Development of a Well to Tank Emission Tool for Heavy Goods Vehicles

Model Documentation

21st September 2018

Element Energy Ltd

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Project details

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- **Disclaimer**

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- **Acknowledgements**

  The authors would like to thank all current gas station operators in the UK, who have supported this project with information and data regarding their station operational performance. The authors are grateful to the LowCVP, National Grid and the Energy Technologies Institute for their support.

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This work was commissioned by a gas industry working group. The project aim was to model the WTW emissions of gas and diesel HGVs

Background, Aims and Objectives

Background

- Political support for gas as a fuel for Heavy Goods Vehicles (HGVs) is currently uncertain because previous real world trials of these vehicles showed that their climate change benefit was marginal.
- However, a new generation of gas HGVs is currently being trialled in the Low Emissions Freight and Logistics Trial. This will deliver Tank To Wheel (TTW) emission figures for gas and diesel vehicles, and will support the Department of Transport (DfT) in their recommendations to Treasury, in the context of the fuel duty review. Under current rules, gas has a fuel duty rebate compared to diesel, which makes gas trucks cost competitive.

Aims and Objectives

- For a fair comparison, gas and diesel HGVs should be compared on a Well to Wheel (WTW) basis. The aim of this work was, therefore, to build a model that incorporates the TTW test figures with calculated Well to Tank (WTT) figures to provide the user with WTW emission figures.
- These WTW emission figures can be used by policy makers and industry to support discussions around the future rollout of gas as a fuel for HGVs in the UK.

This slide pack provides a complete overview of the structure and values used to build the HGV WTW emission tool

What this slide pack covers

- The model (an Excel file) will be handed over to DfT. This slide pack provides the information needed to understand the model, namely:
  - An overview of the model, including the layout of the calculation and output tabs
  - The model inputs and sources used, broken down by model tab
    - This includes an analysis of the potential availability of biomethane for transport over time
  - A comparison of the model results with the standard factors used in BEIS modelling

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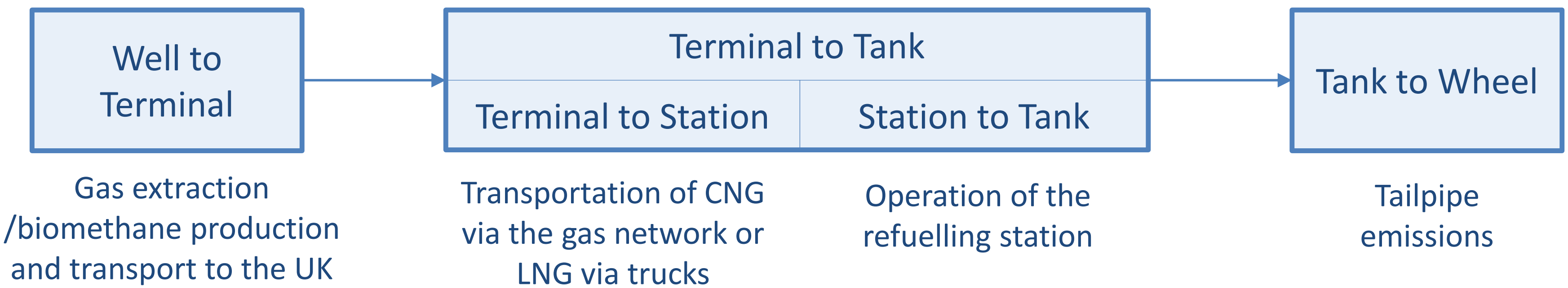
Overview of model scope

- The Excel based model compares the Well to Wheel emissions for gas HGVs
  - under a number of gas pathways [CNG, L-CNG, LNG, biomethane variants]
  - against the case of diesel trucks, with varying levels of biodiesel blend & accounting for AdBlue
  - with the TTW emissions being an user input

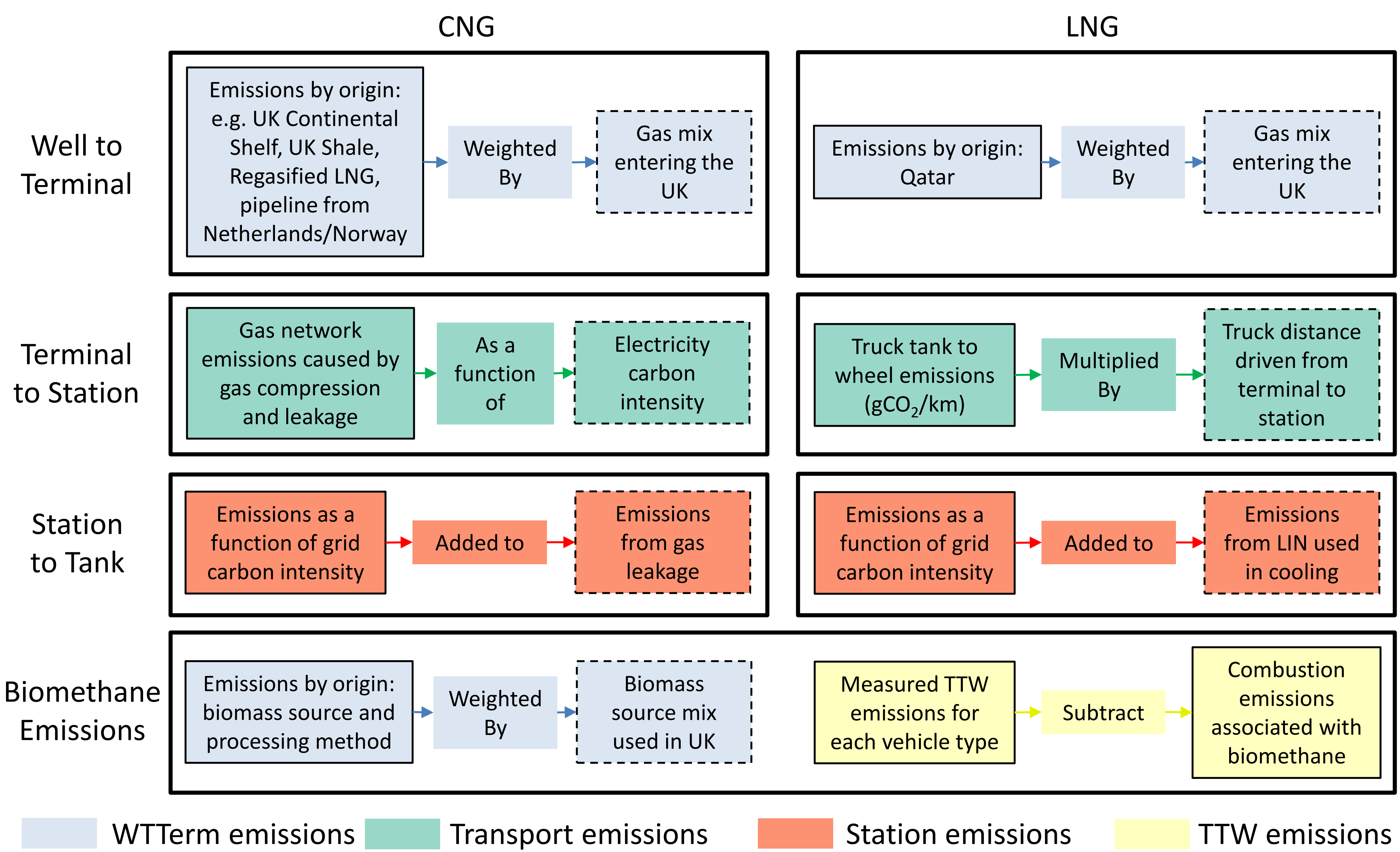
- The Well to Wheel emissions are split into a number phases, as summarised here:



- The model recognises some key factors influencing the Well to Tank results will change over time. To this effect, it is pre-loaded with values for several time horizons: 2024 and 2032. These correspond to policy milestones or reporting point (end of current gas fuel duty rebate, end of 5th Carbon Budget)
- The model is populated with UK specific data as much as possible, with data sources made transparent & reviewable.

Overview of calculation steps

Inputs/settings the user can amend



The Excel model is structured under a number of tabs as outlined below

- **Notes** – An introduction to the model to help the user navigate the model tabs
- **Input** – Space for the user to input the TTW emission results from the testing conducted at Millbrook (emissions expected include CO_2, CH_4 and N_2O)*
- **Output - Model Summary** – Graphs and tables summarising the results of the model. This includes a dashboard where the user can control the model inputs [shown later]

Calculation Tabs

1. **Gas Well to Terminal** – Emissions from gas extraction and transport to the UK
2. **Bio-Gas Production** – Emissions from the manufacture, transport and blending of bio-gas
3. **Terminal to Station** – Emissions from the transportation of CNG via the gas network and emissions from truck transportation of LNG
4. **Station to Tank** – Emissions from the filling station (CNG and LNG)
5. **Diesel Well to Tank** – Emissions from the extraction, distillation, transportation and storage of diesel

Tabs where values and calculations behind each steps are provided, along with data sources. This is where the user can enter the 'user defined' values, when applicable.

