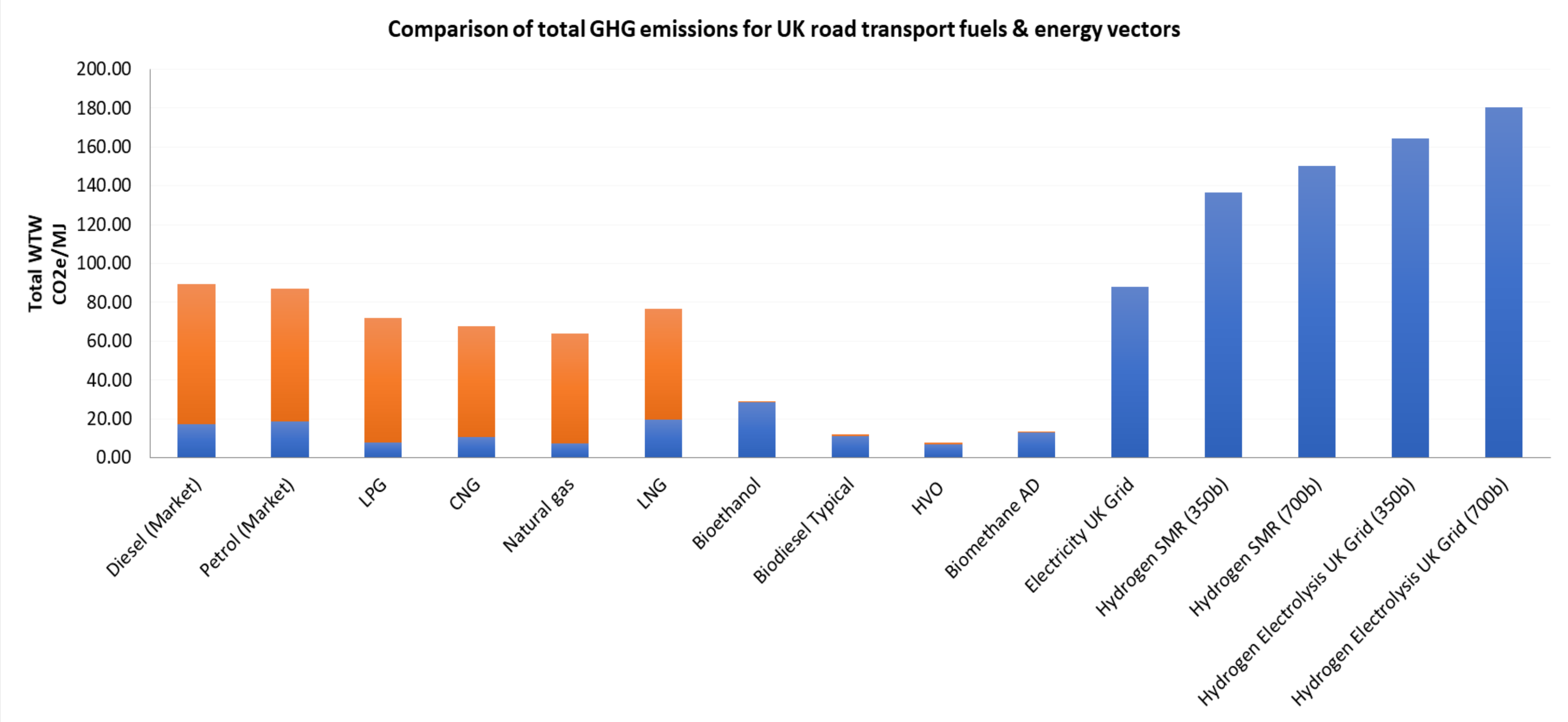
c) A study should be commissioned to demonstrate WTT GHG emissions from different hydrogen production pathways for the UK, with scenarios showing the impacts of flexing key assumptions. This could include carbon intensity of current and future electricity and natural gas grid, equipment efficiency, changes to IPCC's GWP for methane and nitrous oxide (AR5). This should be accompanied by a roadmap identifying when different low carbon hydrogen pathways will be commercialised, and scalable, from 2020 to 2050.

d) Currently data sets accounting for GHG emissions from SMR fitted with CCS are hypothetical as no CCS plants are in operation in the UK and very few globally. It is recommended that hydrogen production with CCS demonstration projects in the UK (eg H21 City Gate) are required to undertake a life cycle CO_2e emission assessment, in accordance is ISO14064. Results should be published. The life cycle boundary should cover the complete hydrogen production supply chain, CCS plant operation, extraction of CO_2 from the waste gas stream, CO_2 conditioning, transportation and storage.

e) There is no mechanism in the UK to give assurance to a vehicle operator that the hydrogen used in a HFC vehicle is associated with low carbon production. The exception is the ULEB scheme. LowCVP's Low Carbon Fuel Assurance Scheme could be extended to cover hydrogen.

f) BEIS to strengthen evidence base on the long term environmental impacts of decarbonising heat and transport via hydrogen.

Figure 7: Comparison of WTW CO_2 emissions for UK road transport fuels and energy vectors



- Blue WTT, Orange TTW.

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[6] The Transport Energy Model was used as part of DfT's the preparation for the Road To Zero Strategy 2018.