* The model delivered in September 2018 to DfT contains dummy TTW values as the latest testing emissions results are not publicly available

The model has been designed with a common format on each tab

Each tab has four zones:

- Top Left: Calculates the overall emissions
- Bottom Left: Stores the model input data for the tab
- Top Right: Allows the user to input values (greyed out when the variable is set to Baseline)
- Bottom Right: References

Project Name: WTW tool for gas HGVs
Client: Gas Industrial Working Group
Developed by Element Energy Ltd. July 2018

Calculated results

Gas Well to Terminal Emissions (gCO2eq/MJ gas)   Gas Mix input type selected on the Outputs tab: Baseline

Year	Baseline CNG	Baseline LNG	User Defined CNG	User Defined LNG
2018	5.0	12.8	5.0	12.8
2024	6.0	12.7	6.0	12.7
2032	6.1	12.5	6.1	12.5

Baseline inputs

Gas Well to Terminal Emissions (gCO2eq/MJ gas)

	CNG Sources					LNG Sources
Year	UK Cont. Shelf	UK Shale	Norway	Netherlands	Qatar LNG regas	Qatar LNG
2018	4.34	3.575	4.7	2	14.30	12.83
2024	5.81	3.125	4.7	2	13.58	12.69
2032	7.77	2.525	4.7	2	12.87	12.50

UK Gas Mix by Source (%)

	CNG Sources					LNG Sources
Year	UK Cont. Shelf	UK Shale	Norway	Netherlands	Qatar LNG regas	Qatar LNG
2018	45.96%	0.00%	47.58%	1.57%	4.88%	100.00%
2024	41.32%	1.47%	45.32%	2.01%	9.88%	100.00%
2032	28.44%	17.18%	40.10%	2.39%	11.89%	100.00%

User defined inputs

UK Gas Mix by Source (%)   Values add up to 100%

	CNG Sources					LNG Sources		
Year	UK Cont. Shelf	UK Shale	Norway	Netherlands	Qatar LNG regas	Qatar LNG	CNG Total	LNG Total
2018	38%	0%	38%	5%	19%	100%	100%	100%
2024	20%	30%	60%	0%	0%	100%	100%	100%
2032	20%	30%	50%	0%	0%	100%	100%	100%

User's comment: sample comment, data based on latest estimate

Reference colour coding

Colour code	References
	National Grid, 2017, Future Energy Scenarios
	ThinkStep, 2017, Greenhouse gas intensity of natural gas
	ETI, 2017, Natural Gas Pathway Analysis for Heavy Duty Vehicles

The Output Tab displays two stacked bar charts: 1 for gas industry agreed baseline values and 1 for user controlled values

The output tab displays two plots a **Baseline Plot** and a **User Defined Plot**

The **Baseline Plot** displays

- Baseline results (bar chart) for diesel, CNG and LNG
- All results are fixed with no user control
- Advantage: the user can see results based on recommended settings without having to engage with any decision making

The **User Defined Plot** displays

- Results (bar chart) for diesel, CNG and LNG reflecting user selected/defined inputs (the user may select the baseline values)
- The user can choose to see results across year, vehicle type or drive cycle
- Advantage: provides flexibility to the user to explore

See next slide for an illustration of the Output Tab

The Output Tab displays two stacked bar charts: 1 for gas industry agreed baseline values and 1 for user controlled values

The output tab displays two plots a **Baseline Plot** and a **User Defined Plot**

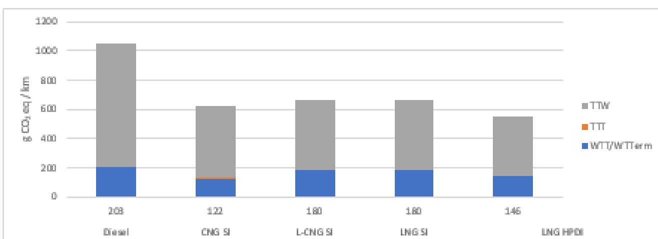
Project Name: WTW tool for gas HGVs
Client: Gas Industrial Working Group
Developed by Element Energy Ltd. July 2018

User Inputs

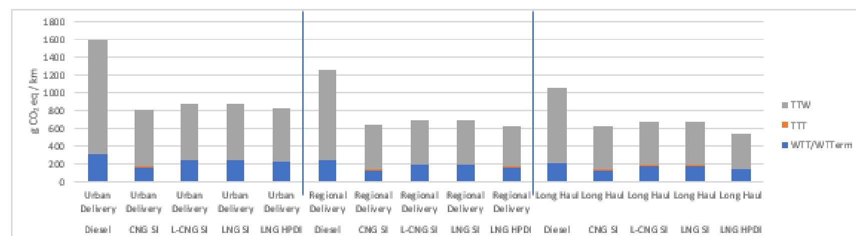
Gas Mix	**Baseline**	Baseline based on: National Grid, 2017, Future Energy Scenarios
Electricity Grid Carbon Intensity	**Baseline**	**Baseline Scenario based on: BEIS - EEP 2017**
Biomethane Mix	**Baseline**	Biomethane Share (45%)
LNG Terminal to Station Truck Distance	**Baseline**	

CNG Station Leakage	**Average Leakage**
Emissions from LIN use	**Fully Utilised**
Graph Display	**Drive Cycle**

Baseline. Long Haul Truck. Biomethane Share (45%)



User Defined Emissions Projections



Results Table

Baseline	g CO2 eq / km				%
Fuel type	**WTT/WTTerm**	**TTT**	**TTW**	**TOTAL WTW**	**relative to diesel**
Diesel	203	0	849	**1052**	-
CNG SI	122	16	483	**621**	**-41%**
L-CNG SI	180	4	483	**667**	**-37%**
LNG SI	180	4	483	**667**	**-37%**
LNG HPDI	146	3	401	**550**	**-48%**

Baseline	gCO2 eq / MJ gas dispensed			%
Fuel type	**WTT/WTTerm**	**TTT**	**TOTAL WTT**	**relative to diesel**
Diesel	18	0.0	**18**	-
CNG SI	8	1.1	**9**	**-48%**
L-CNG SI	12	0.2	**12**	**-31%**
LNG SI	12	0.2	**12**	**-31%**
LNG HPDI	29	0.2	**30**	**69%**

Emissions Projection		g CO2 eq / km				%
Fuel type	**Selection**	**WTT/WTTerm**	**TTT**	**TTW**	**TOTAL WTW**	**relative to diesel**
Diesel	Urban Delivery	306	0	1282	**1588**	-
CNG SI	Urban Delivery	160	21	629	**810**	**-49.0%**
L-CNG SI	Urban Delivery	236	5	629	**870**	**-45.2%**
LNG SI	Urban Delivery	236	5	629	**870**	**-45.2%**
LNG HPDI	Urban Delivery	217	4	598	**820**	**-48.4%**
Diesel	Regional Delivery	244	0	1021	**1264**	-
CNG SI	Regional Delivery	128	17	504	**649**	**-48.7%**
L-CNG SI	Regional Delivery	189	4	504	**697**	**-44.9%**
LNG SI	Regional Delivery	189	4	504	**697**	**-44.9%**
LNG HPDI	Regional Delivery	165	3	454	**622**	**-50.8%**
Diesel	Long Haul	203	0	849	**1052**	-
CNG SI	Long Haul	122	16	483	**621**	**-40.9%**
L-CNG SI	Long Haul	180	4	483	**667**	**-36.6%**
LNG SI	Long Haul	180	4	483	**667**	**-36.6%**
LNG HPDI	Long Haul	146	3	401	**550**	**-47.7%**

Contents

The model is underpinned by a thorough literature review and dedicated data collection to make the model UK specific

Published data / scenarios

- Key literature references include:
  - ETI, 2017: refers to the public report resulting from the research conducted for the Energy Technologies Institute in 2015-16 by a consortium made up of Element Energy, CNG Services, University College London, Strateco and GHG Genius. (This work has been compared to the latest literature to ensure the findings are still up to date[1])
  - UK Government standard factors and electricity carbon intensity (BEIS)
  - RTFO Year 10 reporting
- For future values, we have used values in line with government policies and/or recognised projections, including:
  - RTFO target to 2032 for biodiesel blend
  - National Grid Future Energy Scenarios, for the gas sources

New data collection

- The following data has been collected during the project from the UK industry:
  - Leyland station electricity use, gas dispensed and gas leaks alarms for 2017-18
  - DIRFT station electricity use for 2015
  - Number of CNG stations per pressure tier
  - Usage of LIN at LNG stations
  - Share of RTFO biomethane sold to gas HGVs and short term projections
  - Calorific value of gas injected in the national grid

Full list of sources provided later

[1] including (ThinkStep, 2017, Greenhouse Gas Intensity of Natural Gas)

Overview of model inputs

WTTerm emissions | Transport emissions | Station emissions

Variable	Unit	Scenario	Year		
			2018	2024	2032
Gas Mix	%	Baseline / User	NG FES: Steady Progression / Any mix		
Gas Emissions by Source	gCO_2/MJ	Baseline	Values based on extensive literature review for ETI		
Share of biomethane	%	Baseline / User	45% / User can select any percentage for each year		
Biomethane Source Mix	%	Baseline / User	100% AD	99/1% AD/Gas	50/50% AD/Gas
Biomethane Emissions by Source	gCO_2/MJ	Baseline	Current value based on RTFO and RED II emission factors by feedstock; future values based on literature		
CNG Transport Emissions	gCO_2/MJ	Baseline	Current connection mix. Moving to mostly LTS and IP		
LNG Transport Emissions	gCO_2/MJ	Baseline / User	Truck transport / User set distance		
CNG Station Emissions	kWh/MJ	Baseline	0.003 (LTS) to 0.01 (LP); assumes steady state efficiency		
CNG Station Leakage	gCO_2/MJ	Baseline / User	Current Leyland leakage / No leakage		
LNG Station Emissions	kWh/MJ	Baseline	0.0004 (assumes DIRFT has reached steady state efficiency)		
Emissions from LIN Use	gCO_2/MJ	Baseline / User	No LIN use / Early station (5 vehicles) LIN use		
Share of Biodiesel	%	Baseline	Current share 2.5%	RTFO target 4.8% (2024-32)	
Electricity carbon Intensity	gCO_2/kWh	Baseline / User	BEIS projections / Any NG FES scenario/user defined		

AD/Gas = Anaerobic Digestion/Gasification
WTTerm: Well to Terminal Emissions.

NG FES: National Grid Future Energy Scenario

Contents

Gas Well to Terminal Sources

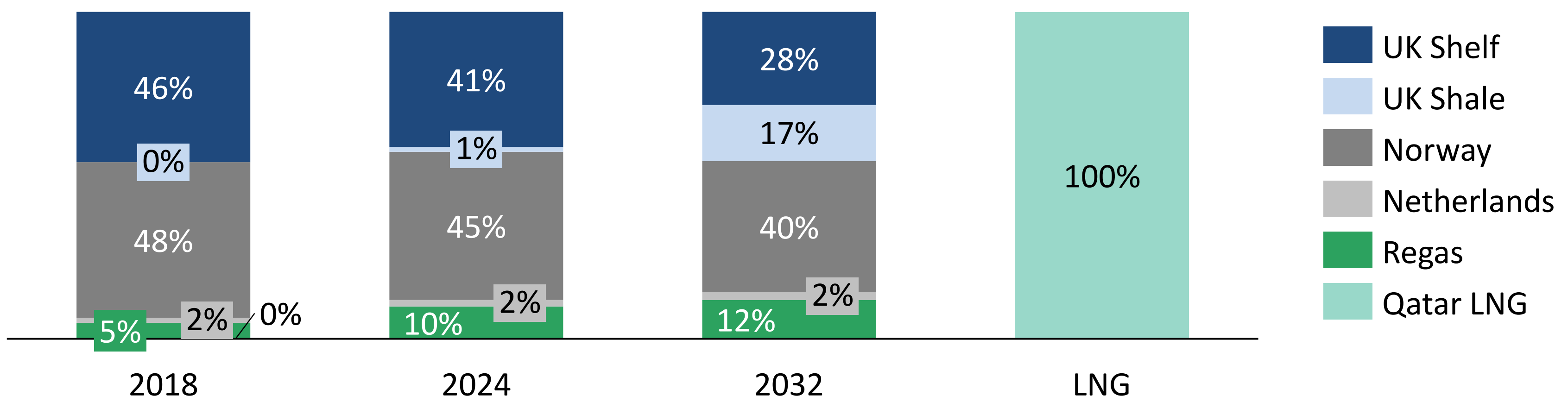
WTTerm emissions | Transport emissions | Station emissions

Gas mix and electricity intensity is based on the National Grid Slow Progression scenario. This has been chosen because it is the middle scenario (no large swing to green gas or shale gas) and is therefore seen as the most probable – see Appendix for a comparison of all National Grid scenarios

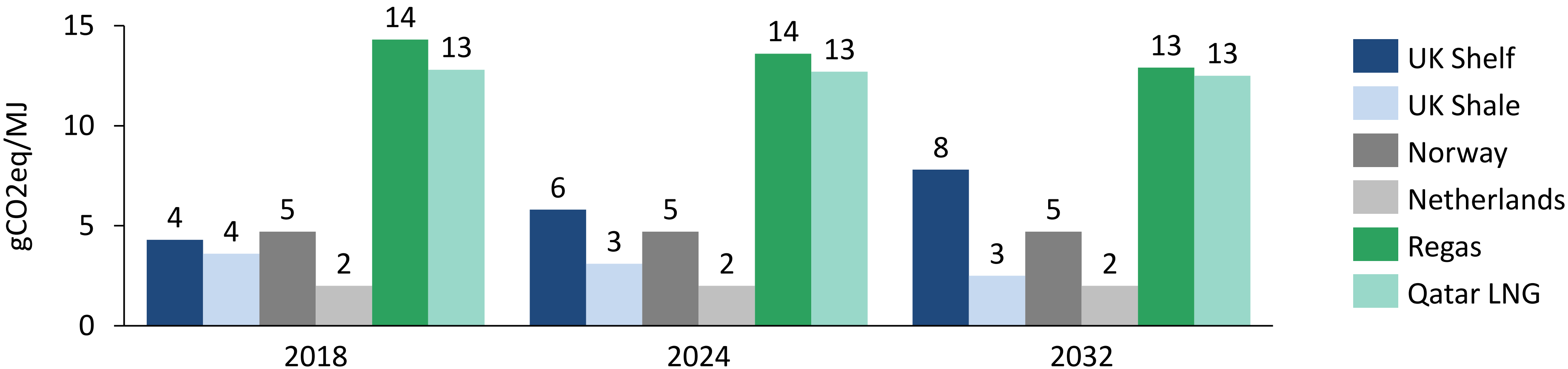
Variable	Unit	Source	Values
Gas Mix	%	National Grid, 2018, Future Energy Scenarios	CNG: UK Shelf (46→28%), UK Shale (0→17%), Norway (48→40%), Netherlands (2%), Regas LNG (5→12%). LNG: Qatar (100%)
Gas Emissions by Source	gCO_2/ MJ	ETI, 2017, Natural Gas Pathway Analysis for Heavy Duty Vehicles	Selected values (2018): CNG 2-7.8 depending on country of origin. LNG 13

Gas mix and gas emissions by source

UK Gas Mix (National Grid – Steady Progression)



Gas Emissions By Source (from: ETI, 2017)



Regas: LNG regasified in terminals in the UK before being injected into the national grid

ETI, 2017, Natural Gas Pathway Analysis for Heavy Duty Vehicles

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Biomethane Sources

WTTerm emissions | Transport emissions | Station emissions

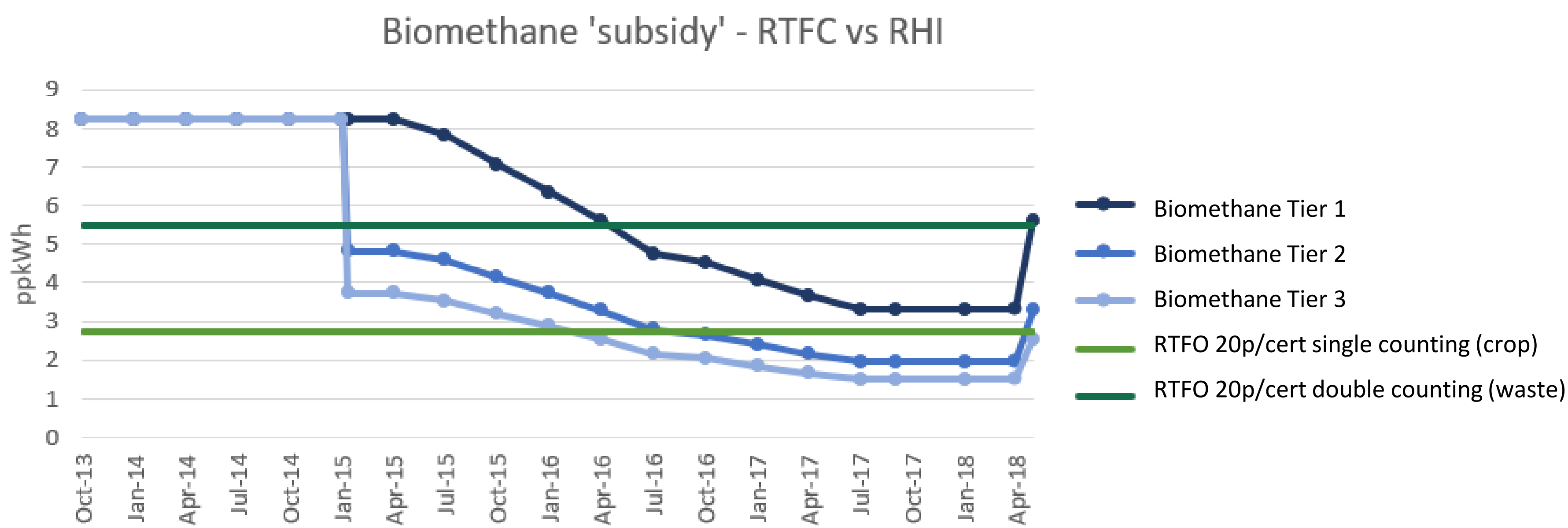
Variable	Unit	Source	Values
Natural Gas / Biomethane Mix	%	Literature review and Element Energy projections, summarised in following slides	65% / 45%
Biomethane Source Mix	%	RTFO Year 10 Reporting Literature review, summarised in following slides	2018: 100% waste, processed with AD. 2032: 100% waste, processed 75% with AD and 25% with gasification
Biomethane Emissions by Source	gCO_2/ MJ	RTFO Year 10 Reporting. RED II emission factors by feedstock ETI, 2017, Natural Gas Pathway Analysis for Heavy Duty Vehicles	AD: 10.8 in 2018 falling to 9.2 in 2024 onwards Gasification: 23

WTTerm: Well to Terminal Emissions

Even with the recent increase in Renewable Heat Incentive (RHI) tariffs, the RTFO can be more profitable for large producers, RHI Tier 2 and 3

The value of the RTFO versus the RHI

- The advantage of the RHI over the RTFO is that a scheme receives a guaranteed tariff for 20 years. However, at all RTFC prices seen to date (9-20p/cert) the RTFO would be more profitable than the RHI for Tier 3 suppliers and at current RTFC prices (20p/cert) it matches the RHI even for Tier 1 suppliers
- In summer 2018 the RHI tariffs for biomethane were increased to: Tier 1: 5.60p/kWh. Tier 2: 3.29p/kWh. Tier 3: 2.53p/kWh in an attempt to boost uptake before the RHI closes in 2021.
- At current RTFC prices (20p/cert) biomethane suppliers can receive 5.50-2.70p/kWh for biomethane from waste (double counted, dark green line) and crop (single counted, light green line) sources respectively



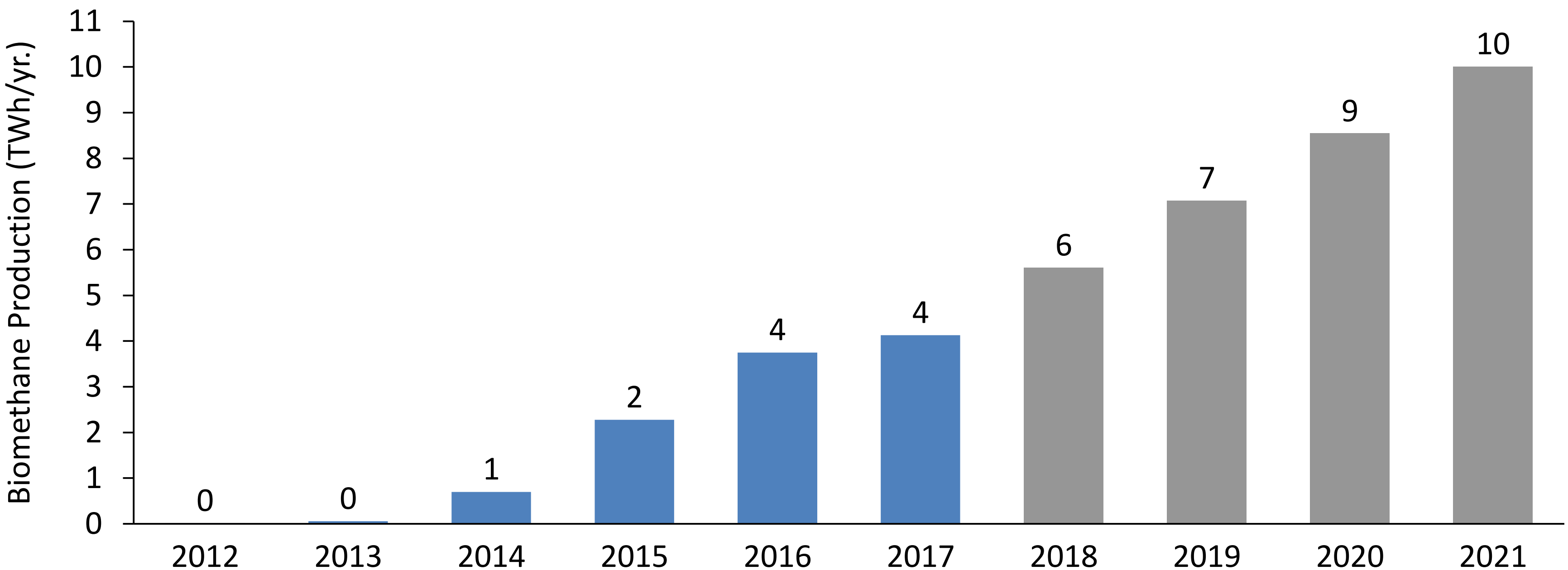
Tier 1 < 40GWh. Tier 2 40-80GWh. Tier 3 > 80GWh biomethane production

Source: NNFCC RTFC calculator and Gaynor Hartnell, 2017, THE RTFO – AN OPPORTUNITY FOR LFG?

With the new tariffs, biomethane production under the RHI is set to increase significantly

Growth of biomethane under the RHI

- Biomethane production has grown significantly under the RHI but increased production capacity has stalled because of falling tariffs (recorded data blue bars)
- However, the new tariff rates increase the tariffs up to those last seen in 2016. Using the industry growth rate in 2016 it is possible to predict the amount of additional biomethane capacity that could be added under the RHI before it closes in 2021 (grey bars)



We have created a low and high uptake scenario for the growth of biomethane under the RTFO to reflect current uncertainty

Biomethane potential under the RTFO

The amount of biomethane supported by the RTFO is expected to range between our low and high scenarios. These are a function of biomethane production ramp up rates (based on experience of the RHI) and the biomethane feedstock available (14TWh)[1]

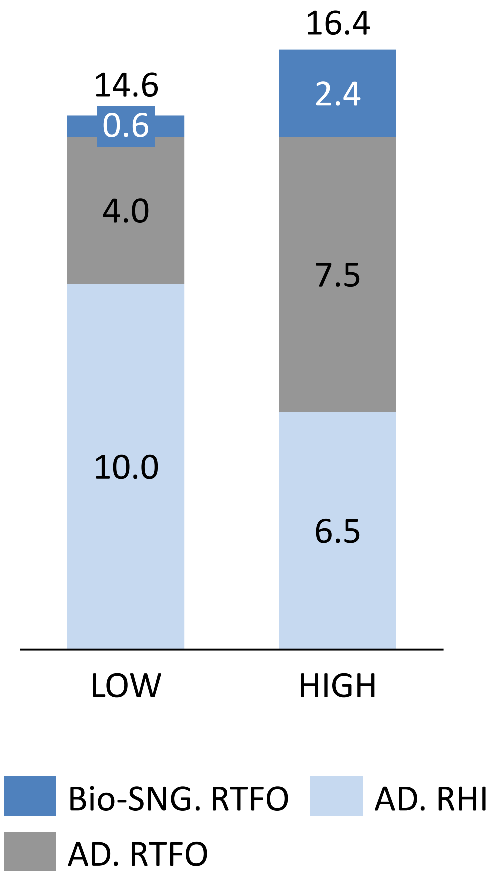
Low Scenario

- AD biomethane production ramps up at one third the rate achieved under the RHI in 2016
- AD biomethane is limited to 4TWh (the difference between the total available (14TWh) and that used by the RHI (10TWh))
- The first full scale bio-SNG plant (0.6TWh/yr.) plant comes online by 2032.

High Scenario

- AD biomethane production ramps up at half the rate achieved under the RHI in 2016
- AD biomethane is limited to 7.5TWh (assuming all available feedstock is used and some Tier 2 and 3 suppliers claim the RTFO over the RHI)
- Four full scale bio-SNG plants (0.6TWh/yr. each) come online by 2032.

Biomethane production in 2032, TWh



[1] E4Tech for Cadent, 2017, Review of Bioenergy Potential

With biomethane supported by the RTFO ~45% of gas used by trucks in the 2020s and 2030s could be biomethane or bio-SNG

Proportion of biomethane used by gas trucks

Element Energy's gas HGV uptake predictions for Cadent, and shared with DfT, suggests that gas HGV uptake could range from 11,000 to 26,000 in 2024 and 40,000 to 88,000 in 2032.

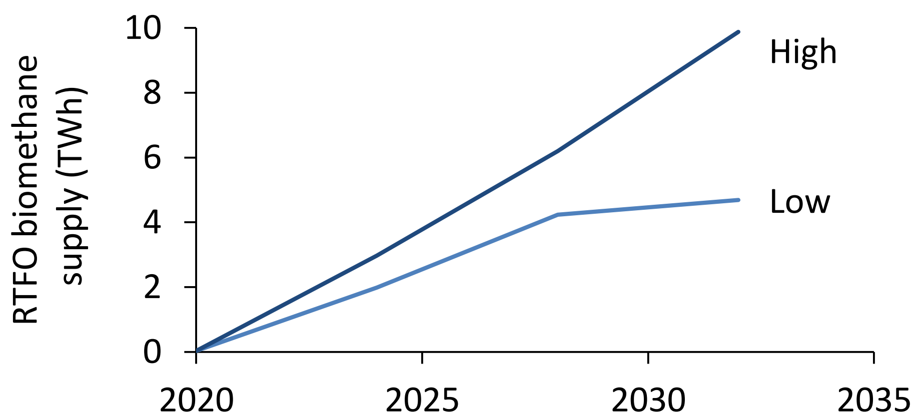
If gas vehicle uptake is low then it is unlikely biomethane providers will push supply through the RTFO. Therefore, it is expected that if the gas truck uptake is low then the biomethane supply will be low, while the opposite, high gas truck uptake, could encourage stronger support for biomethane through the RTFO.

The worst case for gas trucks (high gas truck uptake and low biomethane supply) still results in at least 20% biomethane mix

% of gas supplied to HGV that could be biomethane

	2024	2032
Low case	64%	46%
High case	45%	43%
High Truck/Low Biomethane	27%	20%

Projections for biomethane supply under the RTFO



[1] E4Tech/Cadent analysis

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Gas Terminal to Station Emissions Sources

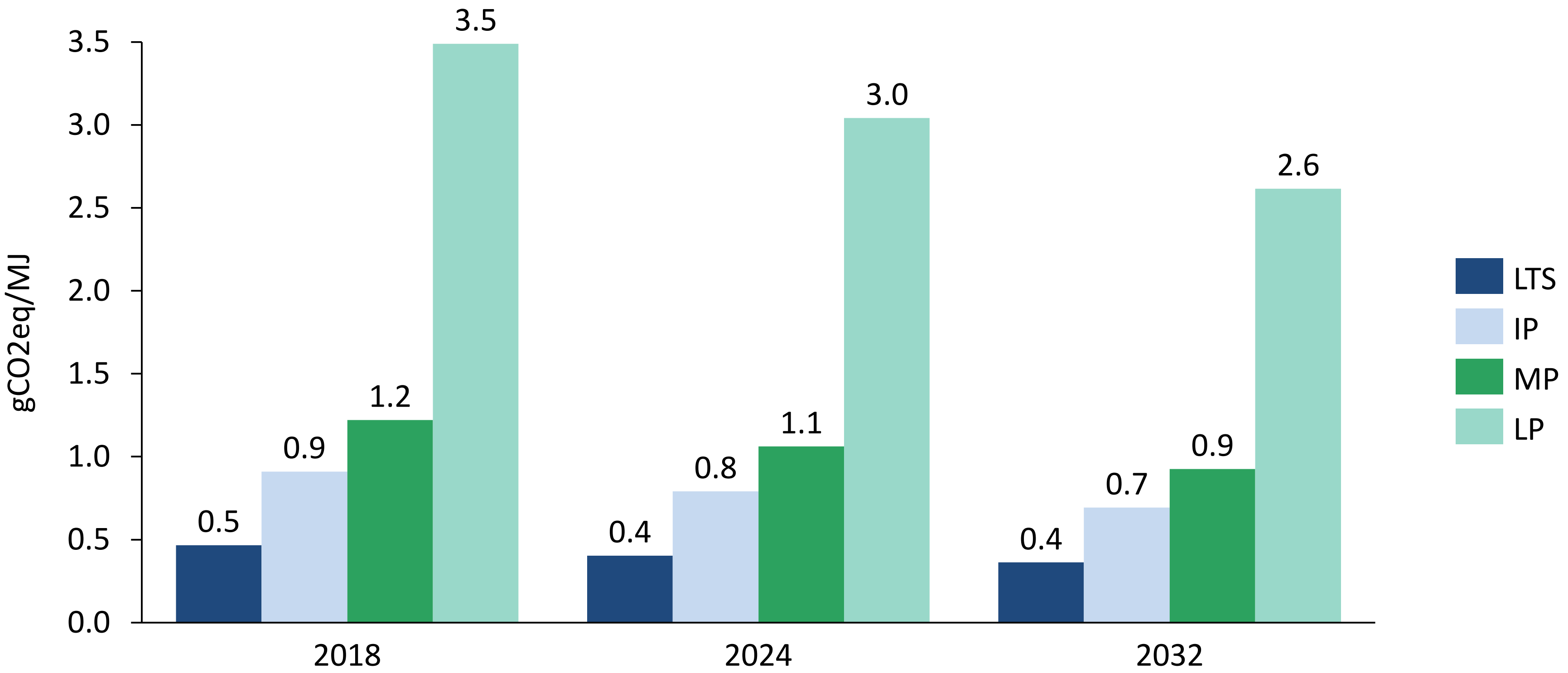
WTTerm emissions | Transport emissions | Station emissions

Variable	Unit	Source	Values
CNG Transport Emissions by Network Tier	gCO_2/ MJ	ETI, 2017, Natural Gas Pathway Analysis for Heavy Duty Vehicles	In 2018, LTS: 0.5, IP: 0.9. MP: 1.2. LP: 3.5. (Changes over time but only due to falling electricity carbon intensity)
LNG Terminal to Station Truck Transport Emissions	gCO_2/ km		Assumes LNG truck. WTT: based on model results TTW: assumes use of a new HPDI LNG truck with an engine efficiency equal to a similar spec diesel. Truck distance 400km (Based on DIRFT)

CNG transport emissions

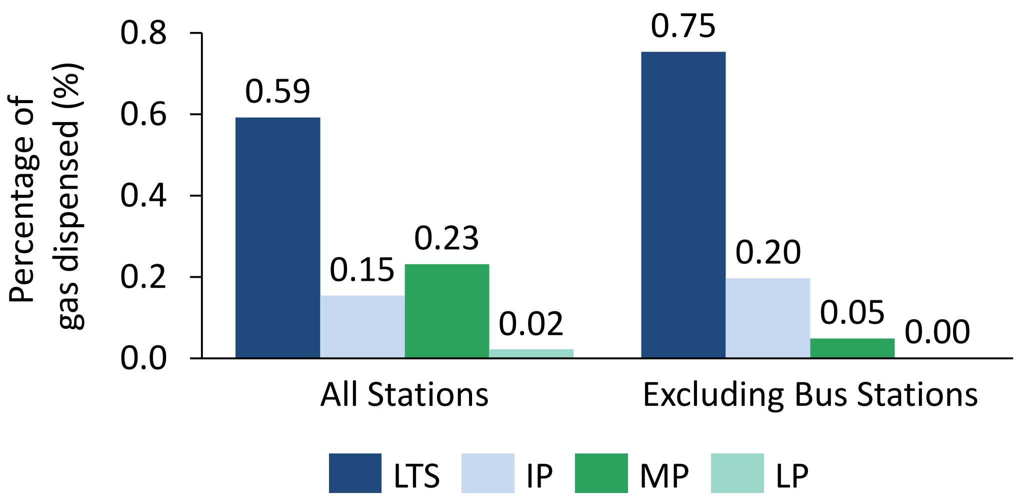
CNG Transport Emissions (Source: ETI, 2017)

The transport of CNG through the national gas grid is caused by gas and electric compressors used to compress the gas when it is injected into the national transmission system. Gas is also lost through leakage, especially at the lower pressure tiers. This has a very large effect on the emissions as methane has a very large global warming potential.



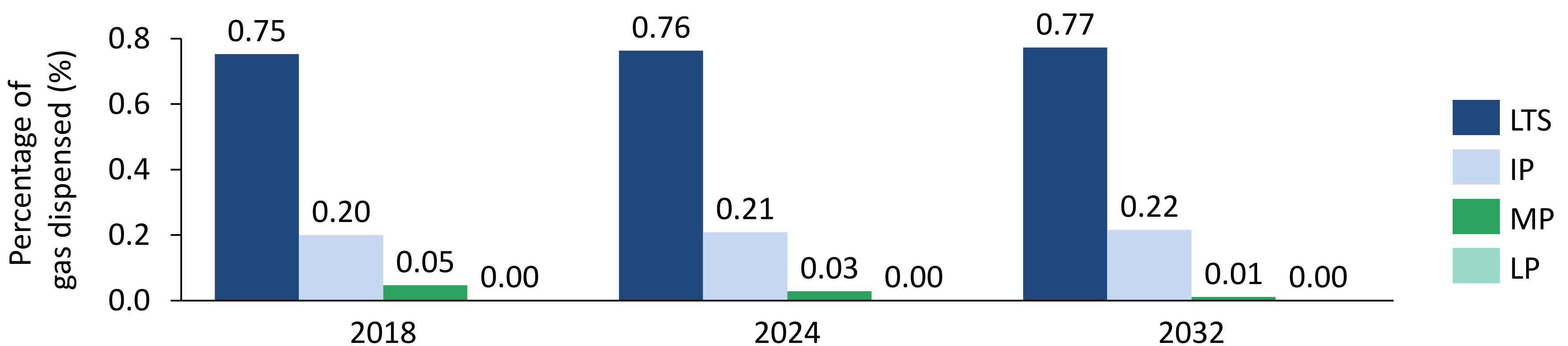
Station Connection Tier – We assume the focus on higher pressure connections will increase in the future due to better economics

Connection tiers of gas dispensed at CNG stations



Station (* upcoming)	Connection Tier
CNG Fuels. Leyland	LTS
CNG Fuels. Milton Keynes*	LTS
CNG Fuels. Crewe	IP
Gasrec. Alperton	IP
Howard Tenens. Swindon	MP
Leeds*	LTS

Future connection tiers of grid connected CNG stations



Assumed station sizes LTS 46t/day, IP 18t/day, MP 9t/day, LP 5t/day. (ETI, 2017, Natural Gas Pathway Analysis for Heavy Duty Vehicles)

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Station to Tank Emission Sources

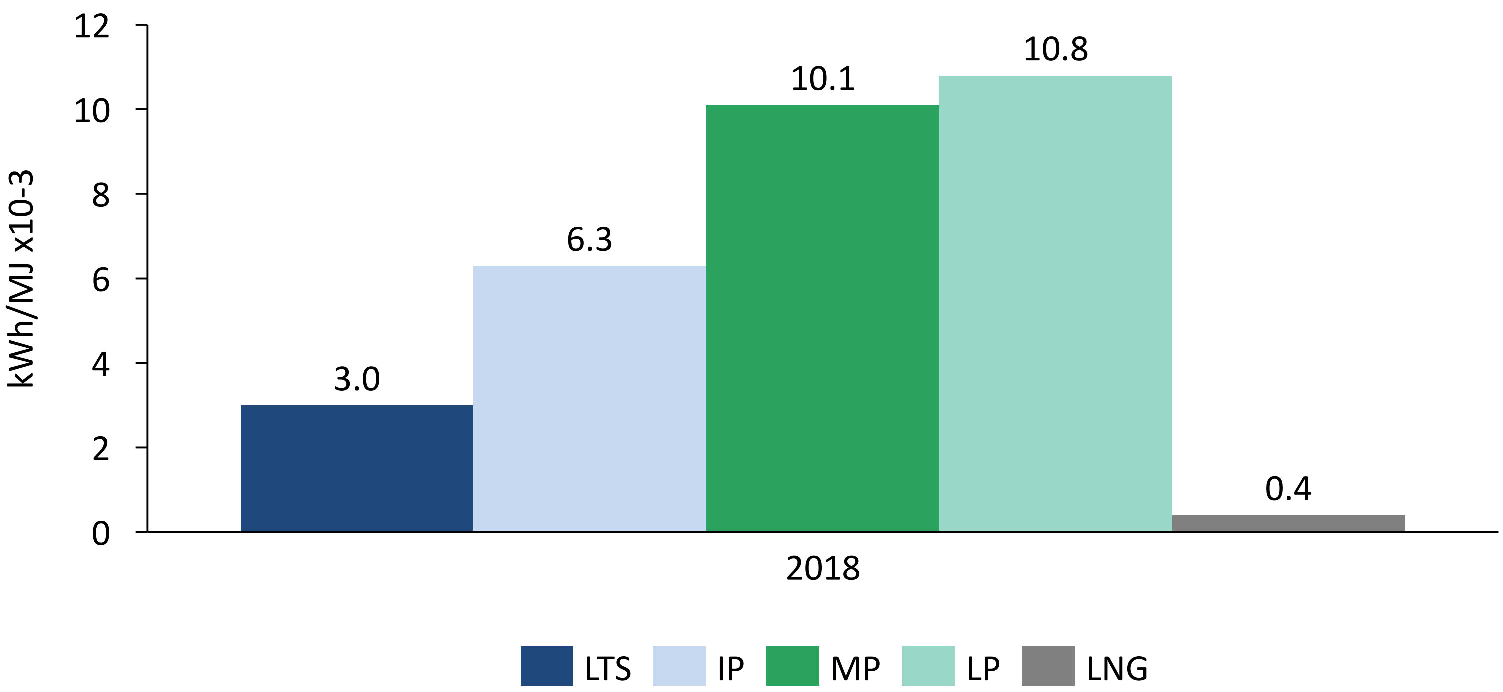
WTTerm emissions | Transport emissions | Station emissions

Variable	Unit	Source	Values
CNG Station Emissions	kWh/ MJ	LTS, recorded data from Leyland.	Leyland LTS: 0.003.
		ETI, 2017, Natural Gas Pathway Analysis for Heavy Duty Vehicles	ETI IP: 0.006, MP: 0.01, LP 0.01.
CNG leakage emissions	gCO_2/ MJ	Recorded data from Leyland	Baseline: Leyland leakage (0.002) User selected leakage: 0
LNG Station Emissions	kWh/ MJ	Recorded data from DIRFT	0.0004
Emissions from LIN Use	gCO_2/ MJ	Recorded data from DIRFT	Baseline: 0 (No LIN use)
		Interviews with LNG station operators	Alternative ('early rollout'): 2.7 (2018) and 1.2 (2032)

Station energy demand

Station emissions (sources: Leyland data, DIRFT data, ETI 2017)

The station energy demand comes predominantly from electricity used for compressors. The values presented here assume that two thirds of CNG stations compress the CNG to 200 bar and one third compress the CNG to 250 bar.



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Diesel Well to Tank Emission Sources

Variable	Unit	Source	Values
Diesel Well to Tank Emissions	gCO_2/MJ	BEIS, 2017, UK Government GHG conversion factors for company reporting	2018-2032: 17.4
Biodiesel Well to Tank Emissions	gCO_2/MJ	RTFO Year 10 Reporting	2018-2032: 9
Share of Biodiesel	%	(RTFO Year 10 Reporting)	2018: 2.5% 2024: 4.8% 2032: 4.8%.
AdBlue Emissions	gCO_2/MJ	Calculated based on Plant Soil Environ, Vol. 63, 2017, No. 12: 531–544	2018-2032: 0.54

WTT: Well to Terminal Emissions

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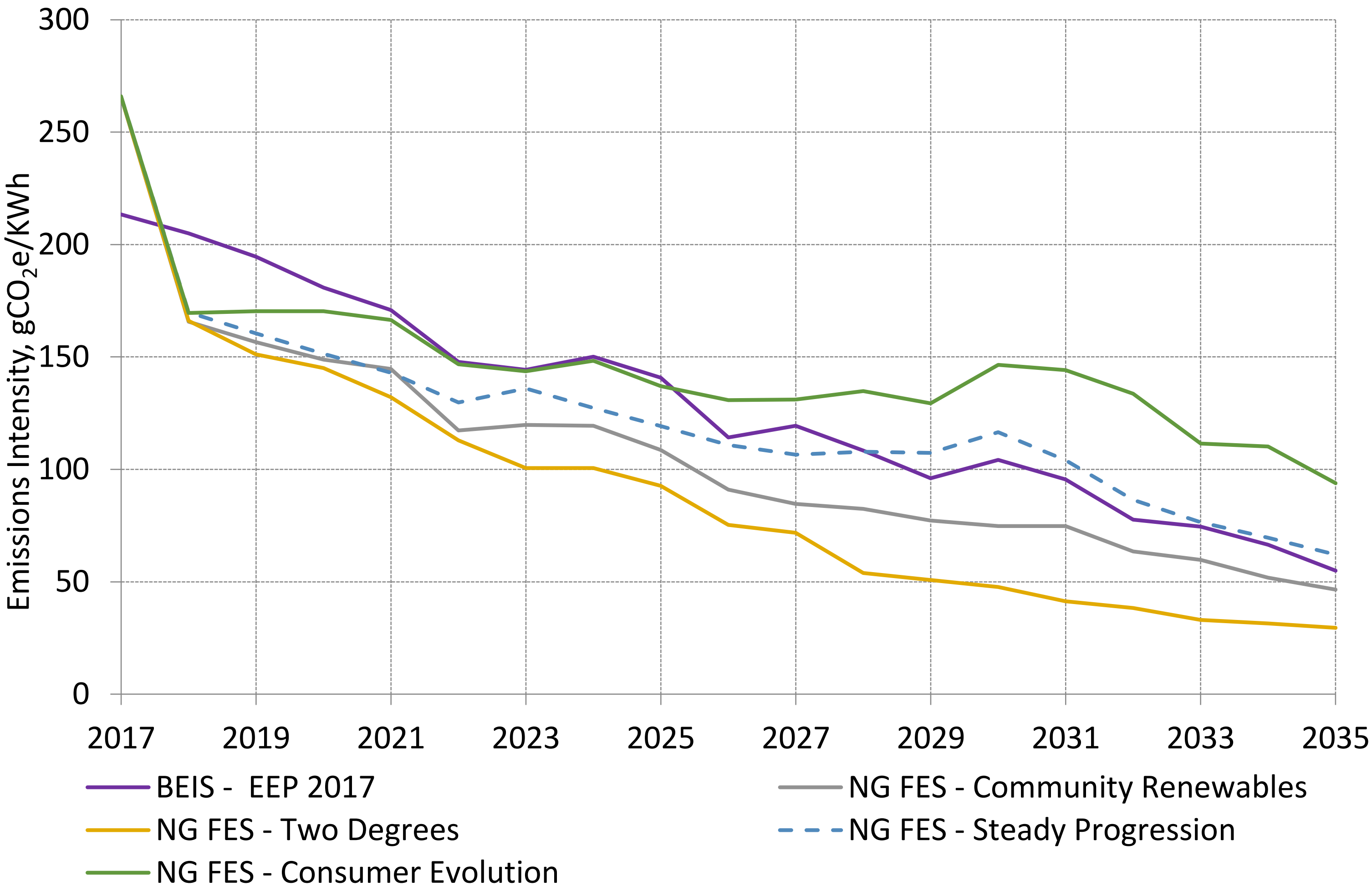
There are many electricity carbon intensity projections – the model uses the BEIS 2017 projections in the baseline

BEIS 2017 is used as the baseline although all the scenarios are embedded into the model for the user to select from.



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The calorific value of gas is not used directly in the model but it plays an important role in the input data from the truck trial

A change in gas calorific value changes the WTT emission figures

- The calorific value of gas is used in the truck trial reporting to convert from the measured data of emissions per km, to vehicle efficiency data in MJ of gas used per km
- This method first calculates the fuel used from the tailpipe emissions using a carbon balance and secondly calculates the vehicle efficiency from the fuel use
- The calorific value of CNG and LNG changes based on the gas mix on a particular day
- National Grid report the gas calorific value on their network at a Local Distribution Zone (LDZ) level[1]. **This data for the last 6 months shows that the gas calorific value can fluctuate by +/-5% (gas calorific value fluctuates from 37.5 MJ/m^3 to 43.0 MJ/m^3)**
- A +5% change in the calorific value leads to a 5% change in the vehicle efficiency value and a 5% change in the WTT emission value in the model – this translates to about +/-0.5% at WTW level in the case of CNG.
- This demonstrates the importance of **recording the exact calorific value of the gas used in vehicle testing.**

[1] http://mip-prod-web.azurewebsites.net/DataItemExplorer

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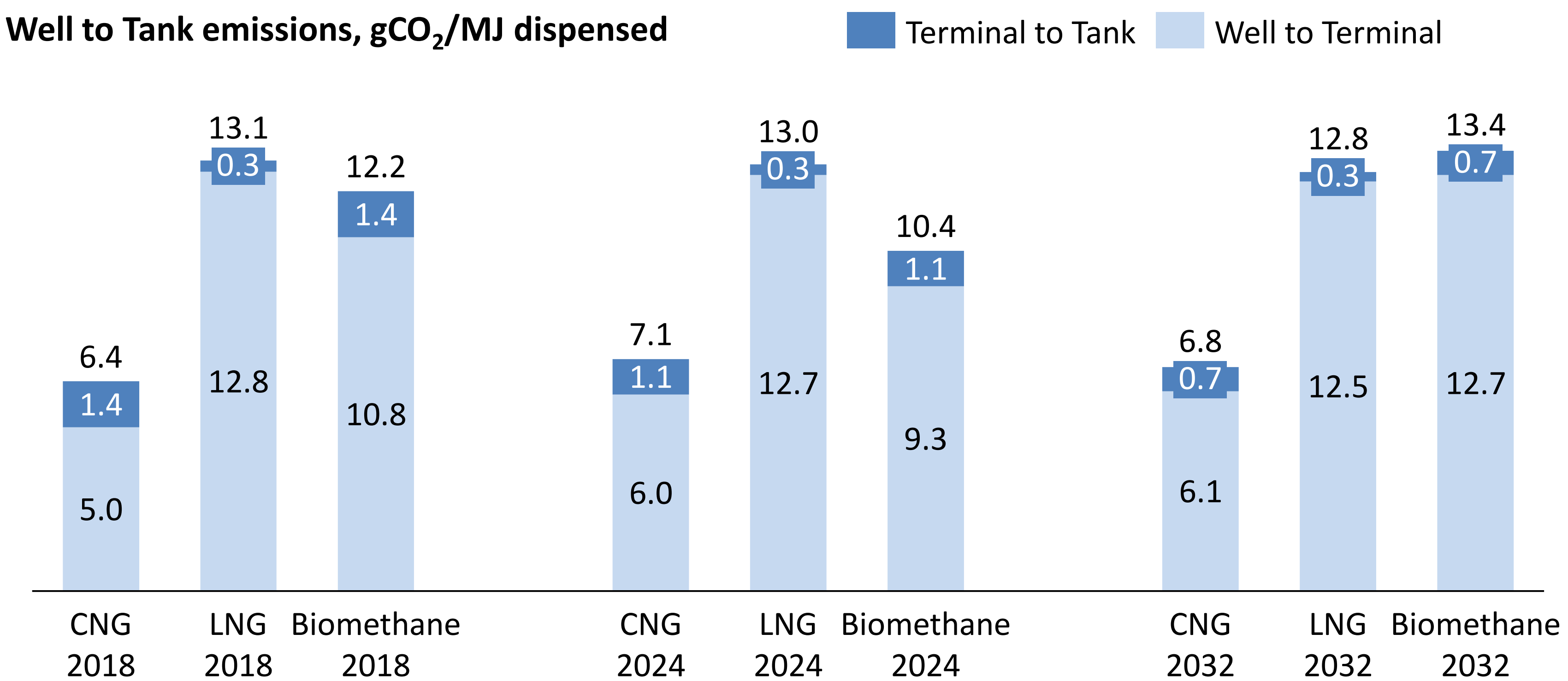
With the proposed baseline inputs, the Well to Tank results are as follows:

The well to tank emissions are dominated by the well to terminal emission with UK transport and station emissions falling quickly due to the decarbonisation of the electricity grid.

The biomethane emissions are one of the largest in terms of well to tank emissions but not in terms of well to wheel emissions because under standard accounting methods the biological carbon is deducted from the emissions at the tank to wheel stage.

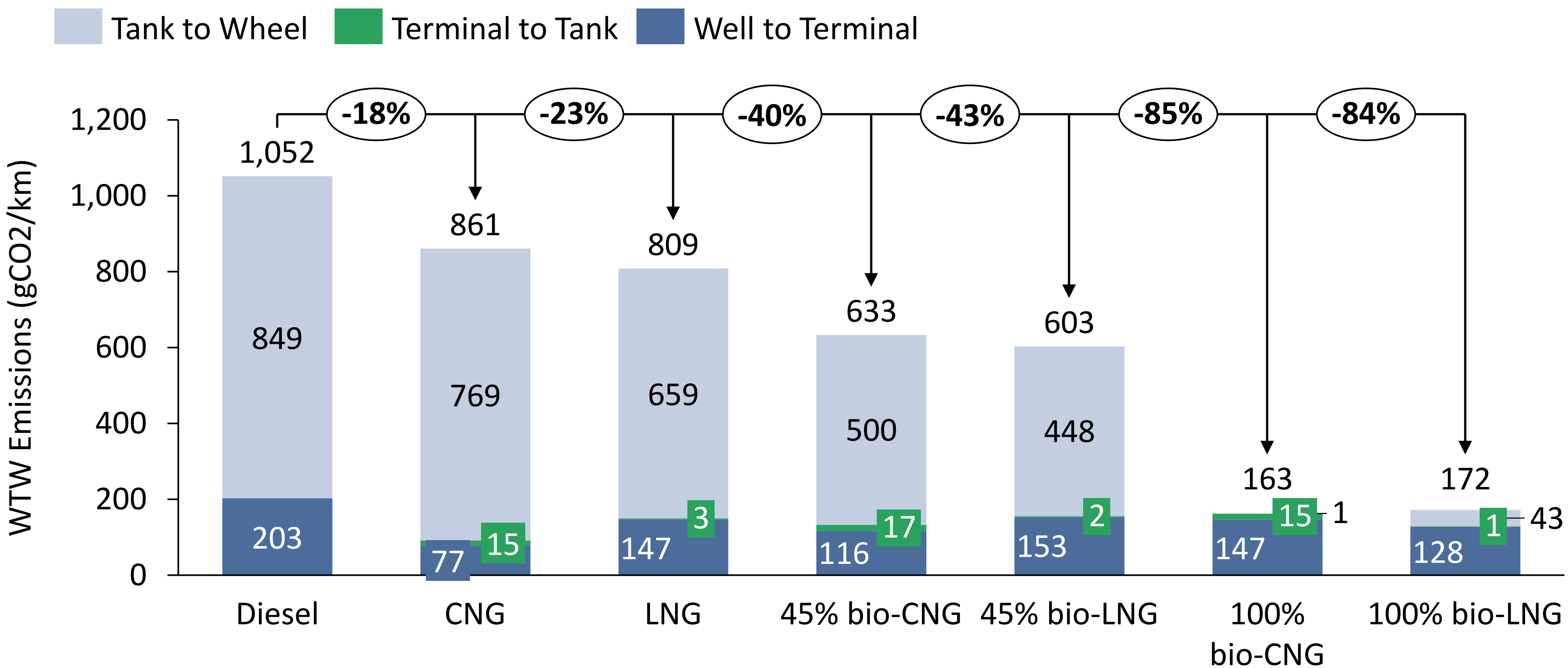


Based on placeholder TTW emissions, the total WTW emissions of all gas HGVs are significantly lower than diesel HGVs

Draft TTW emissions

These results are based on the modelled well to tank emissions and placeholder tank to wheel emissions. For the tank to wheel emissions the CNG truck is assumed to be 17% less efficient than the equivalent diesel and the LNG truck is assumed to be an HPDI CI engine with the same efficiency as an equivalent diesel (this engine burns 95% LNG 5% diesel).

2018 Well to Wheel emissions, gCO_2/km



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Comparison with the BEIS Well to Tank emissions for CNG and LNG

What are we comparing against

The data used by BEIS for standard CNG and LNG well to tank emissions is calculated by Ricardo AEA and is sourced from

- Exergia, EM Lab and COWI, 2015. Study on Actual GHG Data for Diesel, Petrol, Kerosene and Natural Gas' for DG Ener.

The following slides compare the values and assumptions used in Element Energy's 2018 work with those set out here to understand the differences in final CNG/LNG well to wheel emission projections.

No changes to our modelling was done following the comparison, as it was found the proposed assumptions are more reflective of today's industry practice and energy landscape.

For CNG the difference is predominantly caused by the assumed proportion of regas LNG in the grid mix and the amount of leakage

Lifecycle Stage	Exergia Report (gCO_2/MJ)		Element Energy Modelling (gCO_2/MJ)	Expected cause of differences
Production	4.945	6.892	4.96	The difference here is predominantly driven by the high proportion of re-gasified LNG in the grid mix in Ricardo's calculation from 2015 (19% versus 5% today)
Processing	0.001			
Transportation	1.946			
Terminal to Station	1.256		0.6	Ricardo modelling uses an electricity carbon intensity of 546 gCO_2/kWh; this has dropped to 205 gCO_2/kWh in the latest BEIS 2018 figures. It is also expected that the Ricardo modelling assumes a similar proportion of CNG is extracted from each pressure tier. Whereas EE modelling weights the CNG output to higher pressure tiers to reflect the better economics and observed UK trends
Station to Tank	4.535		0.81	Same points as above. The Exergia report assumes station leakage of 0.34%. Gas alarm data from Leyland station has demonstrated leakage of much less than 0.01% is possible
Total	**12.683**		**6.37**	

For LNG the difference in mainly caused by assumptions around production emissions and leakage

Lifecycle Stage	Exergia Report (gCO_2/MJ)		Element Energy Modelling (gCO_2/MJ)	Expected cause of differences
Production	11.272	17.037	12.830	Production emissions for Qatar LNG vary widely between sources depending on many assumptions, especially leakage. The value chosen in the EE model is based on an extensive literature review conducted by EE for the Energy Technologies Institute which included both of the sources used by Ricardo AEA.
Processing	1.38			
Transportation	4.385			
Terminal to Station	0.589		0.26	Difference expected to be caused by truck distance travelled and truck efficiency (this work assumes an LNG truck is used which means figures are expected to fall when new LNG TTW data is added to the model). A comparative diesel with an efficiency of 7.9MPG[1] carrying 56m^3 of LNG over 400km gives an emissions per MJ figure of 0.35.
Station to Tank	1.971		0.08	The Exergia report is expected to include emissions from LIN use. Discussions with LNG station operators has shown that once a station passes its initial ramp up phase (refuels more than 15 trucks a day) LIN for LNG cooling is no longer needed
Total	**19.597**		**13.17**	

[1] Department for Transport, 2017, Table ENV0104, Average heavy goods vehicle fuel consumption

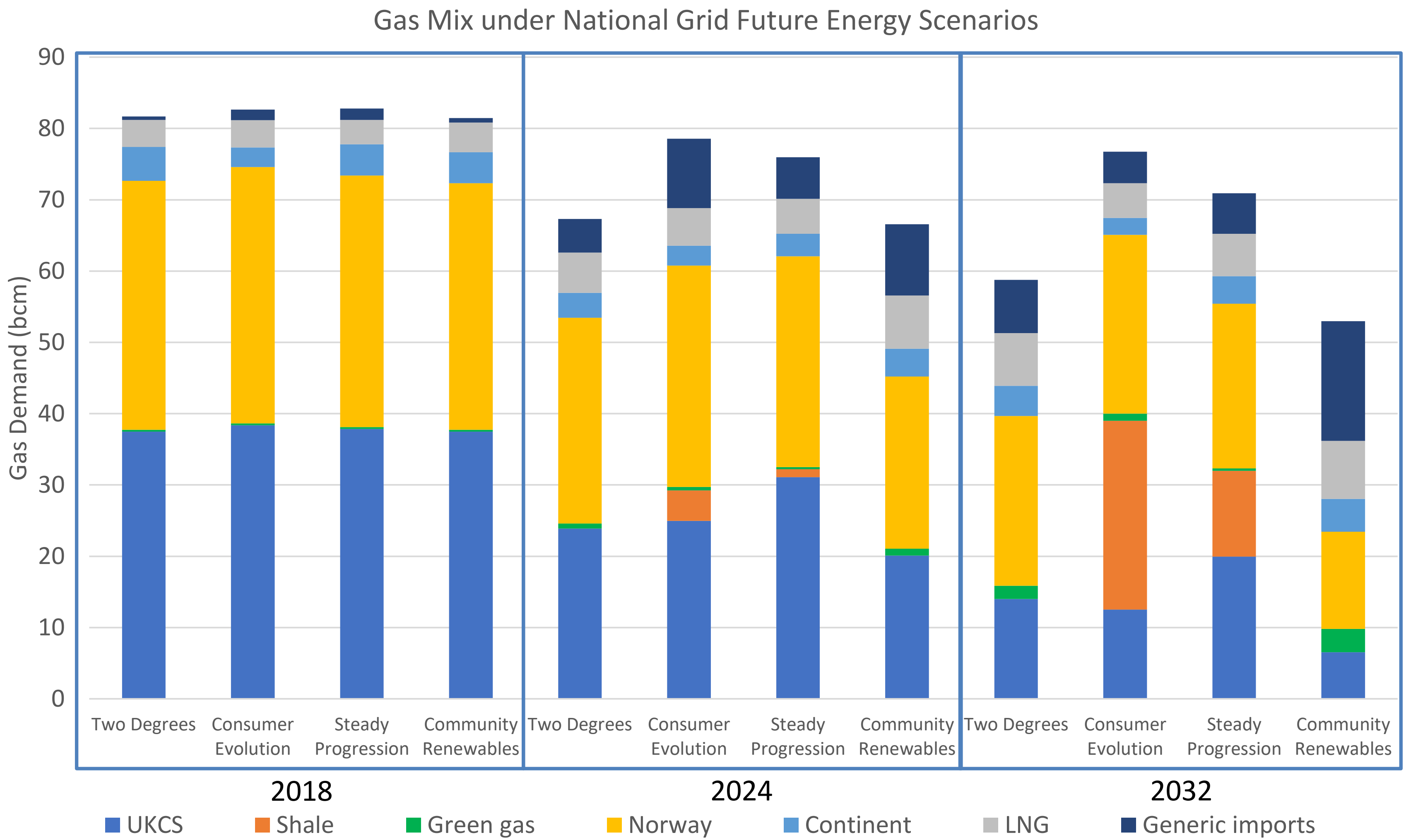
Contents

Acronyms

- Bio-SNG: Bio- Synthetic Natural Gas
- CNG: Compressed Natural Gas
- HGV: Heavy Goods Vehicle
- IP: Intermediate Pressure
- IWG: Industry Working Group
- L-CNG: CNG produced on site from LNG delivered by truck
- LIN: Liquid Nitrogen
- LNG: Liquefied Natural Gas
- LP: Low Pressure
- LTS: Local Transmission System
- MP: Medium Pressure
- NG FES: National Grid Future Energy Scenarios
- RHI: Renewable Heat Incentive
- RTFC: Renewable Transport Fuel Certificate
- RTFO: Renewable Transport Fuel Obligation
- StT: Station to Tank
- TtS: Terminal to Station
- TTW: Tank To Wheel
- WTT: Well To Tank
- WTTerm: Well To Terminal
- WTW: Well To Wheel

Gas Mix Scenarios from National Grid

The NG Steady Progression scenario has been selected because it is the middle scenario (no large swing to green gas or shale gas or an ambitious reduction in gas use) and is therefore seen as the most probable



Source: National Grid Future Energy Scenarios (2018)